Chesapeake Bay Oyster Recovery
Native Oyster Restoration Master Plan

Maryland and Virginia

APPENDICES

SEPTEMBER 2012

LIST OF APPENDICES

APPENDIX A: Study Authority

A-1: SECTION 704(b) AUTHORITY

This study is being accomplished under Section 704(b) of the Water Resources Development Act of 1986, as amended, which authorizes USACE to construct alternative or beneficially modified habitats for indigenous fish and wildlife, including man-made reefs for fish habitat in the Maryland portion of the Chesapeake Bay. The full text of this authority and amendments is provided below.

Water Resources Development Act of 1986, Section 704 (P.L. 99-662)

The non-Federal share of the cost of any project under this section shall be 25 percent.

(a) The Secretary shall investigate and study the feasibility of utilizing the capabilities of the United States Army Corps of Engineers to conserve fish and wildlife (including their habitats) where such fish and wildlife are indigenous to the United States, its possessions, or its territories.

(b) The Secretary is further authorized to conduct projects of alternative or beneficially modified habitats for fish and wildlife, including but not limited to man-made reefs for fish. Such projects shall include construction of a reef for fish habitat in the Chesapeake Bay in Maryland.

Water Resources Development Act of 1996, Section 505 (P.L. 104-303)

SEC. 505. CORPS CAPABILITY TO CONSERVE FISH AND WILDLIFE.

Section 704(b) of the Water Resources Development Act of 1986 (33 U.S.C. 2263(b); 100 Stat. 4157) is amended—(1) by striking ‘‘$5,000,000’’; and inserting ‘‘$7,000,000’’; And (2) in paragraph (4) by inserting ‘‘and Virginia’’ after ‘‘Maryland’’.

Water Resources Development Act of 2000, Section 342 (P.L. 106-541)

SEC. 342. CHESAPEAKE BAY OYSTER RESTORATION.

Section 704(b) of the Water Resources Development Act of 1986 (33 U.S.C. 2263(b)) is amended--

(1) in the second sentence by striking `$7,000,000' and inserting `$20,000,000';

(2) by striking paragraph (4) and inserting the following:

(4) the construction of reefs and related clean shell substrate for fish habitat, including manmade 3-dimensional oyster reefs, in the Chesapeake Bay and its tributaries in

Maryland and Virginia if the reefs are preserved as permanent sanctuaries by the non-Federal interests, consistent with the recommendations of the scientific consensus document on Chesapeake Bay oyster restoration dated June 1999.'; and

(3) by inserting after `25 percent.' the following: `In carrying out paragraph (4), the Chief of Engineers may solicit participation by and the services of commercial watermen in the construction of the reefs.

Energy and Water Development Appropriations Act of 2003, Section 113

SEC. 113. STUDY OF CORPS CAPABILITY TO CONSERVE FISH AND WILDLIFE.

Section 704(b) of the Water Resources Development Act of 1986 (33 U.S.C. 2263(b)) is amended -

(1) by redesignating paragraphs (1), (2), (3), and (4) as subparagraphs (A), (B), (C), and (D), respectively;

(2) by striking `(b) The Secretary' and inserting the following:

(b) PROJECTS-

(1) IN GENERAL- The Secretary'; and

(3) by striking `The non-Federal share of the cost of any project under this section shall be 25 percent.' and inserting the following:

(2) COST SHARING-

(A) IN GENERAL- The non-Federal share of the cost of any project under this subsection shall be 25 percent.

(B) FORM- The non-Federal share may be provided through in-kind services, including the provision by the non-Federal interest of shell stock material that is determined by the Chief of Engineers to be suitable for use in carrying out the project.

(C) APPLICABILITY- The non-Federal interest shall be credited with the value of in-kind services provided on or after October 1, 2000, for a project described in paragraph (1) completed on or after that date, if the Secretary determines that the work is integral to the project.'.

Water Resources Development Act of 2007 (P.L. 110-114)

SEC. 5021. CHESAPEAKE BAY OYSTER RESTORATION, VIRGINIA AND MARYLAND
Section 704(b) of the Water Resources Development Act of 1986 (33 U.S.C. 2263(b)) is amended—
(1) by redesignating paragraph (2) as paragraph (4);
(2) in paragraph (1)—
(A) in the second sentence by striking ''$30,000,000''

and inserting ''$50,000,000''; and

(B) in the third sentence by striking ‘‘Such projects’’
and inserting the following:
‘‘(2) INCLUSIONS.—Such projects’’;
(3) by striking paragraph (2)(D) (as redesignated by paragraph
(2)(B) of this subsection) and inserting the following:
‘‘(D) the restoration and rehabilitation of habitat for
fish, including native oysters, in the Chesapeake Bay and
its tributaries in Virginia and Maryland, including—
‘‘(i) the construction of oyster bars and reefs;
‘‘(ii) the rehabilitation of existing marginal habitat;
‘‘(iii) the use of appropriate alternative substrate
material in oyster bar and reef construction;
‘‘(iv) the construction and upgrading of oyster
hatcheries; and
‘‘(v) activities relating to increasing the output of
native oyster broodstock for seeding and monitoring of
restored sites to ensure ecological success.
‘‘(3) RESTORATION AND REHABILITATION ACTIVITIES.—The
restoration and rehabilitation activities described in paragraph
(2)(D) shall be—
‘‘(A) for the purpose of establishing permanent sanctuaries
and harvest management areas; and
‘‘(B) consistent with plans and strategies for guiding
the restoration of the Chesapeake Bay oyster resource and
fishery.’’; and
(4) by adding at the end the following:
‘‘(5) DEFINITION OF ECOLOGICAL SUCCESS.—In this subsection,
the term ‘ecological success’ means—
‘‘(A) achieving a tenfold increase in native oyster biomass
by the year 2010, from a 1994 baseline; and
‘‘(B) the establishment of a sustainable fishery as determined by a broad scientific and economic consensus.’’

A-2: SECTION 510 AUTHORITY

CHESAPEAKE BAY ENVIRONMENTAL RESTORATION AND PROTECTION PROGRAM.

(a) ESTABLISHMENT-

(1) IN GENERAL- The Secretary shall establish a pilot program to provide environmental assistance to non-Federal interests in the Chesapeake Bay watershed.

(2) FORM- The assistance shall be in the form of design and construction assistance for water-related environmental infrastructure and resource protection and development projects affecting the Chesapeake Bay estuary, including projects for sediment and erosion control, protection of eroding shorelines, protection of essential public works, wastewater treatment and related facilities, water supply and related facilities, beneficial uses of dredged material and restoration of submerged aquatic vegetation, and other related projects that may enhance the living resources of the estuary.

(b) PUBLIC OWNERSHIP REQUIREMENT- The Secretary may provide assistance for a project under this section only if the project is publicly owned, and will be publicly operated and maintained.

(c) LOCAL COOPERATION AGREEMENT-

(1) IN GENERAL- Before providing assistance under this section, the Secretary shall enter into a local cooperation agreement with a non-Federal interest to provide for design and construction of the project to be carried out with the assistance.

(2) REQUIREMENTS- Each local cooperation agreement entered into under this subsection shall provide for--

(A) the development by the Secretary, in consultation with appropriate Federal, State, and local officials, of a facilities or resource protection and development plan, including appropriate engineering plans and specifications and an estimate of expected resource benefits; and

(B) the establishment of such legal and institutional structures as are necessary to ensure the effective long-term operation and maintenance of the project by the non-Federal interest.

(d) COST SHARING-

(1) FEDERAL SHARE- Except as provided in paragraph (2)(B), the Federal share of the total project costs of each local cooperation agreement entered into under this section shall be 75 percent.

(2) NON-FEDERAL SHARE-

(A) VALUE OF LANDS, EASEMENTS, RIGHTS-OF-WAY, AND RELOCATIONS- In determining the non-Federal contribution toward carrying out a local cooperation agreement entered into under this section, the Secretary shall provide credit to a non-Federal interest for the value of lands, easements, rights-of-way, and relocations provided by the non-Federal interest, except that the amount of credit provided for a project under this paragraph may not exceed 25 percent of the total project costs.

(B) OPERATION AND MAINTENANCE COSTS- The non-Federal share of the costs of operation and maintenance of activities carried out under an agreement under this section shall be 100 percent.

(e) COOPERATION- In carrying out this section, the Secretary shall cooperate with the heads of appropriate Federal agencies, including--

(1) the Administrator of the Environmental Protection Agency;

(2) the Secretary of Commerce, acting through the Administrator of the National Oceanic and Atmospheric Administration;

(3) the Secretary of the Interior, acting through the Director of the United States Fish and Wildlife Service; and

(4) the heads of such other Federal agencies and agencies of a State or political subdivision of a State as the Secretary determines to be appropriate.

(f) PROJECT- The Secretary shall establish at least 1 project under this section in each of the States of Maryland, Virginia, and Pennsylvania.

(g) PROTECTION OF RESOURCES- A project established under this section shall be carried out using such measures as are necessary to protect environmental, historic, and cultural resources.

(h) REPORT- Not later than December 31, 1998, the Secretary shall transmit to Congress a report on the results of the program carried out under this section, together with a recommendation concerning whether or not the program should be implemented on a national basis.

(i) AUTHORIZATION OF APPROPRIATIONS- There is authorized to be appropriated to carry out this section $40,000,000.

APPENDIX B: PEIS for Oyster Restoration Including Use of Native and/or Non-Native Oyster

B-1: *PEIS* RECORD OF DECISION

Record of Decision

Final Programmatic Environmental Impact Statement for Oyster Restoration in Chesapeake Bay Including the Use of a Native and/or Nonnative Oyster

I have reviewed the Final Programmatic Environmental Impact Statement (PEIS), as well as the correspondence received in response to coordination of this document. Based on the conclusions of the PEIS, the reviews of other Federal, State, and local agencies, input from the public, and the review of my staff, I find the plan identified as the Preferred Alternative in the PEIS to be in the public interest and in accordance with environmental statutes.

The Norfolk District of the U.S. Army Corps of Engineers, the Maryland Department of Natural Resources, and the Virginia Marine Resources Commission (known collectively as the lead agencies) completed the PEIS which presents information regarding a variety of strategies for attempting to restore the population of oysters throughout Chesapeake Bay in Virginia and Maryland. The proposed action that prompted the preparation of this PEIS was to introduce a nonnative species, the Suminoe oyster, and continue efforts to restore the native Eastern oyster.

The Executive Committee, which comprised senior representatives of each of the lead agencies, carefully reviewed the summaries of projected outcomes and evaluated the benefits and risks associated with the proposed action and each of the alternatives for each of the decision criteria. Each of the lead agencies conducted its review from its own management perspective. The Norfolk District took the lead in developing consensus for a preferred alternative among the lead agencies through development and application of a decision-making framework and a series of meetings and conference calls. Applying that decision-making process and accounting for science, public comments, observations, and professional judgment resulted in ranking the assessment category of Environment and Ecological as the highest priority, and the category of Social Effects as the lowest priority. Ecosystem effects were ranked the most important of the specific decision criteria, and visual and aesthetic effects were ranked the least important. Implementation of these decision-making tools resulted in ranking Alternative 8a highest in three of the four priority categories. Alternative 8b was ranked highest in the Economic category.

The Norfolk District acknowledged considerable uncertainty regarding the likelihood that Alternative 8a will result in establishing a sustainable, Bay-wide oyster population and the possibility that the Bay-wide population of Eastern oysters will continue to decline in the future; however, the District considered Alternative 8a to be a conservative choice because of the ecological uncertainties associated with implementing Alternative 8c and the strong opposition of most stakeholders to that alternative. The Norfolk District considered ecological uncertainties associated with Alternative 8b to be somewhat less than those associated with Alternative 8c, but those uncertainties could not be resolved with the data and information available for preparing the PEIS. The State of Maryland emphasized that not all strategies for native oyster restoration have yet been exhausted and that past native oyster restoration efforts were limited in scope (i.e., scale, lacked an ecological focus, and precluded a regional, large-scale response). Maryland favored a "zero-risk" policy regarding the Suminoe oyster based upon the precautionary principle, the potential for significant negative ecological consequences, and the irreversible nature of an introduction of the species, whether intended or unintended.

After considering all available information and the input of all stakeholders, the lead agencies have concluded that **Alternative 8a** is the preferred approach for restoring the Chesapeake Bay oyster population, using a combination of alternatives that involves only the native Eastern oyster (*Crassostrea virginica*). The Preferred Alternative is also identified as the environmentally preferable alternative which is defined as "the alternative that will promote the national environmental policy as expressed in the National Environmental Policy Act's Section 101. Ordinarily, this means the alternative that causes the least damage to the biological and physical environment; it also means the alternative which best protects, preserves, and enhances historic, cultural, and natural resources" (Forty Most Asked Questions Concerning Council on Environmental Quality's National Environmental Policy Act Regulations, 1981). The Preferred Alternative 8a consists of the following elements:

Alternative 2 (Enhanced Native Oyster Restoration) - Expand, improve, and accelerate Maryland's oyster restoration and repletion programs, and Virginia's oyster restoration program in collaboration with Federal and private partners. This work would include but would not be limited to an assessment of cultch limitations and long-term solutions for this problem and the development, production, and deployment of large quantities of disease resistant strain(s) of C. *virginica* (Eastern oyster) for brood stock enhancement. Enhanced restoration activities to be implemented in the future may differ substantially from the traditional restoration programs previously conducted in both states. Although the kinds of future restoration activity may differ from those evaluated in some detail in the Final PEIS, the level of activity will be substantially greater than past levels.

As presented in Final PEIS, this alternative includes roughly doubling the number of acres of habitat to be rehabilitated over a 10-year period and increasing the number of seed oysters to be planted by a factor of 4.5 over 10 years. Initial evaluations lead to the conclusion that using disease-resistant strains of the native oyster developed in hatcheries to restore wild oyster populations is inadvisable; consequently, that element of the alternative was not considered in further analysis for the Draft PEIS. Numerous stakeholders who commented on the draft suggested an approach known as "revolving brood stock" hatchery production in which wild oysters taken from areas in which disease resistance appears to be developing are used as brood stock in the hatchery. The brood stock would be replaced each year with new brood stock from those locations. Analyses for Alternative 2 assume the use of offspring of the brood stock of wild Eastern oysters spawned in hatcheries each year in Maryland and Virginia. Under Alternative 2, most spat would be planted on sanctuary bars.

Alternative 3 (Harvest Moratorium) – Implement a temporary harvest moratorium on native oysters and an oyster industry compensation (buy-out) program in Maryland and Virginia or a program under which displaced oystermen are offered on-water work in a restoration program. In lieu of a total moratorium, the lead agencies envision implementing more restrictive oyster harvesting management regimes (e.g., annual harvest quotas; closed and open harvesting areas) that would be biologically and economically sustainable, that would include accountability measures, and that would minimize the effects of harvest on the potential development of disease resistance.

Alternative 4 (Expansion of Native Oyster Aquaculture) - Establish and/or expand State-assisted, managed or regulated aquaculture operations in Maryland and Virginia using the native oyster species. Both states may expand technical aquaculture support programs, particularly in the training of watermen who may be interested in transitioning from wild harvest to aquaculture. State expenditures to support aquaculture expansion may increase in the future and, thus, may be greater than those considered in the PEIS.

As part of the Preferred Alternative, the Corps, together with the cooperating Federal agencies, the State of Maryland, the Commonwealth of Virginia, and PRFC will pursue the establishment of realistic metrics, accountability measures, and a performance-based adaptive management protocol for all efforts to revitalize the native oyster for purposes of achieving commercial and ecological goals.

In addition to the Preferred Alternative, the PEIS evaluated four additional alternatives, and combinations thereof, that represent a variety of distinct strategies for attempting to restore oysters in Chesapeake Bay. The alternatives represent the major approaches being advocated by different agencies or stakeholders in Chesapeake Bay oyster restoration. The other alternatives considered included:

Alternative 1: No Action- Not taking the proposed action: Continue Maryland's present oyster restoration and repletion programs, and Virginia's oyster restoration program under current program and resource management policies and available funding using the best available restoration strategies and stock assessment techniques.

Alternative 5: Aquaculture - Establish State-assisted, managed or regulated aquaculture operations in Maryland and Virginia using suitable triploid, nonnative oyster species.

Alternative 6: Introduce and propagate in the State sponsored, managed or regulated oyster restoration programs in Maryland and Virginia, a disease resistant oyster species other than *C. ariakensis*, or an alternative strain of *C. ariakensis*, from waters outside the United States in accordance with the International Council for the Exploration of the Sea (ICES) 1994 Code of Practices on the Introductions and Transfers of Marine Organisms.

Alternative 7: Introduce the Suminoe Oyster and Discontinue Efforts to Restore the Eastern Oyster - Introduce the oyster species, *C. ariakensis*, into the tidal waters of Maryland and Virginia for the purpose of establishing a naturalized, reproducing, and self-sustaining population of this oyster species.

The original stand alone alternatives (1 through 7) were initially all evaluated equally along with the Proposed Action, and an eighth alternative was identified simply as "a combination of alternatives." Later in the NEPA process, the "combination of alternatives" was more specifically identified to form Alternatives 8a, 8b, and 8c. The eventual Preferred

Alternative, 8a, consists of a combination of Alternatives 2, 3, and 4. The other combinations, 8b, and 8c are described as follows:

Alternative 8: Combination of Alternatives

- ***Combination 8b –*** Eastern oyster and triploid Suminoe oysters
  - Alternative 2: Enhance efforts to restore Eastern oysters
  - Alternative 3: Impose a temporary harvest moratorium and a compensation program for the oyster industries
  - Alternative 4: Cultivate Eastern oysters
  - Alternative 5: Cultivate triploid Suminoe oysters

- ***Combination 8c –*** Eastern oyster and both diploid and triploid Suminoe oysters.
  - Alternative 2: Enhance efforts to restore native oysters
  - Alternative 3: Impose a temporary harvest moratorium and a compensation program for the oyster industries
  - Alternative 4: Cultivate Eastern oysters
  - Alternative 5: Cultivate triploid Suminoe oysters

Based on the current state of the science and extensive public discourse, the lead agencies concluded that the use of nonnative oysters in Chesapeake Bay, its tidal tributaries, and the coastal bays and waters of Maryland and Virginia poses unacceptable ecological risks. Therefore, the Preferred Alternative established by the lead agencies, and presented in the PEIS, is Alternative 8a.

I have reviewed and evaluated documents concerning the Preferred Alternative, views of other interested agencies and the general public and responded to comments containing those views, and have examined the various practicable means to avoid and/or minimize environmental harm from the implementation of the Preferred Alternative. All practicable means to avoid or minimize adverse environmental effects have been incorporated into the recommended plan. The public interest will best be served by implementing the oyster restoration plan identified and described in the Final PEIS. This Record of Decision completes the National Environmental Policy Act process.

Andrew W. Backus

ANDREW W. BACKUS
Colonel, Corps of Engineers
Commanding

13 AUGUST 2009
DATE

B-2: *PEIS* SECTION 5- PUBLIC OUTREACH, AGENCY COORDINATION, AND CONSULTATION

5 Public Outreach, Agency Coordination, and Consultation

5.1 PURPOSE, NEED, AND REQUIREMENTS FOR PUBLIC OUTREACH AND AGENCY COORDINATION

In 1977, the CEQ promulgated regulations associated with the implementation of NEPA, as enacted in 1970. These regulations and associated procedural requirements for compliance are stipulated in 40 CFR Part 1503 (http://www.nepa.gov/nepa/regs/ceq/1503.htm#1503.3) and include procedures for obtaining, submitting and responding to public comments for an EIS.

The USACE's policy and guidance requires work in addition to the minimum public outreach and agency coordination standards outlined in 40 CFR Part 1503, to include a pre-scoping or conceptual-level scoping phase and a public scoping phase before issuing the draft EIS. During these additional phases, the lead agencies provided opportunities to engage affected and interested parties in the planning and development stages of the EIS process, including the process of defining alternatives. The purposes of pre-scoping and public scoping phases are to

- introduce the public to the lead agencies and the planning process;
- inform the public and decision makers about the project;
- assess support for the project;
- gather information;
- coordinate with citizens, interest groups, and agencies;
- provide a mechanism for citizens to participate in the planning process; and
- provide for fiscal accountability.

The lead agencies for this Programmatic EIS (i.e., USACE, DNR, and VMRC) engaged various groups of stakeholders in the EIS process: watermen and industry representatives (recreational and commercial anglers, boaters, and aquaculture firms); local, regional, State, and Federal agencies; academic institutions; and environmental, historical, and biological resource protection organizations. Collectively, these groups have informed the lead agencies regarding the scientific, socioeconomic, cultural, legal, and policy factors of the project. The lead agencies involved the stakeholder groups early on and continuously throughout the course of the project and have accepted and carefully considered their feedback.

5.2 PUBLIC OUTREACH AND AGENCY COORDINATION PROCESS

5.2.1 Participants

5.2.1.1 Agency Coordination

According to January 30, 2002, CEQ guidance to the heads of Federal agencies on implementing the procedural requirements of NEPA, lead agencies preparing a PEIS are required to determine if other Federal agencies are interested and appear to be capable of assuming the responsibilities of becoming a cooperating agency under 40 C.F.R. § 1501.6. "Cooperating agency" as defined under this title includes any other Federal agency that has jurisdiction by law or that has special expertise with respect to any environmental issue that should be addressed in the PEIS.

The 2002 guidance states: "The benefits of enhanced cooperating agency participation in the preparation of NEPA analyses include: disclosing relevant information early in the analytical process; applying available technical expertise and staff support; avoiding duplication with other Federal, State, Tribal and local procedures; and establishing a mechanism for addressing intergovernmental issues. Other benefits of enhanced cooperating agency participation include fostering intra- and intergovernmental trust (e.g., partnerships at the community level) and a common understanding and appreciation for various governmental roles in the NEPA process, as well as enhancing agencies' ability to adopt environmental documents. It is incumbent on Federal agency officials to identify as early as practicable in the environmental planning process those Federal, State, Tribal and local government agencies that have jurisdiction by law and special expertise with respect to all reasonable alternatives or significant environmental, social or economic impacts associated with a proposed action that requires NEPA analysis."

USACE is the lead Federal agency for preparing this PEIS. VMRC (on behalf of the Commonwealth of Virginia) and DNR (on behalf of the State of Maryland) are the lead State agencies. The U.S. Environmental Protection Agency (EPA), U.S. Fish and Wildlife Service (FWS), and National Oceanic and Atmospheric Administration (NOAA) are cooperating Federal agencies. Additional review and assistance was provided by the Maryland Environmental Service (MES), the Potomac River Fisheries Commission (PRFC), and the Atlantic States Marine Fisheries Commission (ASMFC). EPA will be responsible for rating the environmental impact of the proposed action and the adequacy of the PEIS document. The lead agencies established a project delivery team (PDT) to coordinate with State, Federal, and regional agencies whose goals, objectives, policies, and regulations are implicated in, or would be affected by the outcome of the process. The PDT includes representatives of USACE's Norfolk and Baltimore Districts, DNR, VMRC, NOAA, EPA, FWS, and PRFC.

The PDT met monthly to discuss the schedule for the project, development of the alternatives, content of the PEIS, the status of research and availability and findings, the status of the peer review process and findings, legal requirements, and other project-delivery issues. The goal of the PDT was to share information among the participating agencies and, to the extent possible, to ensure that affected agencies were comfortable with the findings and that potential legal and programmatic implications were addressed before completion of the PEIS. PDT meetings were open to the public and were listed on DNR's Oyster *In Focus* Web site. PDT members reviewed summaries of these meetings were for accuracy.

The lead agencies also established an Executive Committee that was responsible for the management of the PEIS project, including active collaboration with senior management from the Federal cooperating agencies and a Management Team that was responsible for executing the activities defined by the Executive Committee.

5.2.1.2 Research Review Committees and Peer Review Groups

Several research-review committees and peer-review groups were established to provide guidance regarding appropriate research projects and schedules, the accuracy of the findings of the research and assessment efforts, and suggestions for next steps, in order to support the scientific integrity of the PEIS. The following text describes the roles and membership of the research-review committees and peer-review groups, as well as the roles of other groups of stakeholders in completing one of the major assessments for this PEIS: the Cultural and Socioeconomic Assessment.

Cultural and Socioeconomic Assessment **–** A cultural and socioeconomic assessment, which assessed the cultural value of oyster restoration and the socioeconomic importance of different approaches for restoring oysters to a diverse range of stakeholders, was completed as part of the supporting documentation for the PEIS. This study involved informal and structured interviews with and two cumulative surveys of stakeholders, including commercial watermen, oyster aquaculturists, shellfish processors and shippers, scientists investigating oysters and marine-estuary ecosystems, environmentalists who are active in efforts to restore Chesapeake Bay, recreational fishers, and owners of seafood restaurants in the region.

A report entitled *Oyster Restoration in the Chesapeake Bay: A Cultural & Socioeconomic Assessment* (Paolisso and Dery 2008) reports findings about the cultural value of oyster restoration and the socioeconomic importance of different approaches for restoring oysters in the Bay for a diverse range of stakeholders within the Chesapeake region. The PEIS includes an analysis of this information.

Review Committees and Peer Review Groups **–** In addition to providing information and opportunities to comment on the content of the PEIS, the lead agencies established research-review committees and peer-review groups to provide scientific and technical insight to inform the project and associated research and assessment efforts. Each advisory group or committee included stakeholders from the research community who are experts in their respective fields:

- Scientific Advisory Committee (SAC) – This group was composed of all of the principal investigators involved with the Oyster PEIS research effort designed to satisfy the critical gaps in knowledge identified in the 2000 NRC report.
- Ecological Risk Assessment Advisory Group (ERAAG) – This group was composed of Federal agency risk assessment specialists and was established to assist in the development of the ERA framework and advise on the technical content of the ERA.

- OAP – This group was established to provide peer review and to provide technical guidance on suitable data sources/input parameters for the modeling and assessment projects in support of the PEIS, including determining the adequacy of available information to inform a decision and the degree of risk associated with each alternative.

- Peer Review Groups (PRGs) – These groups provided independent review of research results to be incorporated into the PEIS assessments; specifically, research that was funded for the PEIS, but was not published in a scientific peer reviewed journal. Each PRG was composed of two to five nationally recognized members of the scientific community. The peer review effort was divided among PRGs according to research and assessment subject matter and expertise (e.g. larvae transport, natural resource economics, etc.). Each PRG's review included an evaluation of: the clarity of the hypotheses, if applicable; the validity of the research design; the quality of data collection procedures; the robustness of methods employed; the appropriateness of the methods for the hypotheses being tested; the extent to which the conclusions follow from the analysis; and the strengths and limitations of each research project. The PRG's comments and/or peer review reports were provided to the research or assessment project principal investigators. Responses from the principal investigators on how the peer review comments would be addressed in continued research efforts and/or final research project documentation were requested.

- The ASMFC, Interstate Shellfish Transport Committee (ISTC) – This committee is comprised of shellfish technical representatives from each of the Atlantic coastal states from Maine through Florida, the District of Columbia, the PRFC, the National Marine Fisheries Service (NMFS), and the FWS. This group provided technical input from a coastal perspective. They reviewed and developed consensus statements on issues related to the methodology and analytical results of research, modeling and assessment projects being completed to support the PEIS, and forwarded the consensus statements to the PDT.

The lead agencies and principal investigators of research projects and assessments periodically updated the advisory groups, as well as the Executive Committee and Management Committee, on project and research advancements as appropriate throughout the course of the Oyster PEIS project.

5.2.1.3 Other Stakeholder Groups

In addition to soliciting Cooperating Agency input through the PDT process and technical guidance through the establishment of advisory groups, the lead agencies initiated and/or accepted written correspondence from the following interested agencies, organizations, industry representatives, and academic institutions:

- FWS
- Virginia Department of Historic Resources
- NMFS Habitat Conservation Division
- National Park Service
- EPA

- Maryland Historic Trust
- Virginia Department of Conservation and Recreation's Division of Natural Heritage
- NOAA
- Florida Fish & Wildlife Conservation Commission
- South Carolina Department of Natural Resources
- Virginia Office of the Governor
- Harris Seafood
- Delaware River Keeper
- State of Rhode Island
- Anne Arundel County Watermen’s Association
- Coastal Conservation Association (CCA)
- The Nature Conservancy (TNC)
- Virginia Seafood Council (VSC)
- National Wildlife Federation
- Defenders of Wildlife
- International Council for Exploration of the Seas (ICES)
- Maryland Department of the Environment (MDE)
- Audubon Society of Maryland – D.C.
- ASMFC
- Maryland House of Delegates – Del. Dan Morhaim
- Maryland Department of Natural Resources
- Virginia Institute of Marine Science (VIMS)

Additional information on the content of the correspondence can be found in Appendix G: Agency Coordination.

5.2.2 Communication Methods

Communication methods used by the lead agencies to distribute information included: television, radio, newspapers, fliers, electronic mail, postal mail and Web sites.

Public presentations of the project proposal, and research and assessment findings provided at public meetings, conferences, trade shows and fairs, were advertised with fliers and newspaper postings, as well as in radio and television announcements.

Maryland Public Television recorded interviews with representatives from the lead and Cooperating Agencies on the progress of the PEIS. PEIS briefings were also provided in numerous newspaper articles throughout the course of the project, available in hardcopy and electronic format including via the Chesapeake Bay Program’s *Bay News* electronic mail list server distribution.

Information sharing was geared toward electronic and internet submissions due to its potential for immediate mass distribution, high accessibility, low cost and low environmental impact. The lead agencies maintained a continuously updated postal and electronic mail server interest list used to coordinate advisory group reviews and provide project updates to interested parties. Work group meetings were announced on Web sites and through electronic mail distributions.

A project Web site was established to facilitate public input within and outside the Chesapeake Bay region (DNR's Oyster *In Focus* Web site http://www.dnr.state.md.us/dnrnews/infocus/oysters.asp). The scheduling of public meetings and project accomplishments, including updates on key research components, were publicized in press releases available on the Web site. A calendar of meetings and events was also posted on the Oyster *In Focus* Web site throughout the course of the project, beginning with the first posting on April 21, 2003. A copy of the presentation given by the lead agencies at the January 28, 2004 and February 5, 2004 public scoping meetings was posted to the Oyster *In Focus* Web site, along with summaries of the meetings and written public comments provided during the public scoping period. The Oyster *In Focus* Web site also contains

- copies of the project Purpose and Need Statement and funding authorization
- a list of the PEIS alternatives
- links to the PEIS press releases and progress reports
- overviews of the research, modeling and assessment frameworks, peer review plan and a list of research projects
- a diagram of the peer review process and copy of the approved peer review plan (for compliance with the 2004 Office of Budget and Management bulletin)
- a link to the NRC Report on Nonnative Oysters in the Chesapeake Bay
- a link to the STAC report *Identifying and Prioritizing Research Required to Evaluate Ecological Risks and Benefits of Introducing Diploid Crassostrea ariakensis to Restore Oysters to Chesapeake Bay*
- a list of PEIS working group membership and responsibilities
- links to project Web sites created by NOAA and PEIS research institutions, including the University of Maryland (UMD) (containing contact information for the research Principal Investigators) and VIMS (including a timeline for VIMS involvement in the project and associated efforts and links to research work products and background documents)
- a link to ICES' 1994 *Code of Practice on the Introductions and Transfers of Marine Organisms*

Copies of Oyster PEIS "Progress Reports", news releases and a link to the *In Focus* Web site were provided on the USACE-Norfolk District Oyster PEIS homepage: http://www.nao.usace.army.mil/OysterPEIS/homepage.asp. Public notices and events related to the Oyster PEIS project were posted to the VMRC public information webpage: http://www.mrc.state.va.us/public-info.shtm.

Updates on the scientific and technical components of the project, including research and assessment findings, were presented at PDT meetings and NOAA (PEIS) Quarterly Research

Review meetings. These review meetings were an opportunity for the Federal and State agencies and the research community to receive summaries of critical research findings directly from, and pose questions directly to, the research principal and/or associate investigator. Opportunities were provided for the public to participate in the research review meetings via Internet Webcast. NOAA posted summaries of the Quarterly Research Reviews to its Web site: http://noaa.chesapeakebay.net/nonnativeoysterresearch.aspx along with:

- a list of funded PEIS research
- an explanation of the PEIS process
- a summary of the findings of the NRC report *Nonnative Oysters in the Chesapeake Bay* and a link to purchase the report
- links to the STAC report and 2005 ICES code
- work products and information distributed at scientific conferences

5.2.3 Process

5.2.3.1 Project Authorization and Funding

Federal authorization for the USACE – Norfolk District to initiate the Oyster PEIS project was established by Section 510 of Water Resources Development Act of 1996, as amended by Title 1, Department of Defense – Civil, Department of the Army, Corps of Engineers – Civil, Construction General provisions of the Energy and Water Appropriations Act. Federal project funding was established by H.R.2754: *Making Appropriations for Fiscal Year Ending September 30, 2004*. http://thomas.loc.gov/cgi-bin/bdquery/z?d108:h.r.02754.

5.2.3.2 Scoping Meetings and Proposal Development Prior to Publication of the Notice of Intent

A pre-scoping stakeholder workshop was held in October 2003 in Annapolis, Maryland to obtain perspectives from researchers and stakeholders with regard to their expectations of the PEIS proposal and process for its evaluation. The meeting screened the proposal for issues that needed to be addressed and identified critical research issues on which research plans were developed.

A pre-scoping planning meeting was called in November 2003 following the development of the Memorandum of Understanding (MOU) between the lead Federal and State agencies. In the meeting, a group of upper-level project managers from Federal and State lead agencies, later forming the Management Team, agreed to the development of a Scientific Advisory Committee (SAC) to guide research, a peer review panel to review the PEIS, and a Web site for sharing information on the PEIS.

On November 18, 2003, a pre-scoping research workshop was held to discuss the desired output and necessary inputs to the model of the dispersal of *C. ariakensis* larvae and potential impacts to water quality, as well as input data available and additional input data needed for the modeling effort. Following the meeting, the UMD submitted a proposal to the lead agencies for the hydrodynamic modeling of the larval transport of *C. ariakensis*.

In December 2003, an additional pre-scoping research workshop was held by the technical advisory committee, for the Chesapeake Bay Program (CBP; Chesapeake Bay Program STAC), in cooperation with the NRC, to identify and prioritize research required to evaluate ecological risks, benefits and alternatives related to the potential introduction of *C. ariakensis*. A timeline for research was developed in this meeting. It was recommended that the finalized STAC report, released in March 2004, be used as a foundation for further *C. ariakensis* research.

On December 4, 2003, a meeting was held to discuss the economic analysis requirements needed to evaluate alternatives in the PEIS. Shortly thereafter, the UMD submitted a proposal to the lead agencies for the economic assessment. Also in December 2003, the ASMFC became an active participant in the programmatic PEIS process.

On December 10, 2003, an additional pre-scoping planning meeting was held by representatives from the cooperating Federal and State agencies and the PRFC, who would become the initial members of the PDT. Discussion included the creation of a PDT with representatives from the cooperating Federal agencies; inclusion of representatives from the ASMFC on the PDT and in a research review work group; language specifications for the Notice of Intent (NOI); and the presentation of the proposal at the public meetings. The USACE – Norfolk District agreed to request that all of the Cooperating Agencies designate personnel for assignment to the PDT. Edits to the draft NOI were incorporated and publication of the NOI and the initiation of public meetings was set for to January 2004 to allow for additional PDT review.

On December 17, 2003, a pre-scoping meeting involving PDT members was held to discuss and clarify the language for the NOI. The USACE agreed to distribute briefing materials to non-governmental organizations.

Seven preliminary alternatives to the proposed action were developed at pre-scoping meetings and workshops, held with the prospective lead agencies, cooperating agencies, researchers, and other stakeholders. These alternatives were presented in the NOI, published in the Federal Register on January 5, 2004.

5.2.3.3 Public Scoping Process

Project-specific outreach began in 2004 with the publication of the formal NOI in Volume 69, Number 2, pages 330 through 332 of the Federal Register, which is available via the internet as well as in hardcopy form. The lead agencies also published the NOI and summaries of the NOI in newspapers, including the following, and on the DNR Web site established for the Oyster PEIS project (DNR Oyster *In Focus* Web site: http://www.dnr.state.md.us/dnrnews/infocus/notice_of_intent2.asp):

- Richmond Times Dispatch
- The Daily Press
- The Virginian Pilot

- The Eastern Shore News
- The Baltimore Sun
- Evening Capital
- Star Democrat
- Daily Banner

The NOI was posted in about 150 locations in Virginia in tackle shops, marinas, post offices, courthouses and other public areas.

In addition, the lead agencies distributed copies of the NOI to interested parties, including the:

- Maryland Department of Agriculture
- Maryland Seafood and Aquaculture Task Force
- Maryland Oyster Roundtable Steering Committee and Interest List
- Maryland Oyster Roundtable and Interest List
- Maryland Sportfish Advisory Commission
- Maryland Tidal Fish Advisory Commission
- Maryland Coastal Bays Fishery Advisory Commission
- Maryland Watermen's Association
- Maryland County Oyster Committees
- Maryland CBF
- Maryland Coastal Bays Program
- Maryland CCA
- Maryland Saltwater Sportfishing Association
- PEIS research community (future SAC)

Copies of the NOI were subsequently posted to Web sites of interested parties, including the Maryland Watermen's Association Web site.

In addition to introducing the purpose and intent of the PEIS process, the preliminary alternatives, and providing a description of the scoping process, the NOI identified

- the lead and cooperating agencies
- scheduled dates for public scoping meetings
- a deadline for submittal of public comments (set at three weeks beyond the last public scoping meeting)
- names, affiliations, and contact information for submitting public comments
- key issues for research and assessment
- applicable legislation and regulations for environmental review and consultation

Public comment on the overall scope of the Oyster PEIS, including the purpose and need, list of alternatives to be evaluated, and project schedule were collected from the participants at the two public meetings held in both the Commonwealth of Virginia and State of Maryland on January 28, 2004 and February 5, 2004, respectively. Each public scoping meeting provided a briefing and presentation on the state of *C. virginica* in the Chesapeake Bay and its tributaries, the status of restoration efforts, preliminary programmatic PEIS alternatives, and the proposed action of the programmatic PEIS.

Participants at the public scoping meetings were organized into discussion groups and asked to identify the top five project priorities. Responses were used to further develop the PEIS alternatives, coordination process and research and assessment components.

In addition to hosting the January 28, 2004 and February 5, 2004 public meetings, the lead agencies provided an internet forum for individuals that were unable to attend the public meetings to provide comments: http://www.dnr.state.md.us/dnrnews/infocus/oystercomments.html. Approximately 36 posts were made. These internet postings included positions on the proposed action and alternatives and suggestions for research and management strategies.

5.2.3.4 Finalization of Alternatives

Comments produced by the public as well as Federal agencies, and State and local governments, were used to assist the USACE, DNR, VMRC, NOAA, EPA, and FWS representatives in defining the issues that would be evaluated in the PEIS. All public scoping comments were collected, reviewed, and discussed at a PDT meeting on March 26, 2004. Workshops and meetings were held at the PRFC office in Colonial Beach, Virginia to further refine the alternatives. A workshop held on February 1, 2006, provided data specifically for the refinement of the aquaculture alternatives. The PDT and representative members of the research community, CBP, Oyster Recovery Partnership (ORP) and aquaculture community attended. A meeting on the harvest moratorium alternative was held November 15, 2006.

5.2.3.5 Briefings and Updates

Over the course of the project, the lead agencies gave many briefings on the PEIS project including regular briefings to the ASMFC Policy Board. Briefings included updates on the research findings and project schedule and provided opportunities for public input. Venues at which project information was provided include fairs, trade shows, scientific conferences, and local and regional government and advisory organization public meetings including, but not limited, to

- 2004 Maryland Trade Association show
- 2004 Maryland State Fair
- 2005 and 2006 Interstate Shellfish Sanitation Conference (ISSC), Annual Interstate Seafood Seminars
- October 18, 2004 ORP Board of Directors' meeting
- 2006 Annual CBP Citizens Advisory Committee meeting

- February 22, 2005 DNR Monitoring and Non-Tidal Assessment (MANTA) noon seminar series
- April 16, 2005 annual Maryland Tributary Strategies Team meeting
- NOAA noon seminars
- October 15, 2005 Horn Point, Aquaculture and Restoration Ecology Laboratory public open house
- CBP's Chesapeake Bay seminar series
- January 12, 2006 Maryland Outdoor Caucus meeting
- 32nd East Coast Commercial Fishermen's & Aquaculture Trade Exposition
- 2006 Science & Seafood Seminar Series – *Savor the Bay*
- March 15, 2006 CBP, Scientific and Technical Advisory Committee (STAC) meeting
- April 13, 2006 Caroline County Health Department Tidewater Environmental Health Association meeting
- May 12, 2006 Oyster CAC annual meeting
- September 6, 2006 Blue Ribbon Oyster Panel meeting
- September 14, 2006 PRFC meeting
- May 14, 2007 Chesapeake Bay Commission meeting
- December 6, 2006 NOAA, Fisheries Office of Policy Seminar on Policy Development and Analysis Techniques
- March 18, 2004, April 20, 2006, July 20, 2006 and May 17, 2007 CBP Implementation Committee meetings
- Estuarine Research Federation 2007 Biennial Conference
- December 4-5, 2007 Oyster Management Workshop
- March 10 and April 9, 2008 Briefings to the Oyster Advisory Commission
- April 23, 2008, Briefing to ASMFC, ISTC and the CBP, STAC

5.2.4 Public Outreach and Agency Coordination Following Publication of Draft PEIS

On October 14, 2008, the lead agencies convened a press conference to announce their intent to release the Draft PEIS to the public on October 17, 2008. The Draft PEIS was released according to that schedule. The Notice of Availability (NOA) for the Draft PEIS was published in the EPA Federal Register (Vol. 2, No. 202, p. 61859) on October 17, 2008, simultaneously with the distribution of hardcopies and CDs of the document to the 35 libraries and 90 agencies and individuals included in the PEIS distribution list included in Section 8.

The USACE – Norfolk District's updated PEIS Web page was activated on October 17, 2008, and contains a downloadable copy of the Draft PEIS, a copy of the NOA, peer review reports for the Draft PEIS, related research and assessment documents, and a link to other supporting documentation. The USACE – Norfolk District monitored download activity during the public comment period; Figures 5-1 and 5-2 summarize that activity. In addition, DNR's PEIS Web page was updated to include a list of frequently asked questions concerning the PEIS and a copy of the October 14, 2008, press release.

During the 60-day public comment period following the publication of the Draft PEIS (October 17 – December 15, 2008), the lead agencies coordinated a series of public meetings – three each in Maryland and Virginia - to receive comments on the document. The dates, locations, and times of the meetings were announced in the October 14, 2008, press release and were included in the NOA. The press release emphasized the importance of public input in this process and encouraged public participation in the meetings. The USACE – Norfolk District issued subsequent press releases during the week before the first public meeting and on the day before the first meeting to promote involvement. On October 17, 2008, the NOA was distributed via email to approximately 200 representatives of the cooperating Federal agencies; resource agencies in Maryland, Virginia, Delaware, Georgia, South Carolina, North Carolina, New Jersey, New York, and Connecticut; various research institutions; and members of the general public who previously had indicated their interest in the project. The meeting dates also were advertised on the USACE – Norfolk District's Web site (http://www.nao.usace.army.mil/OysterEIS/Public Comment.asp) and DNR's Web site (http://www.dnr.state.md.us/dnrnews/infocus/oysters.asp).

According to the USACE – Norfolk District's Public Affairs Office, 58 media articles covering the Draft PEIS were released to an estimated audience of more than 3 million during the months of October and November, 2008. Several of these articles advertised the dates, locations, and times of the public meetings. Specifically, the schedule of public meetings was announced in articles that appeared in the Washington Post (Washington, D.C.), The Star Democrat (Easton, Maryland), The Daily Times (Salisbury, Maryland), and the Daily Banner (Cambridge, Maryland) on October 17, 2008, and in the Eastern Shore News on October 18, 2008, for a combined circulation of approximately 700,000 people.

Table 5-1 lists the dates and locations of the public meetings and indicates the approximate number of participants and their affiliations. All of the public meetings concerning the Draft PEIS were scheduled for 6:00 p.m. to 9:00 p.m. and followed a uniform agenda. The lead agencies procured an independent contractor who specializes in meeting facilitation and team-building to facilitate the meetings. As part of this service, the facilitator provided bulleted lists of participants' key concerns relayed during the meetings. The participants were asked to confirm the facilitator's summary at the close of each meeting.

Dr. William Richkus of Versar, Inc., manager of the PEIS Writing Team, opened the meetings with an overview of the Draft PEIS, which consisted of a visual presentation and handouts (Appendix G, Attachment D: Public Meeting Materials). A question-and-answer session followed during which Dr. Richkus answered participants' questions about technical content of the Draft PEIS.

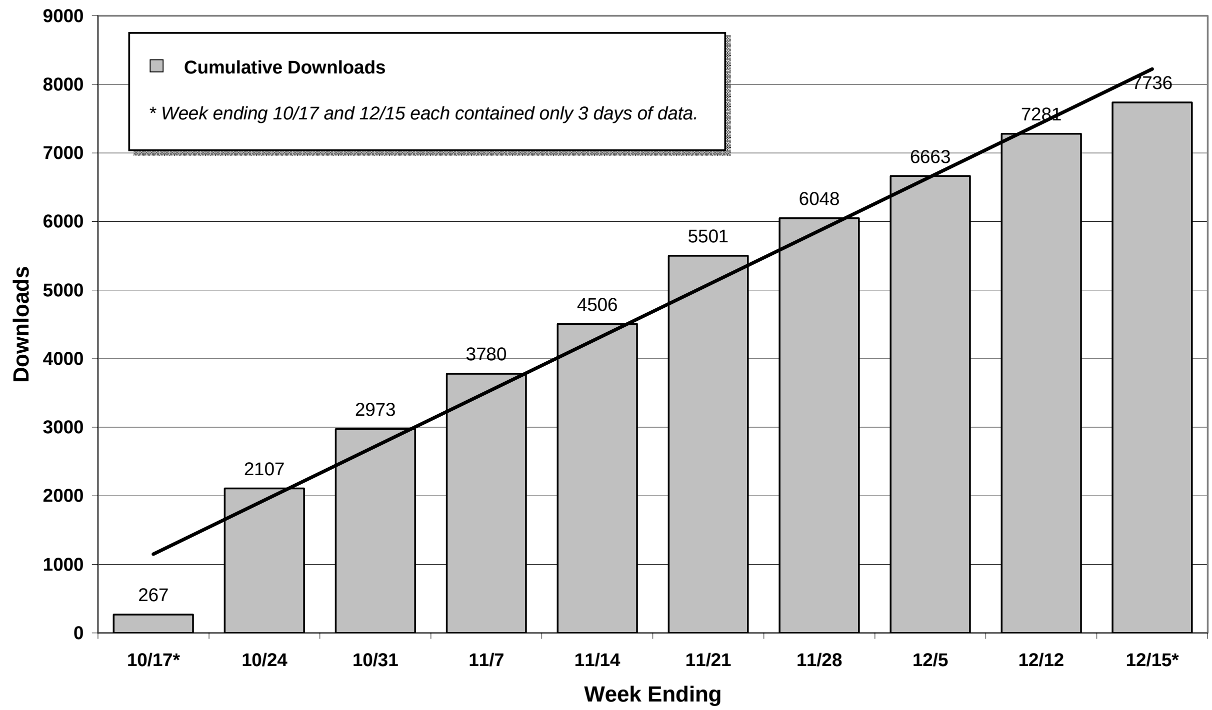


Figure 5-1. Cumulative downloads of the Draft PEIS from USACE's PEIS Web page during the public comment period (October 17 through December 15, 2008).

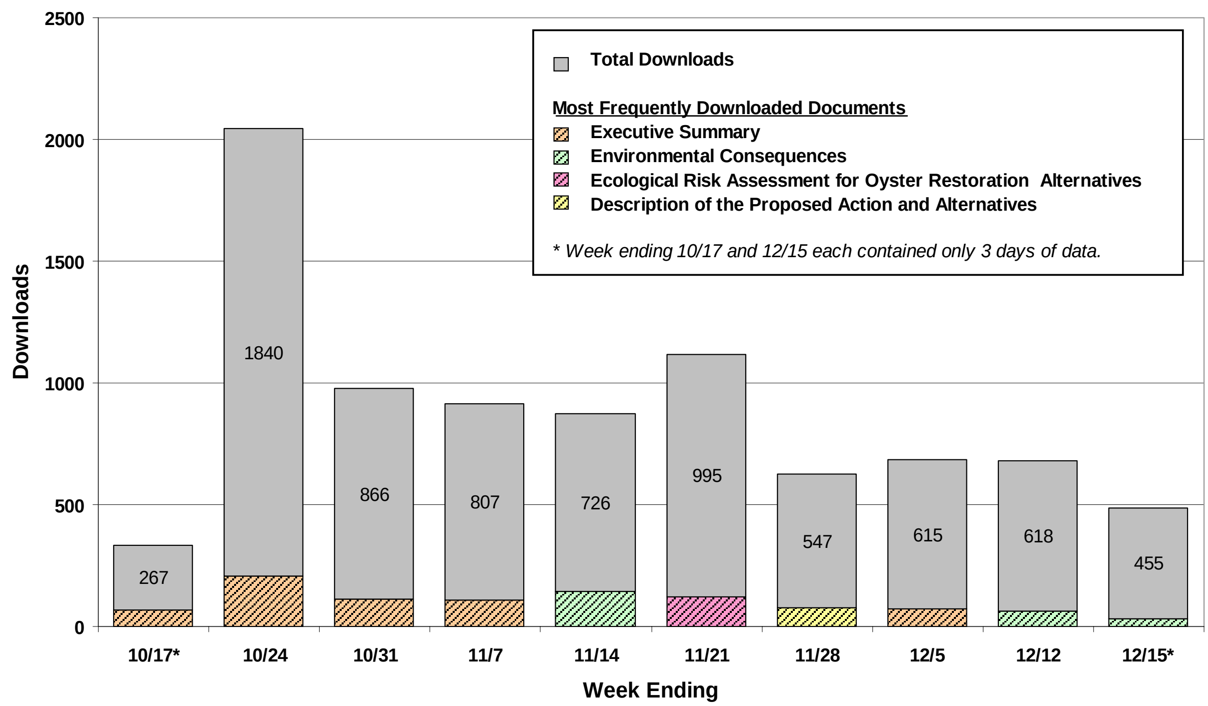


Figure 5-2. Weekly downloads of the Draft PEIS from USACE's PEIS Web page showing the most frequently downloaded sections of the document.

Table 5-1. Public Meetings for the Draft PEIS for Oyster Restoration		
Number of Participants	**Affiliations of Participants**	
November 5, 2008 – Potomac River Fisheries Commission – Colonial Beach, VA		
~ 50	PEIS Management Team TNC NOAA	EPA VMRC VSC Members of the general public
November 7, 2008 – Virginia Marine Resources Commission – Newport News, VA		
~ 30	PEIS Management Team CBF TNC	FWS VIMS VSC Members of the general public
November 10, 2008 – Nandua High School – Onley, VA		
~ 50	PEIS Management Team CBF Eastern Shore Post Elizabeth River Project	Lynnhaven River Now TNC VMRC VSC Members of the general public
November 12, 2008 – Calvert Marine Museum – Solomons, MD		
~ 50	PEIS Management Team CBF CCA	TNC NOAA VSC Members of the general public
November 13, 2008 – Miller Senate Building – Annapolis, MD		
~ 90	PEIS Management Team ASMFC CBF CCA TNC	USACE – Baltimore District EPA CBP FWS VSC Members the general public
November 14, 2008 – Minnette Dick Hall – Cambridge, MD		
~ 60	PEIS Management Team CBF Maryland State legislature	Maryland Watermen's Association TNC VSC Members of the general public
ASMFC - Atlantic States Marine Fisheries Commission CBF - Chesapeake Bay Foundation CBP - Chesapeake Bay Program CCA - Coastal Conservation Association EPA - Environmental Protection Agency FWS - U.S. Fish and Wildlife NOAA - National Oceanic and Atmospheric Administration	PEIS - Programmatic Environmental Impact Statement PRFC - Potomac River Fisheries Commission TNC - The Nature Conservancy USACE - U.S. Army Corps of Engineers VIMS - Virginia Institute for Marine Science VMRC - Virginia Marine Resources Commission VSC - Virginia Seafood Council	

Written and oral comments were submitted during the public meetings. Attendees were requested to indicate on the sign-in sheet if they wished to make a formal statement during the meeting. Following the technical question-and-answer session, those individuals were invited to speak before the audience. After those statements, the facilitator invited the audience to comment. When the audience offered no further comments, the facilitator informed the attendees of the date, time, and location of the next meeting and adjourned the meeting. Each meeting was recorded on audiotape to ensure accurate documentation of the oral comments. A subcontractor to DNR prepared detailed summaries of the proceedings of each of the public meetings (Appendix G, Attachment E: Public Meeting Documentation).

5.2.5 Overview of Comments on the Draft PEIS

During the 60-day comment period, the USACE – Norfolk District received comments from 2,175 respondents in the form of letters, emails, and statements offered during the public meetings. A total of 92 individuals provided comments during one or more of the public meetings. A variety of concerned residents, business owners, and representatives of watermen's associations and other non-profit organizations provided testimony during those proceedings; attendance records and summaries for each meeting are included in Appendix G. Formal responses to comments are presented in Appendix I. All comments received during the public comment period were considered, and copies of all letters and emails received prior to the closing date of the comment period (December 15, 2008) are included in Appendix J.

5.2.5.1 Government Agencies

A total of 30 Federal, State, and local resource agencies, government commissions, and committees and one academic institution, the Virginia Institute for Marine Science (VIMS), submitted letters of comment on the Draft PEIS. VIMS' comments were submitted with the Commonwealth of Virginia's comments and are grouped with "Agency Comments" in Appendix J.

The following Federal agencies submitted written comments: NOAA, U.S. Department of the Interior, and EPA. Each of those agencies formally expressed support for Alternative 8a. The main issues raised by the Federal agencies included

- creation and sustainability of critical habitat
- scientific uncertainty concerning the Suminoe oyster
- economic consequences of a moratorium
- the need to improve enforcement of harvest prohibitions for oyster sanctuaries and managed reserves
- human health risks associated with introducing the Suminoe oyster
- interactions between native and nonnative species and biodiversity loss
- irreversibility and widespread effects of the proposed action
- economic viability and risks of cultivating the Suminoe oyster, including the potential for triploid reversion
- policy issues concerning introduction of a nonnative species

Resource agencies representing states along the Atlantic seaboard submitted comments, including agencies in Florida, South Carolina, North Carolina, Virginia, Maryland, Delaware, New Jersey, New York, and Maine. State agencies' raised concerns about the proposed action, specifically regarding the susceptibility of the Suminoe oyster to environmental stressors and the uncertainty regarding the spread and biological interactions of the species. The majority of the State agencies requested the use of only the native species in all future restoration efforts. Multi-state and advisory commissions including the Atlantic States Marine Fisheries Commission, the Gulf States Marine Fisheries Commission, the Delaware River Basin Fish and Wildlife Management Cooperative, and Citizens Advisory Commission to the Chesapeake Bay Executive Council also provided formal comments in opposition to the proposed action, citing the potential for adverse ecological consequences, human health risks, the Suminoe oyster's susceptibility to environmental stressors, and insufficient economic information for comparing the costs of the alternatives. Comments provided by eight State agencies, commissions, and committees specifically supported Alternative 8a or opposed the proposed action. The office of Meyera E. Oberndorf (Mayor, Virginia Beach, Virginia) submitted a letter endorsing Alternative 8a. The office of Virginia Delegate Albert C. Pollard submitted a letter supporting Alternative 8b. The following agencies, commissions, and offices did not indicate support for a specific alternative: Maryland Department of the Environment, Maryland Department of Planning, Maryland Port Administration, Virginia Department of Environmental Quality, and the Delaware River Basin Commission. Table 5-2 and Figure 5-3 summarize the documented preferences of Federal, State, and local agencies for specific combinations of alternatives.

Although it is not officially a governmental agency, the Scientific and Technical Advisory Committee (STAC) provides guidance to EPA's Chesapeake Bay Program and consists of appointed members selected from Federal and State agencies, universities, research institutions, and private industry. STAC formally recommended Alternative 8a. STAC's letter provides a detailed justification for that decision and identifies the members' assessments of the limitations of the Draft PEIS.

In a formal letter, VIMS commented that a single alternative could not meet ecological and economic needs and, therefore, that those needs should be considered separately to evaluate the alternatives. Nevertheless, VIMS formally endorsed Alternative 8a based on positive and negative findings regarding the Suminoe oyster.

5.2.5.2 Nongovernmental Organizations

A total of 32 nongovernmental organizations provided comments on the Draft PEIS. In addition to various environmental organizations, several organizations from Maryland and Virginia that are affiliated with the seafood industry provided comments on the Draft EIS. Sixteen of the responding groups expressed concerns about the ecological risks of introducing a nonnative species and encouraged continued efforts to restore the native species. Ten organizations favored Alternative 8c but requested the elimination of the harvest moratorium from that alternative. The remaining organizations expressed no clear support for any particular alternative. Figure 5-3 illustrates the documented preferences of nongovernmental organizations for specific combinations of alternatives.

5.2.5.3 Individuals

A total of 2,091 citizens submitted letters, postcards, emails, and oral comments concerning the Draft PEIS. Six representatives of businesses associated with the oyster industry commented. Table 5-2 shows the documented preferences of those businesses regarding the combinations of alternatives evaluated in the Draft PEIS. Citizens submitted 410 identical postcards and 1,341 emails supporting CBF's official position on the Draft EIS (Appendix J, p. J-468). Approximately 95% of the individuals who commented expressed

Table 5-2. Documented preferences of governmental agencies, businesses associated with the oyster industry, and nongovernmental organizations regarding combinations of alternatives for restoring oysters in Chesapeake Bay.				
AGENCY or ORGANIZATION	**DOCUMENTED PREFERENCE***			
	None Stated	**8a**	**8b**	**8c**
Federal Agencies and Commissions				
Environmental Protection Agency (EPA)		X		
National Oceanographic and Atmospheric Administration (NOAA)		X		
Department of the Interior (DOI) - including the Fish and Wildlife Service (FWS)		X		
Chesapeake Bay Program (CBP) – Scientific and Technical Advisory Commission (STAC)		X		
CBP – Citizens Advisory Committee (CAC)		Native only		
State and Local Agencies and Commissions				
VA Institute of Marine Sciences (VIMS)		X		
NC Marine Fisheries Commission		Native only		
SC Department of Natural Resources		X		
ME Department of Marine Resources		Native only		
NY Department of Environmental Conservation (DEC)		X		
DE Division of Fish and Wildlife, NJ Division of Fish and Wildlife, and NY DEC (joint position)		X		
DE DNREC Natural Resources and Environmental Control		Native only		
DE River Basin Fish and Wildlife Management Cooperative		Native only		
DE River Basin Commission	X			
VA Department of Environmental Quality	X			
VA DEQ - Waste Division	X			
VA DEQ - VA Dept. of Agriculture and Consumer Services	X			
VA DEQ - Michelle Henicheck	X			
VA DEQ - Tidewater Regional Office/ VA DEQ - Piedmont Regional Office	X			
VA DEQ - Office of Air Data Analysis	X			
VA Department of Historic Resources	X			
VA Department of Conservation and Recreation - Kristal McKelvey	X			
VA Department of Conservation and Recreation - Robert S. Munson	X			
VA Department of Game and Inland Fisheries	X			
VA Department of Health	X			
Hampton Roads Planning District, Virginia	X			
VA Delegate Albert C. Pollard, Jr. District 99			X	
VA Beach Mayor, Meyera E. Oberndorff		X		
MD Port Administration	X			
MD Department of Planning	X			
MD Department of the Environment	X			
FL Fish and Wildlife Conservation Commission		Native only		
Atlantic States Marine Fisheries Commission (ASMFC)		X		
Gulf States Marine Fisheries Commission		X		

Table 5-2. (Continued)

AGENCY or ORGANIZATION	DOCUMENTED PREFERENCE*			
	None Stated	**8a**	**8b**	**8c**
Businesses				
Bevans Oyster Co./A.J. Erskine			X	
Hazelwood Oyster Farms, Inc./Thomas A. Hazelwood				X (Supports proposed action)
Marinetics/Bob Maze		Native only		
Oyster King 1, Inc./Andrew Murdza		Native only		
Mason Seafood/Tommy Mason				X
Rappahannock River Oysters, LLC/Ryan Croxton		Native only		
Non-governmental Organizations				
VA Seafood Council			X	X
Elizabeth River Project		X		
Defenders of Wildlife		X		
Chesapeake Bay Foundation (CBF)		X		
Chesapeake Bay Seafood Industry Association				X
MD Conservation Council		X		
Smithsonian Environmental Research		X		
Natural Resources Defense Council		X		
Lynnhaven River Now		X		
VA Aquarium and Marine Science Center Foundation		X		
The Nature Conservancy		X		
Rappahannock Preservation Society		Native only		
Shore Drive Community Coalition		Native only		
The National Aquarium, Baltimore		X		
South Arundel Citizens for Responsible Development, Inc.		Native only		
South River Federation		X		
Southern Maryland Audubon Society		X		
National Wildlife Federation		X		
Partnership for the DE Estuary		Native only		
Oyster Reef Keepers of VA		Native only		
Coastal Conservation Association		X		
Virginia Watermen’s Association	X			
Queen Anne’s County Seed Committee				X
Queen Anne’s County Watermen’s Association	X			
Maryland Watermen’s Association				X
Maryland Oystermen's Association				X
Dorchester County Watermen’s Association				X
Talbot County Shell Association				X
Calvert County Watermen’s Association				X
Kent County Watermen’s Association				X
St. Mary’s County Watermen’s Association				X
Friends of the Rappahannock	X			

* Some agencies, businesses, and organizations did not specify a preferred alternative; those are noted as None Stated. Some indicated that they preferred the use of only native oysters in any future restoration efforts, which was interpreted to be analogous to Alternative 8a for accounting in this table.

8a – Eastern oysters only: Enhance efforts to restore Eastern oysters; impose a harvest moratorium and compensation program for the oyster industries; cultivate Eastern oysters.

8b – Eastern oyster and triploid Suminoe oysters: Enhance efforts to restore Eastern oysters; impose a harvest moratorium and a compensation program for the oyster industries; cultivate Eastern oysters; cultivate triploid Suminoe oysters.

8c – Eastern oyster and diploid and triploid Suminoe oysters: Introduce diploid Suminoe oyster; enhance efforts to restore Eastern oysters; impose a harvest moratorium and a compensation program for the oyster industries; cultivate Eastern oysters; cultivate triploid Suminoe oysters.

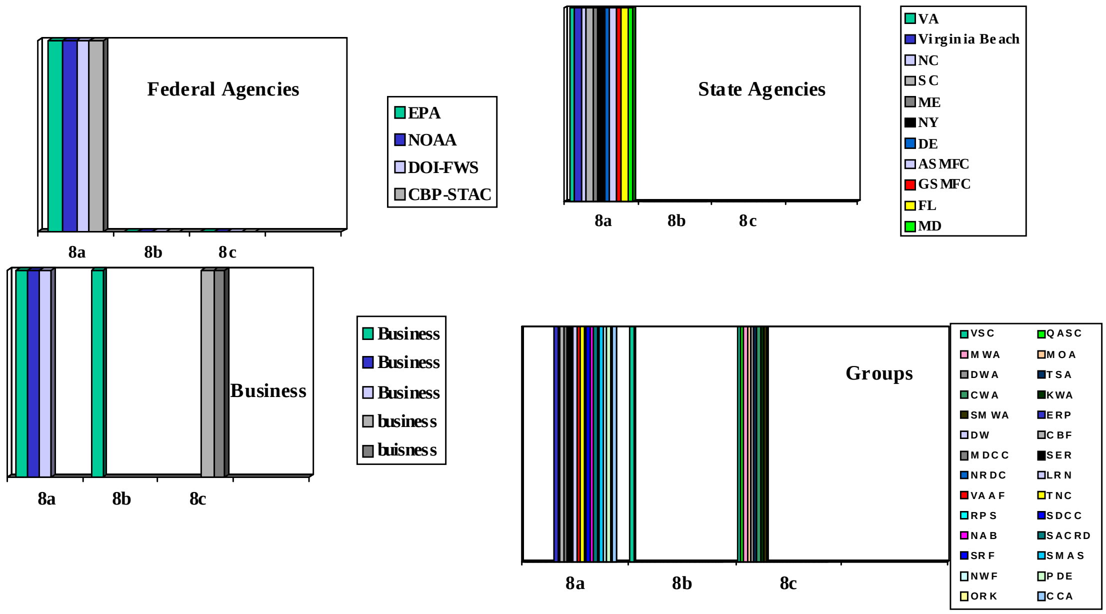


Figure 5-3. Illustration of the documented preferences of major groups for one of the combinations of Alternative 8 specified in the Draft PEIS.

support for Alternative 8a or opposed the proposed action. Approximately 2.6% (56) supported Alternative 8c; 0.2% (4) supported Alternative 8b; and 0.05% (1) endorsed the proposed action only. Approximately 2.4% (51) did not specify support for a particular alternative. Some individuals including some seafood businesses and watermen, opposed the inclusion of a harvest moratorium as part of Alternatives 8b or 8c. Figure 5-3 illustrates the documented preferences of seafood businesses for specific combinations of alternatives.

5.3 REQUIRED CONSULTATIONS

The preferred alternative (Alternative 8a) establishes a broad general direction for future oyster restoration programs to be implemented by the USACE and the States of Maryland and Virginia using only the native Eastern oyster. Preferred Alternative 8a does not define specific projects in specific locations or specify the scope of any individual element of a comprehensive restoration effort. As a result, it is not possible to identify which Federal or State statutes will be applicable and will require coordination with Federal regulatory agencies, State agencies, or both. Section 2.6 listed statues that may be applicable to future programs; this section provides greater detail concerning several of the statutes that would require consultation if they apply to a specific implementation plan.

Any future restoration programs designed to implement the preferred alternative will be likely to require permits from the USACE under Section 404 of the Clean Water Act, Section 10 of the River and Harbors Act, or both because any restoration action probably will involve either placing new substrate on the bottom of the bay or manipulating existing substrates. The USACE will review applications for such permits to determine if the proposed actions are within its jurisdiction and if they would be covered under a nationwide permit or would require individual permits. In some cases in which an individual permit is necessary, the applicant could be required to prepare an appropriate document in compliance with NEPA regulations to facilitate the permitting decision, as noted in Section 2.6. The following statutes have specific consultation requirements that may have to be met before certain actions can be implemented.

5.3.1 Endangered Species Act (ESA) Section 7 Consultation

Section 7(a)(2) of the ESA [16 USC §1536(a)(12)] requires every Federal agency, in consultation with and with the assistance of the Secretaries of the Interior, Commerce, or both to ensure that any action it authorizes, funds, or carries out in the United States or upon the high seas is not likely to jeopardize the continued existence of any species listed as endangered or threatened, or result in destruction or adverse modification of critical habitats for listed species. This PEIS focuses on describing a proposed action and alternative management strategies for attempting to restore the abundance and functions of oysters in Chesapeake Bay and identifies the strategy preferred by the lead agencies. Federal permits may be required later at the project or site-specific level after the lead agencies develop specific, detailed plans for implementing their preferred alternative. At that point, the appropriate permitting agencies will conduct further environmental review, including consultation under Section 7(a)(2) of the ESA, if necessary.

5.3.2 Virginia Department of Conservation and Recreation Consultation

Virginia's Department of Conservation and Recreation (DCR) has requested coordination for project review of any land-based activities in Virginia's Natural Area Preserves (Section 3.10.2) that may result from this PEIS (DCR 2008). According to a Memorandum of Agreement between DCR and Virginia's Department of Agriculture and Consumer Services (VDACS), DCR represents VDACS in comments regarding potential effects on state-listed threatened and endangered species of plants and insects. The primary contact for such consultation is

Kirstal McKelvey
Coastal Zone Locality Liaison
Virginia Department of Conservation and Recreation
217 Governor Street
Richmond, Virginia 23219-2010
(804) 692-0984

5.3.3 Essential Fish Habitat Consultation

The Magnuson-Stevens Fishery Conservation and Management Act requires Federal agencies to consult with the Secretary of Commerce, through the NMFS, with respect to "any action authorized, funded, or undertaken, or proposed to be authorized, funded, or undertaken by such agency that may adversely affect any Essential Fish Habitat (EFH) identified under this Act" [16 USC § 1855(b)(2)]. When the responsible Federal agency determines that an action may adversely affect EFH, the agency must initiate consultation with NMFS [16 USC §1855(b)(2)]. To carry out this EFH consultation the responsible Federal agency must submit an EFH assessment containing "a description of the action; an analysis of the potential adverse effects of the action on EFH and the managed species; the Federal agency's conclusions regarding the effects of the action on EFH; and proposed mitigation, if applicable" to the NMFS. NMFS may request the responsible Federal agency to include additional information in the EFH assessment, such as the results of on-site inspections, views of recognized experts, a review of pertinent literature, an analysis of alternatives, and any other relevant information [50 CFR § 600.920(e)(4)]. Depending on the kinds and magnitudes of effects on EFH, compensatory mitigation may be necessary to offset permanent and temporary effects of the project. If the project were expected to result in substantial adverse effects on EFH, an expanded EFH consultation could be necessary [50 CFR § 600.920(i)].

The implementation of a management strategy to restore the abundance and functions of oysters in Chesapeake Bay may result in future, site-specific projects that, if authorized by the USACE, could affect EFH and thereby trigger the requirements of the Magnuson-Stevens Fishery Conservation and Management Act. This PEIS describes the general kinds of effects that could result from the kinds of site-specific projects for restoring oysters in Chesapeake Bay that might be associated with the preferred alternative. The analysis provided in the PEIS will be used to guide the development of any EFH assessments required for future EFH consultations on site-specific proposals. For any future, site-specific project that requires an authorization from the USACE, the USACE will make a determination about whether the project would adversely affect any EFH in the project area. If adverse effects are possible, the USACE will initiate an EFH consultation by providing an EFH assessment to the NMFS' Northeast regional office. The primary NMFS contact for the required EFH consultation is

NMFS Northeast Regional Habitat Conservation Division
One Blackburn Drive
Gloucester, Massachusetts 01930-2298
Phone: (978) 281-9277

5.3.4 Fish and Wildlife Coordination Act Consultation

The Fish and Wildlife Coordination Act of 1958 (FWCA), as amended (Pub. L. 85-624; 16 U.S.C., et seq.) requires equal consideration of fish and wildlife resources when evaluating water resources development programs and projects. It provides authority for the involvement of FWS and NMFS in evaluating effects on fish and wildlife and requires Federal agencies that construct, license, or permit water resources development projects to first consult with the FWS or NMFS, as appropriate, regarding the potential effects on fish and wildlife resources and measures to mitigate those effects; therefore, in order to comply with the FWCA, the USACE will consult with the FWS and NMFS prior to making a permit decision or authorization required for future actions related to this PEIS.

5.3.5 National Historic Preservation Act Section 106 Consultation

Section 106 of the National Historic Preservation Act (NHPA) requires the head of any Federal agency having direct or indirect jurisdiction over a proposed Federal or Federally assisted undertaking to take into account the effect of the undertaking on any district, site, building, structure, or object that is included in or eligible for inclusion in the National Register of Historic Places. The Advisory Council on Historic Preservation (ACHP) Regulations at 36 CFR Part 800 set forth the procedures that Federal agencies must follow to comply with

Section 106 of the NHPA. The Section 106 compliance process is undertaken in consultation with the State Historic Preservation Office (SHPO), Tribal Historic Preservation Office(s) (THPO), and other interested parties to identify historic properties that may be affected by the project, to assess the potential for adverse effects on those properties and, if the potential for an adverse effect is found, to seek ways to avoid, minimize, or mitigate the adverse effects. Section 36 CFR 800.8 of the ACHP regulations outlines the procedures for coordinating Section 106 compliance with the National Environmental Policy Act (NEPA) process. In that process, consulting parties provide information about specific historic properties that may be affected by the proposed project during the NEPA scoping phase. The NEPA document then provides an assessment of the potential for adverse effects on those properties and identifies proposed measures to mitigate the potential adverse effects. Prior to, or within the time allowed for public comment on the NEPA document, the SHPO, THPO, ACHP, or other consulting party may object that preparation of the NEPA document has not met the standards set forth in the ACHP regulations, or that the substantive resolution of the effects on historic properties proposed in the NEPA document is inadequate. If such an objection is received, the matter is referred to the ACHP, which has 30 days to provide an opinion on the objection. The responsible Federal agency must consider the opinion of the ACHP in reaching a final decision on the issue of the objection and must prepare a summary of the decision that contains the rationale for the decision and evidence of having considered the ACHP's opinion.

This PEIS describes the general kinds of effects on historic properties that could result from the kinds of site-specific projects for restoring oysters in Chesapeake Bay that might be associated with implementing the preferred alternative. The analysis provided in the PEIS will be used to guide consultations on site-specific proposals. For any future, site-specific project, the appropriate responsible Federal agency will make a determination about whether the project would adversely affect any historic properties in the project area. If adverse effects are possible, the responsible Federal agency will initiate a consultation by contacting the appropriate SHPO. The SHPOs for Maryland and Virginia are

J. Rodney Little, Director and SHPO
Maryland Historical Trust
Division of Historical and Cultural Programs
100 Community Place
Crownsville, Maryland 21031-2023

Kathleen Kilpatrick, Director
Virginia Department of Historic Resources
2801 Kensington Avenue
Richmond, Virginia 23221

APPENDIX C: Plan Formulation

C-1: PLAN FORMULATION WHITE PAPERS

Introduction and Summary Table

The USACE team developed white papers focused on eight specific oyster restoration topics. The white papers were formulated to discuss the significance of the paper's topic to oyster restoration and the master plan, summarized the current state of knowledge, and described the application to the master plan. These white papers were provided to the two state sponsors as well as the cooperating agencies for review and comment. Comments were addressed by USACE. Ultimately, the formulation white papers were used to obtain consensus on USACE's proposed strategies between USACE, the sponsors, and the cooperating agencies.

Table C-1. NORMP White Paper Summary

White Paper Topic	Synopsis	How Information Was Used to Develop NORMP	Future Application to Tributary Implementation Plans
SCALE	Scale, as defined in this paper, is the approximate number of acres of habitat in a given area or tributary required to develop a self-sustaining population. The paper describes a methodology, considering 40% of the historical distribution, to arrive at this scale.	NORMP presents the approximate scale of oyster reef required in acres for most tributaries in the Bay in order to achieve self-sustaining populations.	The scale number will be refined by determining existing populations/reefs, hydrodynamics, recruitment, bottom conditions, etc. through field and other technical investigations and study.
DISEASE	Disease-caused mortality is one of the major factors responsible for the dramatic declines in oyster landings observed since the early 1980s. The presence of disease complicates all other factors that must be addressed to achieve oyster restoration. The paper addresses disease, its relationship to salinity and	NORMP recommends: 1) stocking of restored sites with spat-on-shell derived from hatcheries or obtained from the wild population from disease tolerant parent stock; 2) seeding of restoration sites with large adult wild oyster broodstock that have survived disease and/or spat-on-shell collected from areas (within the same salinity regime as	Disease resistance development must continue to be tracked in the wild population. Methods to accelerate this development must also be explored as a better understanding of disease resistance development is gained. Each tributary plan may outline a different strategy to deal with disease depending on salinity, disease prevalence and intensity, and other influencing factors.

	other environmental factors, and the development of disease resistance in the wild population to ensure the sustainability of restoration projects.	restoration site) where a proportion of the parent broodstock has survived disease; 3) using ‘incubator reefs’ to provide a seed source for restoration work; and, 4) transplanting of spat-on-shell produced on incubator reefs throughout the Bay.	
POPULATIONS – BAYSCAPE	The size and extent of oyster habitat and populations (current and historic) and their setting within the bayscape are relevant to oyster restoration. Yates and Baylor surveys were selected as the most comprehensive early oyster surveys. These two surveys overestimated the amount of oyster reef habitat for various reasons. Prior to water quality impairments, the situation of reefs within the bayscape was driven by water currents, hydrodynamics, geologic relief, water depth, and suitable substrate.	NORMP estimates the true extent of oyster habitat by using the Yates and Baylor surveys in conjunction with the Winslow and Moore Surveys, respectively. These comparisons provide an estimate of the percent of the historic surveys (Yates and Baylor) that actually held oyster reef. This information is used to develop scale (see scale white paper for further details).	The location of reefs within the bayscape, while not a major concern for NORMP, will be very important when developing specific tributary restoration plans on the scale of individual reefs. Benthic mapping will be utilized to identify hard bottom and remnant bars that would be able to support additions of hard substrate. Incorporating historic hard features into plans will assist in restoring reefs to their historic place in the bayscape: along terrace scarps, on the sides of channels, in areas where there is a sudden change in water depth, and at the mouths of rivers.

Table C-1. NORMP White Paper Summary (cont'd)

White Paper Topic	Synopsis	How Information Was Used to Develop NORMP	Future Application to Tributary Implementation Plans
POPULATIONS – REEFS	Bar morphology and height has been found to alter flow and ultimately impact growth, recruitment, condition, sedimentation, burial, and mortality. The success of Great Wicomico highlights the importance of sufficient bar height. Microhabitats such as interstitial space within the reef complex are an important feature of oyster habitat. Interstitial space provides marine organisms with protection from predation, physical stresses, and competitors (Bartol et al. 1999). Heterogeneity is an important feature of the reef complex. Proper flow over an oyster reef will maintain a sediment free reef, provide food, and carry away waste products.	NORMP recommends constructing the first phase of reefs in any given DSS to at least a height of 1ft with some minor variation in height across the reef to create topographic heterogeneity. Within the Chesapeake Bay, one foot of relief is expected to be a sufficient height to promote reef longevity. Topographic heterogeneity is an important feature to provide when restoring oyster reef. If alternate substrates are being used for construction, NORMP recommends placing a veneer of clean oyster shell at least 15 cm (6.0 in.) thick upon the alternate substrate core. NORMP discusses the preferred orientation to flow (Northern-style = parallel, Southern-style = perpendicular). Due to concerns with hypoxia and anoxia, NORMP recommends that restoration be restricted to areas with water depths less than 20 ft of water.	NORMP will discuss the preferred orientation of a reef, but this factor will be most important when specific tributary restoration plans are being developed. The size of individual bars will be determined and it is expected that size will vary. Following the initial construction phase, reefs should be evaluated to determine if bar height needs to be adjusted for future reefs constructed in that DSS. Construction methods should continue to be evaluated and improved to fully understand the ability we have to adequately control placement of reef materials.

Table C-1. NORMP White Paper Summary (cont'd)

White Paper Topic	Synopsis	How Information Was Used to Develop NORMP	Future Application to Tributary Implementation Plans
PHYSIOCHEMICAL	Physical environmental factors affect the survival, growth, and reproduction of oysters. The following physical characteristics relevant to oyster restoration are evaluated: 1) salinity, 2) dissolved oxygen (DO), and 3) temperature. Temperature is not a limiting factor to oyster restoration in CB however; DO concentration and salinity are critical factors in locating oyster restoration projects.	The physiochemical factors of salinity and DO were used in a GIS layered format as primary criteria to identify areas in the Bay suitable for restoration. Minimum thresholds for oyster growth and survival and related reef ecosystem health were identified: Average annual growing season bottom salinity >5ppt and DO >5 mg/l.	Individual tributary plans will more closely examine these physiochemical factors and their current state and relationship to the individual plans. For example, DO may improve as Bay nutrient reduction goals are increasingly achieved in the future.
HYDRODYNAMICS	Each tributary has unique hydrodynamics and currents driven by tides, tributary shape and size, freshwater input, benthic structures, and winds. These forces influence oyster larval transport within and between tributaries, as well as local flows over individual reefs. Hydrodynamics and currents control the delivery rate and retention of planktonic oyster larvae and suspended food material to suspension-feeding oysters, as well as sediment, thereby affecting the recruitment, growth, and survival of oysters, and oyster reef habitat quality.	NORMP evaluates hydrodynamics of tributary systems as a secondary criterion to identify Tier 1 tributaries. There is no available analysis of hydrodynamics for all tributaries therefore, NORMP has compiled and considered all available information focused on tributary hydrodynamics and larval transport uses this to provide a hydrodynamic rating to each tributary. Large tributaries are divided into sub-basins and rated as such while small tributaries are rated in their entirety. This permitted the rating of hydrodynamically distinct sub-segments (DSS) regardless of size. The analysis resulted in a ranking of High, Medium-High, Medium, Medium-Low and Low for each tributary or DSS.	Individual tributary plans will include 3-D numerical modeling to refine and better determine the hydrodynamics of the system. This includes identifying the role of hydrodynamics in source/sink dynamics. It has been shown that within metapopulations, oyster reefs can serve either as source and sinks with respect to larval transport. Source reefs provide larvae to reef habitat in both source and sink habitats to maintain the populations. Sink reefs receive larvae, but do not contribute a significant amount of larvae to the population.

Table C-1. NORMP White Paper Summary (cont'd)

White Paper Topic	Synopsis	How Information Was Used to Develop NORMP	Future Application to Tributary Implementation Plans
REPRODUCTION	Oyster biology and reproduction are critical factors to consider in recommending and developing potential restoration projects. Because parent broodstock is severely limited in the Bay, reproduction must be supplemented. The following topics relevant to reproduction and are addressed: 1. Oyster biology/reproduction; 2. Physical and biological influences on reproduction; 3. Larval distribution; 4. Strategies to jump start population reproduction; 5. Research	NORMP recommends various methods to jumpstart reproduction, tailored based on site salinity and disease level including: seeding, shell/substrate repletion, broodstock enhancement, and the use of wild disease resistant stocks. The following is recommended for low salinity (<12 ppt) waters: 1) Stock constructed reefs using spat on shell at a rate of 4 to 5 million spat per acre (~1,000 to 1,200/m^2); 2) use adult disease resistant wild stock to produce the spat-on-shell in hatcheries; 3) where monitoring indicates, restock at the same rate with spat on shell 2 to 3 years following initial planting, to provide a multi-age population. The following recommended for high salinity (>12 ppt) waters: 1) Seeding may not be necessary; 2) Stock and aggregate large natural oysters harvested from areas with demonstrated disease tolerance to enhance fertilization success; 3) Use large adult wild stock to produce the spat-on-shell in hatcheries; 4) Use wild spat-on-shell obtained from areas (within the same salinity regime) where large adult parent broodstocks have demonstrated some level of disease resistance.	Individual tributary plans will evaluate existing populations in the individual tributary to assess natural recruitment, oyster population characteristics, and condition to determine the need for, and the rate of, additional stocking.

Table C-1. NORMP White Paper Summary (cont'd)

White Paper Topic	Synopsis	How Information Was Used to Develop NORMP	Future Application to Tributary Implementation Plans
GROWTH	The rate of oyster growth at restored sites will affect how quickly oysters mature and their fecundity, the ecosystem benefits produced, their defense against predation, and the population's ability to counter sedimentation. Many factors affect oyster growth, but there is no reliable model available to predict oyster growth.	NORMP will rely on an empirical approach that uses available data to predict growth under various physical conditions. NORMP team will gather available monitoring data and compile a list of growth data paired with salinity, T, hydrologic regime (wet, dry, or normal year), water depth, DO, disease prevalence, etc. This data will be used to project the level of growth to be expected by restoration in identified areas and salinity ranges, and under expected environmental conditions. Ultimately, from a programmatic perspective, growth (mm/yr) must exceed sedimentation rates (mm/yr). The available data shows that higher salinity equals higher growth, and therefore oysters planted in Zone 2 (>12 ppt) should grow faster than oysters planted in Zone 1 (5-12 ppt).	Growth rates will vary from tributary to tributary. In order to predict long term survival, fecundity, and delivery of sustainable ecological benefits it will be important to more accurately predict growth rates in the individual tributary plans. This can be accomplished through field investigations, spat set data, and other research data acquired during the plan development or feasibility planning phase.

Physical Characteristics – Physiochemistry White Paper

A. SIGNIFICANCE TO OYSTER RESTORATION AND THE MASTER PLAN

The following physical characteristics are relevant physiochemical parameters of oyster restoration and will be evaluated in this white paper:

- salinity,
- dissolved oxygen, and
- temperature.

1. Salinity

Eastern oysters can tolerate a wide range of salinity- thriving in the mesohaline waters, becoming less abundant toward the head of the Bay and in upper regions of the Bay tributaries. Salinity influences growth, development, reproduction, feeding activity, predation, and disease pressure.

2. Dissolved Oxygen

Dissolved oxygen in the water column is essential for respiration, and estuarine species exhibit a range of vulnerability to decreasing concentrations of dissolved oxygen (i.e., hypoxia = DO< 2 mg/l, anoxia = DO=0 mg/l). Dissolved oxygen influences settlement, growth, survival, development, reproduction, recruitment, feeding activity, and predation.

3. Temperature

Temperature can affect reproduction, feeding rates of oysters, available food sources (phytoplankton), growth and survival, and disease pressure as well as the dissolved oxygen concentration of the water column which in turn affects numerous aspects of oyster growth and survival.

B. SCIENTIFIC BASIS AND STATE OF KNOWLEDGE

Salinity and Temperature

Salinity and temperature are the two main environmental factors affecting survival, growth, and reproduction of oysters (Shumway 1996; NRC 2004). The Eastern oyster is accustomed to water temperatures ranging annually from -2ºC to 36ºC and salinity ranging annually from 5 to 40 ppt, although most major populations occur in salinities between 10 and 30 ppt. Although able to withstand extreme temperatures, the rate of temperature change has been shown to have a great effect on adult oysters. That is, the slower the rate of temperature increase, the lower the upper lethal temperature (Shumway 1996). Adult and spat have the greatest ability to withstand extreme temperatures, followed by veliger larvae and then zygotes (Kennedy 1991).

Oysters can tolerate a wide range of salinities. Adult oysters can survive salinities between 0 and 36+ ppt, but various life stages have narrower salinity ranges (Kennedy 1991) and optimal ranges exist for all stages. Many investigators have attempted to define the temperature and salinity tolerance limits and optimum ranges for *C. virginica*, with considerable divergence in results (Shumway, 1996). Differences in methodology (laboratory versus field observations), acclimation conditions (Davis, 1958; Davis and Calabrese, 1964), and geographically associated genetic traits (Barber and Mann 1994; Dittman et al. 1998) all contribute to observed variations in optimum temperature/salinity ranges, making it difficult and risky to define limits that apply to all populations. In addition, food and turbidity can confound the interpretation of field observations, especially in the case of salinity, as food availability is often limiting at low-salinity sites. Table 1 provides typical population salinity ranges as well as salinity ranges for various life stages of *Crassostrea virginica*.

Optimum salinity and the salinity range for the development of oyster eggs into straight-hinge larvae is influenced by the salinity experienced by the parents during gametogenesis. That is, parents acclimated to higher salinities will produce zygotes that develop optimally at higher salinities; and the opposite for parents acclimated to lower salinities (Kennedy 1991). Low salinity oysters are typically smaller in size than those grown at higher salinities (Shumway 1996).

Oysters are capable of withstanding wide salinity fluctuations, with greater tolerance at reduced temperatures. Gunter (1950, 1953) showed that *C. virginica* could survive salinities as low as 2 ppt for a month, and even fresh water for several days when water temperatures were low. Self-sustaining populations have been identified in areas with salinities as low as 0.2 to 3.5 ppt for five consecutive months annually (Butler 1952). Spat survived salinities of 1.4 to 4.2 pt in the lower Laguna Madre, Texas, during periods of flood and reduced salinities (Breuer 1962). Long-term exposure to high salinities can also inhibit oyster populations. Open ocean waters can support oysters, but they usually do not reproduce or grow well under these conditions. Loosanoff (1953) determined that juvenile oysters could tolerate reduced salinities as well as adult oysters. In a study in the Chesapeake Bay, Chanley (1958) identified that juvenile oysters less than 1 year old survived 5 ppt. The effect of salinity on mortality rate in eastern oysters is highly dependent on ambient temperature as evidenced by variable survival during spring floods and heavy rains (Shumway 1996). Loosenoff (1948) demonstrated that Long Island Sound oysters survived in freshwater and low salinity (3 ppt) for 70 and 115 d at water temperatures between 8 and 12 C. However, all oysters died within 15 d at higher temperatures (between 23 and 27 C). Some evidence suggests that oysters conditioned to low salinity and temperatures have an increased ability to survive low salinities (Andrews et al. 1959).

Table 1: Suitable Salinity Ranges by Oyster Life Stage

Life stage	***Salinity (ppt)***	***Reference***
Eggs	12.5-35[1]	Davis 1958
	7.5-22.5[2]	Davis 1958
Larvae	12.5-27[1]	Davis 1958
	8-39 (10-29 optimal)[3]	Mann et al. 1991

Spat	15-22.5	Chanley 1958
Adults- survival	0-36+	Kennedy 1991
Feeding	5+	Kennedy 1991
Growth	12+	Kennedy 1991
	>5 (12-27 optimal)[3]	Mann et al. 1991
Gametogenesis	7.5-30+	Kennedy 1991
Spawning	10+	Kennedy 1991
	>8[3]	Mann et al. 1991
Commercial Production[4]	0-42.5	Ingle and Dowson 1950 a, b, 1953
Typical Population Range[4]	5-40.0	Galtsoff 1964, Wallace 1966
	1.2-36.6	Menzel et al. 1966
	1.5-39	Amemiya 1926
Minimum for Survival[4]	7.5	Loosanoff 1953
	7	Wells 1961
	4-5.0	Arnold 1868, Ryder 1885, Belding 1912, Loosanoff 1932
Optimum Range (varies geographically)[4]	14-28	Moore 1900, Butler 1949c, Chanley 1958, Galtsoff 1964
	15-18	Shumway 1996
Development of straight-hinge larvae[4]	7.5 to 22.5 (eggs conditioned at 8.7 ppt)	Davis 1958
	12.5-35 (eggs conditioned at 26-27 ppt)	Davis 1958
Release of gametes	>5-10	Kennedy 1996

[1] Adults acclimated to 26-27 ppt; optimal egg development at 22.5 ppt and optimal larval growth at 17.5 ppt.
[2] Adults acclimated to 9 ppt; optimal egg development at 10-15 ppt, some normal development at 7.5 ppt.
[3] Mann et al. 1991
[4] As referenced by Shumway 1996
Table reproduced from Kennedy 1991 with addition of Mann et al 1991 and Shumway 1996 data.

Larval development occurs over a narrower range of temperatures and salinities than those suitable for adult oysters (Shumway 1996). Various studies have identified a suitable salinity range for successful development of oyster larvae from 5.6 to 7.5 ppt through 30 to 33 ppt (Hopkins 1932; Butler 1949a, b; Loosanoff 1948, 1953; Amemiya 1926; Prytherrch 1934 as referenced by Shumway 1996). Investigations by Davis (1958) and David and Calabrese (1964) suggest that larval development is governed by the salinity at which the parent eastern oysters undergo gametogenesis (see Table 1). Further, their work showed that the degree and rapidity of salinity change is likely more important than actual salinity under field conditions. As with adults, the effect of reduced salinities on larvae was to reduce the range of temperature tolerance (Davis and Calabrese 1964).

Unlike most of the other physical characteristics listed, salinity varies from the head to the mouth of the Bay, and with depth, as well as seasonally and annually based upon freshwater input from the watershed. Annual precipitation varies and determines whether wet, dry, or normal hydrologic conditions exist in the watershed in any given year. Seasonally, melting snow and spring rains typically drive salinity down through spring and into summer. Summer dry conditions then result in salinities rising through summer and into the fall.

Salinity is a significant control on survival of oysters because it largely controls the distribution of the oyster diseases, dermo and MSX. Recruitment is higher in high salinity waters, but there is also a higher prevalence and infection rate of disease. High salinities favor disease. Disease pressure is reduced in lower salinity waters, but so is recruitment. Further, disease pressure is increased Baywide in dry years when there is less freshwater discharge into the Bay and salinities are elevated, as opposed to wet years when salinity is decreased.

Historically, the region's climate has tended to shift between wet and dry conditions over several years. That is, wet or dry years tended to occur in clusters through time. During the last 10 years, however, rainfall patterns have shifted between wet and dry years more randomly with clusters of dry years in 1999, 2001, and 2002 and wet years in 2003 and 2004. These unpredictable changes in climate are expected to become more prevalent as average global temperatures rise, following the current trend (Jones and Moberg 2003). Hurricanes and severe tropical storms strike the Chesapeake Bay area during some years. Storms that cause large-scale oyster mortality are relatively rare but can have important population-level effects when they occur. For example, nearly all oysters north of the Chesapeake Bay Bridge died due to a reduction in DO and an influx of sediment and pollutants following the landfall of Tropical Storm Agnes in 1972 (USACE 2009).

As evidenced with Agnes, huge influxes of freshwater during storm events that can kill oysters. Oysters become inactive at salinities less than 4 ppt (Haven et al. 1977). The length of time that oysters can survive at these reduced salinities depends most on water temperature, but also genetics and conditioning (Haven et al. 1977). Oysters can survive reduced salinities for 2 to 3 months in cooler months (<5.5 C), but as temperatures rise (21 to 27 C), Haven et al. (1977) document that 3 weeks is about the longest oysters can survive (Andrews, Quayle, and Haven 1959). It is important to note that freshets are much more likely to occur during months where oysters are not metabolically active, and that adults are capable of tolerating freshets during the colder months of the year far more aptly than juveniles. Regardless, juveniles have much higher survival rates during a colder month freshet than a warmer month event. Freshets kill oyster larvae outright, and oyster larvae are typically in the water column only during the summer months when the chance for a freshet is small.

Low salinity conditions do have a benefit of reducing or eliminating oyster diseases and competitors. Low salinity areas with the risk of an occasional freshet can be important sites for oyster restoration in terms of accumulating biomass. However, areas that have consistently low salinity reduce the opportunities to promote the development of disease resistance in the local population.

Tropical storm Agnes, during the summer of 1972, was one of the largest documented freshwater influx events in recent history. The impact of Tropical storm Agnes on oysters has been documented in the tributaries of the upper west Bay as well as Virginia (Cory and Redding 1977, Haven et al. 1977). The Rhode, West, and South River oyster populations were not terribly impacted by Agnes' freshwater due to reverse circulation patterns in these tributaries that kept bottom waters brackish (Cory and Redding 1977). Haven et al. (1977) estimated mortality on public and leased grounds in the major Virginia tributaries. They documented increased mortalities by mid to late July after salinities had been depressed for over three weeks. Mortalities on leased grounds were documented as follows: James River, 10%; York River, 2%; Rappahannock River, 50%; Corrotoman River, 20-22%; and the Potomac River tributaries, 70%. On public grounds, mortalities were estimated to be: James River, 5%; York River, negligible; Rappahannock River, <2%; Corrotoman River, <20%; and Potomac River (north of Cobb Island), nearly 100%. The upper portions of the Potomac were impacted more extensively than the lower portions. Haven et al. (1977) identified a line from Cobb Island in Maryland across the Potomac to Popes Creek in Virginia as the demarcation between the area upriver where nearly all oysters died and the area in the lower river where mortalities were not as significant. The smaller tributaries of the Potomac River were also investigated. Haven et al. (1977) estimated that about 70% of the oysters in these tributaries were killed by Agnes. The oyster populations in Eastern shore tributaries, the Piankatank and Great Wicomico Rivers, the Mobjack Bay Region and Lynnhaven Inlet were not seriously affected by Agnes as these systems received minimal freshwater input from Agnes (Haven et al. 1977).

As evidenced by the investigations into the impacts of Agnes, the vulnerability of a tributary to the development of freshets is closely tied to the amount of overland runoff a tributary receives. Generally speaking, western shore tributaries receive larger freshwater inputs than eastern shore tributaries are more likely to experience freshets.

1. Dissolved Oxygen

Physical processes in Chesapeake Bay control the seasonal distribution of salinity, temperature, and DO and play an important role in determining water quality. Climate change and variability have caused water temperatures in the Bay to exhibit greater extremes during the 20th century than during the previous 2,000 years. During spring and summer, surface and shallow waters are warmer and fresher than deeper waters; therefore, the water column stratifies into a two-layer system. The zone of change between those two layers is called the pycnocline. The strength of the stratification depends on river flow: the larger the volume of the incoming fresh water, the stronger the stratification. The deeper, more saline water moves up the Bay from the Atlantic Ocean. During autumn, vertical mixing occurs rapidly due to cooling and sinking of the surface waters and the passage of weather fronts. Water temperature and salinity are relatively constant from surface to bottom during winter.

Stratification of the Bay and the development of the pycnocline during warm months restrict the exchange of water between the upper and lower layers and, consequently, limit the supply of oxygen available in water near the bottom. During the spring and summer, as organisms consume increasingly more oxygen, the oxygen content decreases in bottom waters. As stratification persists, the concentration of oxygen in bottom waters may decrease to less than is needed for organisms to function (i.e., the water becomes hypoxic). This process occurs naturally in many estuaries, but in Chesapeake Bay it is exacerbated by excess nutrients from anthropogenic sources (Kemp et al. 2005).

Hypoxic waters generally occur in Chesapeake Bay during the summer of each year in deep areas of the mainstem and at the mouths of the major tributaries as water temperatures increase. The volume of hypoxic water in Chesapeake Bay varies with changes in hydrology (dry versus wet years) and with seasonal changes in water temperature. Years with little precipitation and minimal river flow show less intense hypoxia than years with greater precipitation and river flow. From 1985 to 2006, during the period June through September, on average 1.44% of the volume of the mainstem was anoxic, and 5.25% was hypoxic (D. Jasinski, USEPA CBP, pers. comm.). Water quality data gathered between 2004 and 2006 indicate that only about 33% of the Bay's tidal waters met standards for DO (i.e., the concentrations established by regulatory agencies as appropriate for biota that occupy different habitats in the Bay, including open water, deep water, and deep channel), during the months of June through September (CBP, 2007).

Impaired water quality, including the prevalence of hypoxia and anoxia, is linked to nutrient over-enrichment and high concentrations of suspended sediment. Forest clearing, agricultural practices, and urban development contribute large amounts of nutrients and sediment that are transported to the Bay by its tributaries. Excess nutrients stimulate the growth of phytoplankton populations. When the increasingly abundant phytoplankton (i.e., an algal bloom) die, large amounts of organic matter sink to the bottom. The presence of excess organic matter on the bottom increases the demand for DO, which is required for bacterial decomposition of the organic matter. This increased oxygen demand hastens the seasonal oxygen depletion in the bottom waters of the Bay.

Oxygen concentrations of less than 5 milligrams per liter (mg/l) of water affect the behavior and survival of fish and shellfish, including oysters (EPA 2003, CBP 2007). Concentrations below 2 mg/l are considered to be severely hypoxic and affect the structure, distribution, and productivity of benthic organisms, including oysters (Widdows et al. 1989; Baker and Mann 1992, 1994; Baird et al. 2004; Stickle et al. 1989; Kirby and Miller 2005; Lenihan and Peterson 1998).

Although, typically confined to deep waters below the pycnocline, hypoxia can hamper the shoal areas of the bay where oyster reefs occur if wind stress tilts the pycnocline (Baker and Mann 1992). The pycnocline may remain tilted for several hours to 2 or 3 days (Breitburg 1990; Sanford et al. 1990). Oxygen depletion and the intrusion of hypoxic water into shallow water depths where oyster reefs exist typically overlaps the period of spawning, larval settlement and metamorphosis of the oyster (Baker and Mann 1994).

Numerous efforts have investigated the effects of low dissolved oxygen on various stages of an oyster's lifecycle. Baker and Mann (1992) investigated low oxygen effects on settlement and found that settlement was reduced significantly in hypoxic treatments, as compared to normoxic treatments; almost no settlement took place in anoxic treatments. It is evident that the tolerance of *Crassostrea virginica* larvae to anoxia increases with developmental stage and body size. Median mortality times range from 11 h for prodissoconch larvae to 51 h for pediveliger larvae to 150 h for juvenile oysters (Widdows et al. 1989). Further, larval stages and juvenile oysters (16 mm height) survive anoxia from hours to days (Widdows et al., 1989), while adult oysters survive periods of unsuitable conditions lasting days or weeks (Galtsoff, 1964; Stickle et al., 1989). Hypoxic conditions will affect the feeding activities of only the youngest post-settlement oysters while microxic (<0.4 mg O) conditions will affect all post-settlement oysters (Baker and Mann 1994). Prolonged exposure (144 hours or 6 days) to anoxic water in laboraty experiments caused 51% mortality of Eastern oysters (Matsche and Barker 2007). Similar patterns were observed after 192 hours (or 8 days) of exposure to decreasing levels of dissolved oxygen. These studies were conducted in warm water (30°C), which holds less oxygen in solution; therefore, the studies represent worst-case scenarios. A study by Harlan (2007) found similar differences in hypoxic mortality in Eastern oysters at temperatures of 10°C and 20°C.

Although the threat of hypoxic waters exist, Breitburg (1992) and Seliger et al (1985) showed that the location of oyster reefs in shallow waters provided refuge for oysters and other reef-associated species from the typical and persistent hypoxia that occurs in deep water. Lenihan and Peterson (1998) found that in deeper, bottom water exposed to hypoxia/anoxia, reefs with heights that extended out of the bottom water layer were better habitat because they provided refuge from low DO conditions.

Frequent hypoxic events result in benthic populations dominated by fewer, short-lived species. Persistent hypoxia and anoxia (a complete absence of oxygen) can result in mass mortality of benthic organisms and often in the complete elimination of the macrofauna. Further, the intensification of hypoxia in recent decades has caused a dramatic reduction in the ecosystem's ability to transfer energy to higher trophic levels and has rendered the ecosystem potentially less resilient to other stressors (Baird et al. 2004).

C. APPLICATION TO THE MASTER PLAN

Temperature is not a limiting factor to oyster restoration in the Chesapeake Bay. However, DO concentration and salinity are critical factors in locating oyster restoration projects. Both factors will be applied in the master plan through a GIS layering process. The master plan will target areas for restoration that have average annual growing season surface and bottom salinity greater than or equal to 5 ppt, the minimum concentration for sustained feeding by adult oysters (Kennedy 1991). The specific layer produced defines the upstream limits of the 5 ppt concentration using data from 2001-2006 that covers dry, wet, and average freshwater flow years. Therefore, areas identified as having restoration potential with this layer will not exceed the criterion under any of the flow conditions considered in the data set. Because salinity concentration affects growth and reproduction, plans will be developed for two salinity zones: Zone 1 (5-12 ppt) and Zone 2 (>12 ppt). 5 ppt was identified by Mann et al. (1991) as the lower bound of the optimal range for adult oyster growth in the Chesapeake Bay population. However, salinity greater than 8 ppt is preferential for larvae development and survival (Mann et al. 1991, Shumway 1996). Within Zone 1, consideration will be given to areas with average annual average growing season bottom salinity less than 8 ppt. These areas, although, able to support oyster growth, would be less desirable areas to use for jumpstarting populations due to salinity limited spawning conditions. Areas within Zone 1 with salinities >8 ppt would be targeted first for restoration since they are capable of supporting growth and spawning. The 5-8 ppt zone varies annually depending on whether dry, wet, or average freshwater flow conditions prevail. The 5-8 ppt zone will be estimated from average growing season bottom and surface salinity in wet, dry, and average freshwater flow years (Figures 1-6). Comparing these six maps, the 5-8 ppt zone is typically in the upper portions of tributaries at the limit of oyster habitat. During average rainfall years, the zone is present in parts or all of the Patapsco and Magothy Rivers, as well as minimal upper portions of the Chester, Choptank, York, Rappahannock, Patuxent, Nanticoke, and Pocomoke Rivers near the upstream limits of historic oyster habitat; the Potomac River upstream of its Wicomico River tributary; and upper middle portions of the James River. Given that spawning occurs in the water column, average growing season surface salinity will be used as well as wet year data to give an estimate of the most expansive area that could experience 5-8 ppt conditions. Under wet year conditions, the Magothy, Severn, South, Rhode, West, and Chester Rivers are likely to fall completely within 5-8 ppt. In the other tributaries mentioned above, the zone expands and is located downriver, affecting larger areas of oyster habitat, particularly in the Choptank and Potomac Rivers. The extent of the 5-8 ppt zone does not appear to be limiting to the master plan restoration goals or of an expanse that would warrant its own zone, given the area of bottom available to achieve restoration goals that is not affected by the shifting 5-8 ppt zone.

The location and size of the 5-8 ppt will be considered when determining the initial stocking rate (and cost) as will the level of benefits.

Developing a specific criterion for DO concentration for oyster restoration is difficult because oysters are capable of withstanding anoxic conditions over a period of time (>6 days as discussed above) and comprehensive data that considers duration and concentration over such a short time interval is not available. DO concentrations are lowest during the summer when water temperature and biological activity are high. Therefore, the GIS layer that will be used to define oyster restoration potential for dissolved oxygen will be the mean concentration of bottom DO during the summer (June-August, rather than the growing season (April-October) that will be used for salinity). The master plan will focus on areas for restoration with average annual summer dissolved oxygen greater than or equal to 5 mg/L. Although this concentration does not represent a specific tolerance level for oysters over a specific time period, it will define areas where DO concentration is limiting to habitat value. Areas with an average concentration of less than 5 mg/l simply do not have as great a potential to provide quality habitat as areas with a DO concentration above 5 mg/l. Recognizing that areas with an average summer DO concentration >5 mg/l do experience periods of low DO, a close look at the monitoring data identifies that only 33 of the 1280 suitable sites had at least one minimum DO measurement below 2 mg/l. This suggests that the sites identified as suitable by the chosen criteria do represent areas that are relatively free of hypoxia. As discussed above, oxygen concentrations of less than 5 mg/l affect the behavior and survival of fish and reflect overall conditions of lower habitat quality because of hypoxia. The goal of oyster restoration conducted under the master plan is to restore fish and wildlife value; locating sites in portions of the Bay with higher DO concentration will not only provide greater potential for success in establishing oysters, but also maximize habitat value for other estuarine organisms. Given the relationship between the depth of the pycnocline, hypoxia, and oyster reef health, the master plan further recommends that the location of the pycnocline be considered when specific tributary restoration plans are being developed. Reefs should not be restored in locations below the typical pycnocline depth where hypoxic events are known to frequently occur.

Figures 1-6. Estimates of 5-8 ppt zone for bottom (Fig 1-3) and surface (Fig 4-6) salinity under wet, dry, and average freshwater flow conditions.

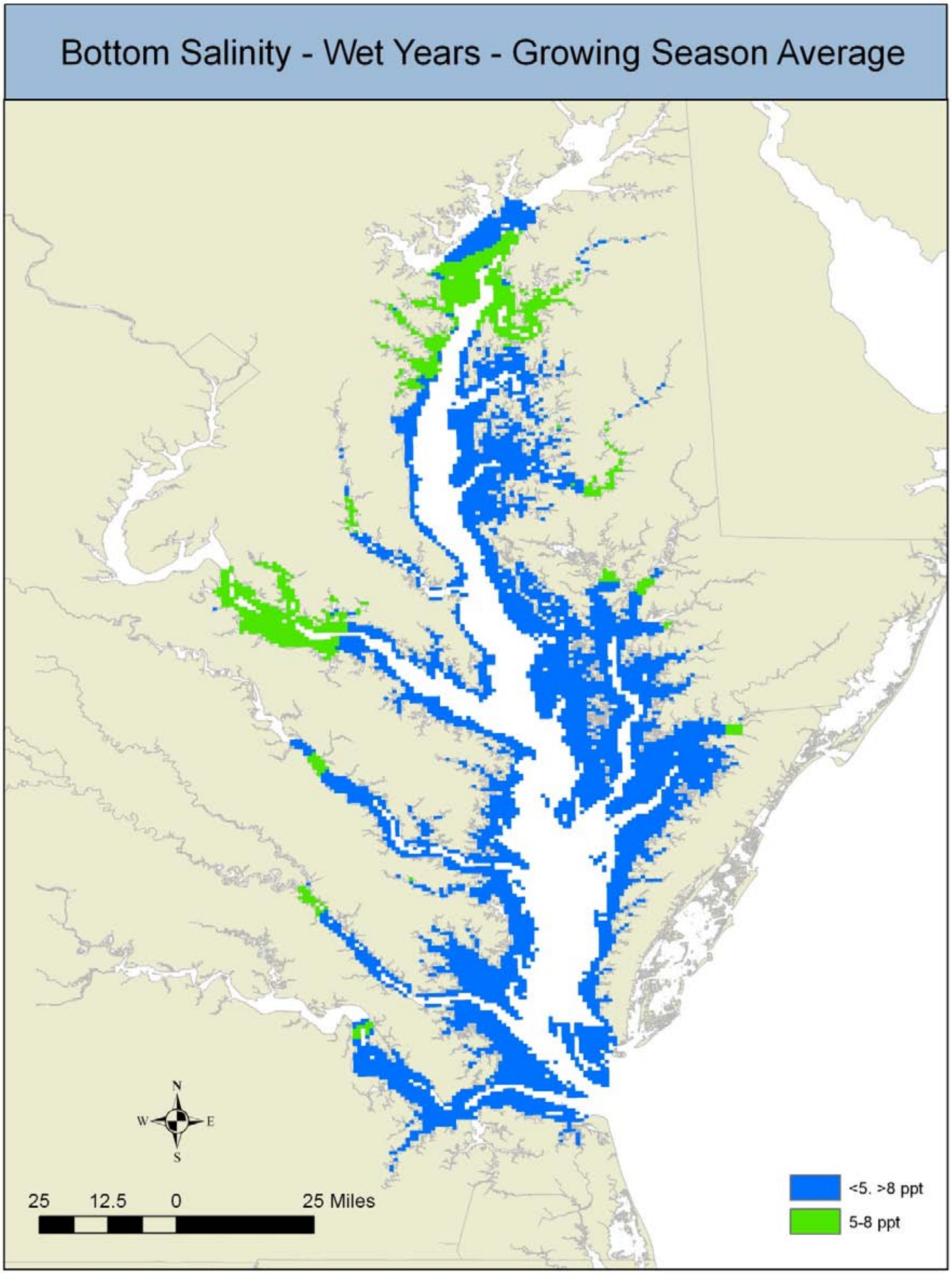


Figure 1. Extent of waters with average growing season bottom salinity in wet hydrologic years between 5 and 8 ppt.

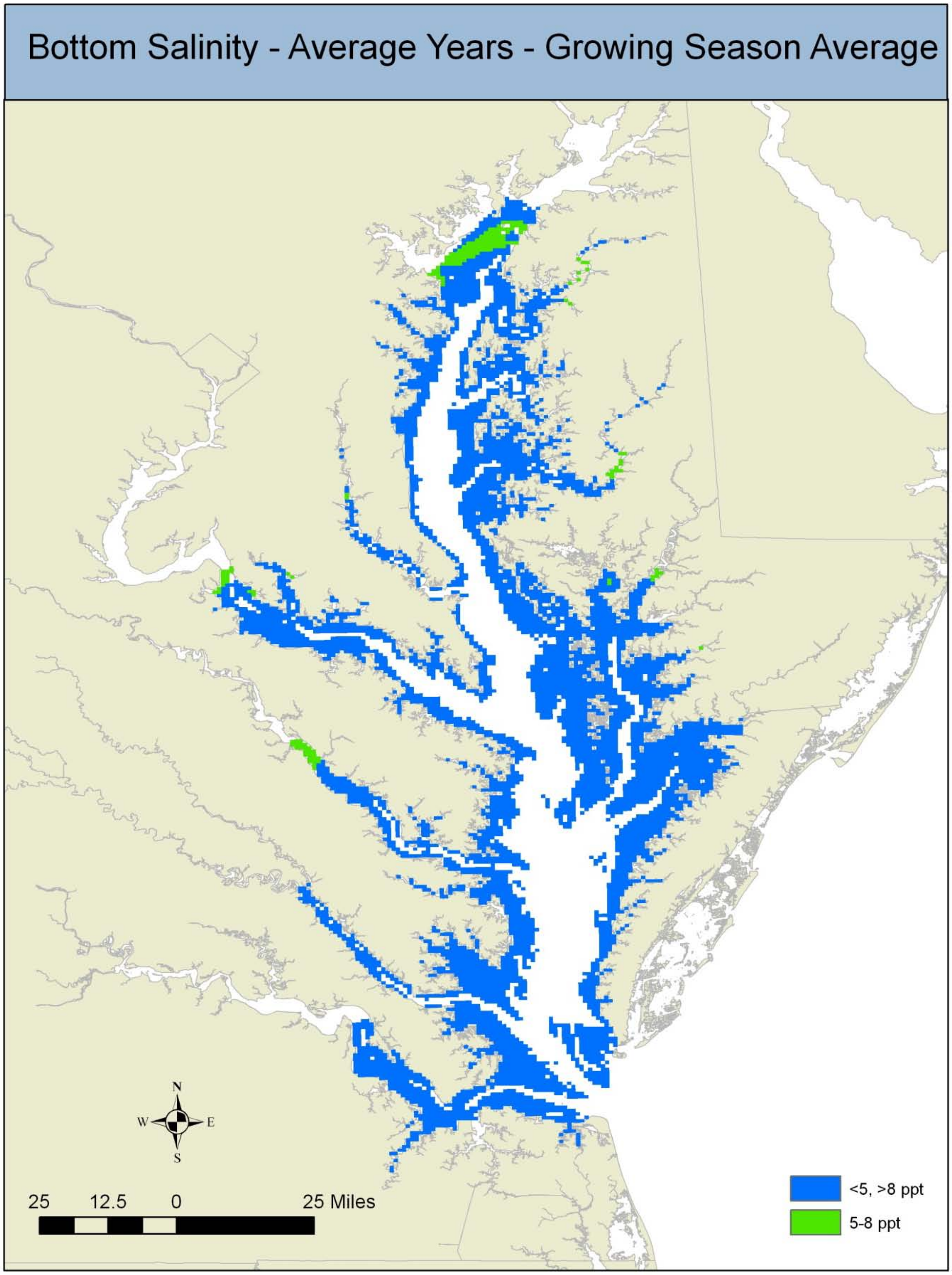


Figure 2. Extent of waters with average growing season bottom salinity in average hydrologic years between 5 and 8 ppt.

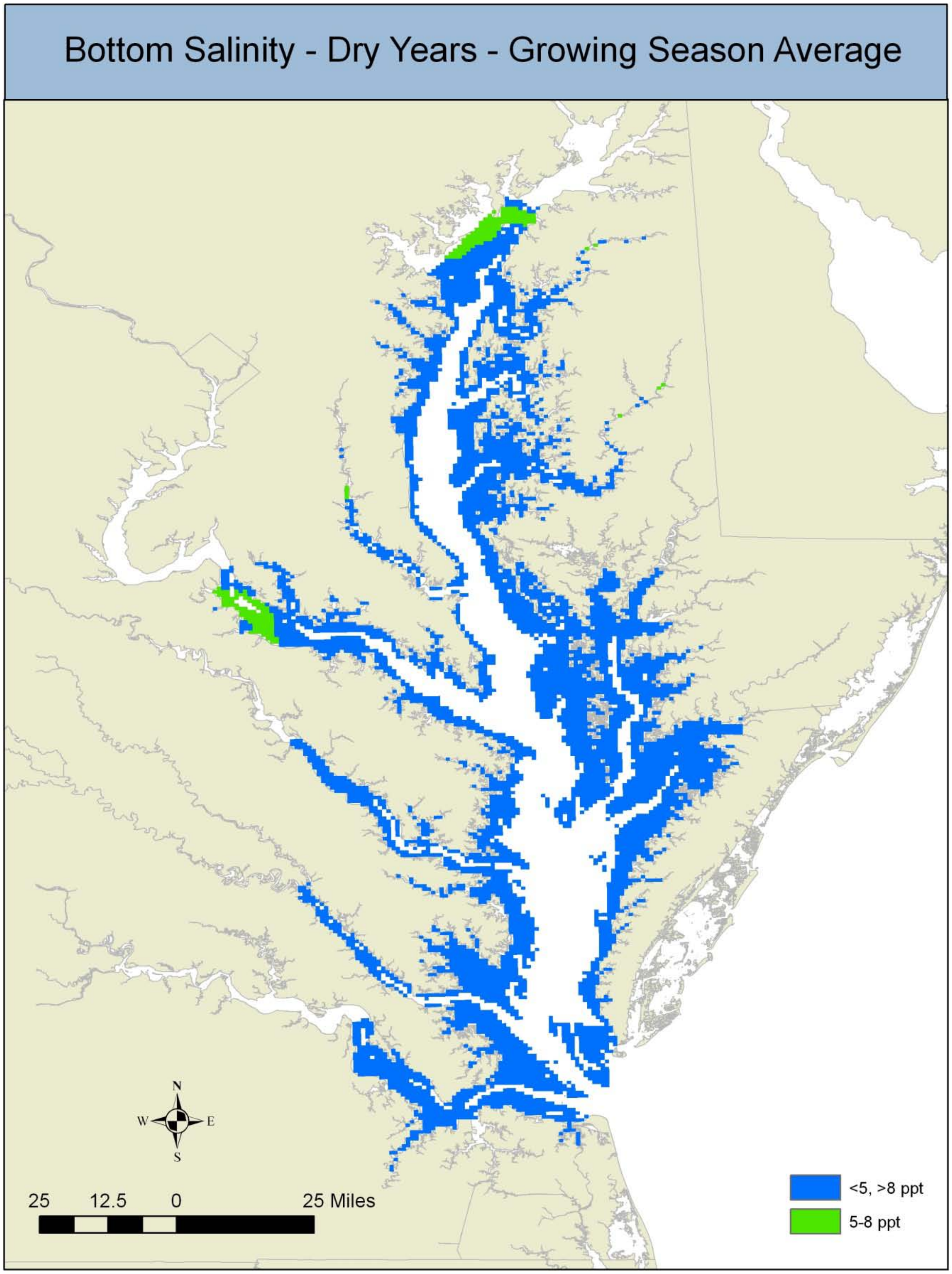


Figure 3. Extent of waters with average growing season bottom salinity in dry hydrologic years between 5 and 8 ppt.

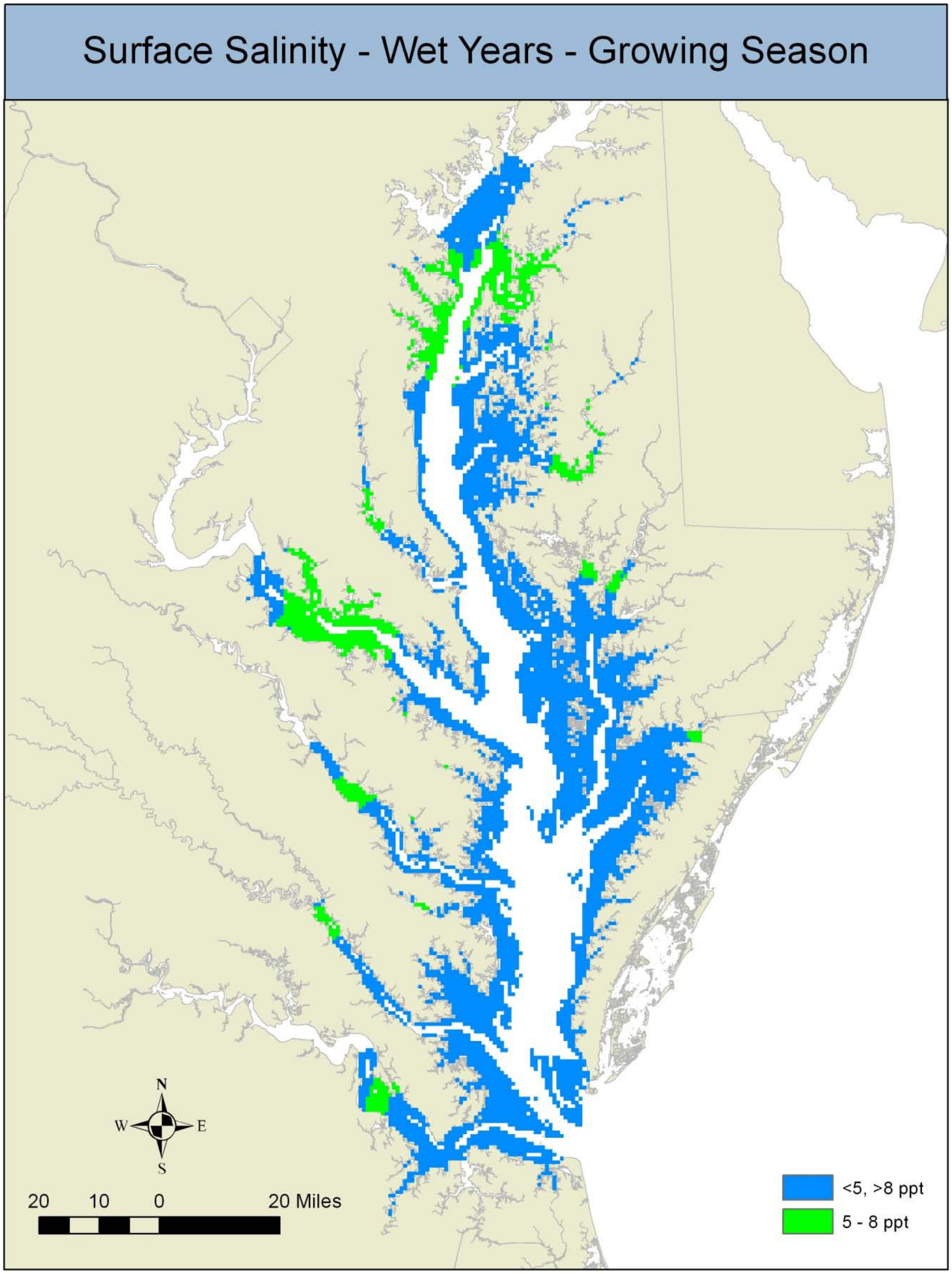


Figure 4. Extent of waters with average growing season surface salinity in wet hydrologic years between 5 and 8 ppt.

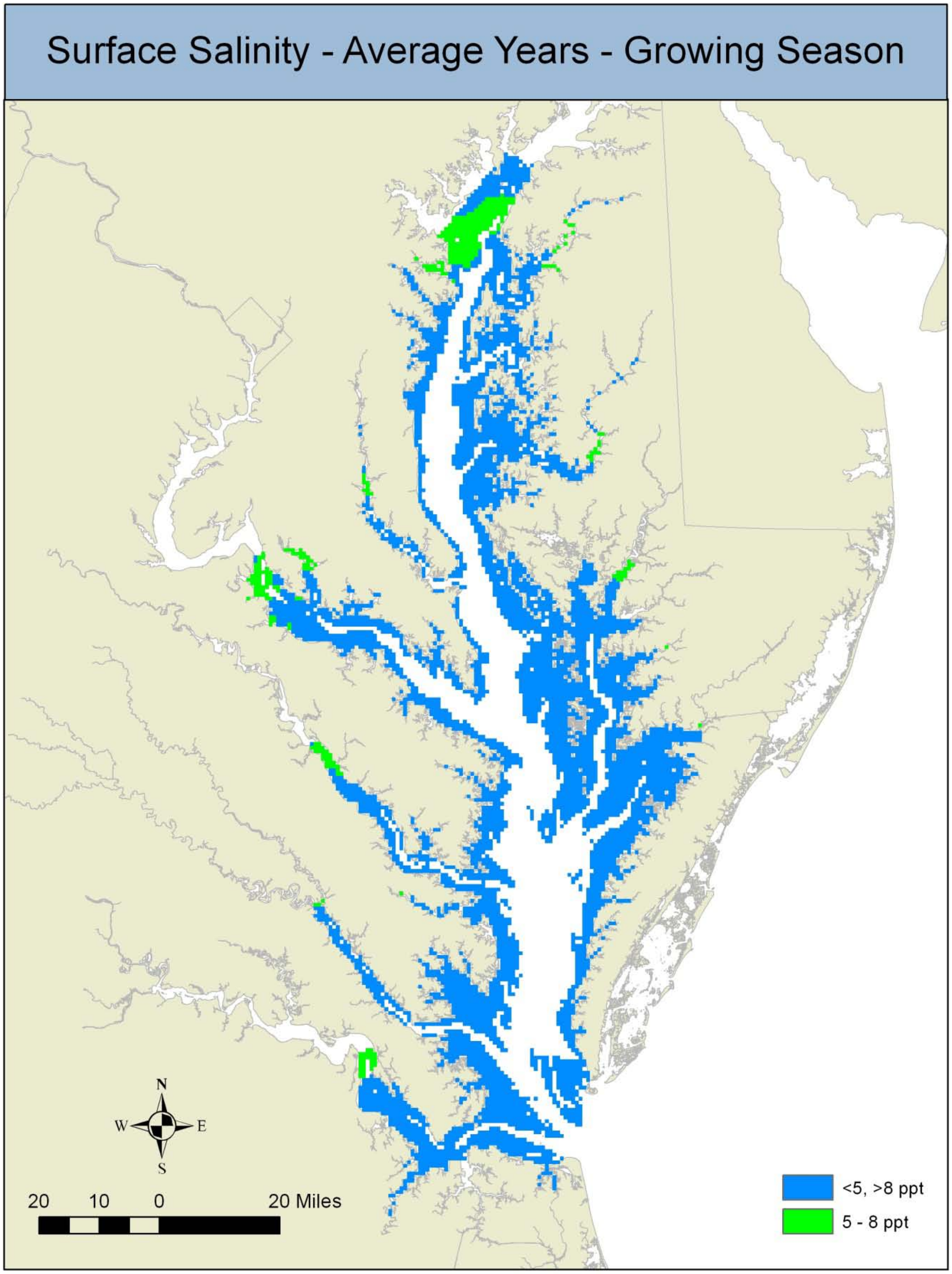


Figure 5. Extent of waters with average growing season surface salinity in average hydrologic years between 5 and 8 ppt.

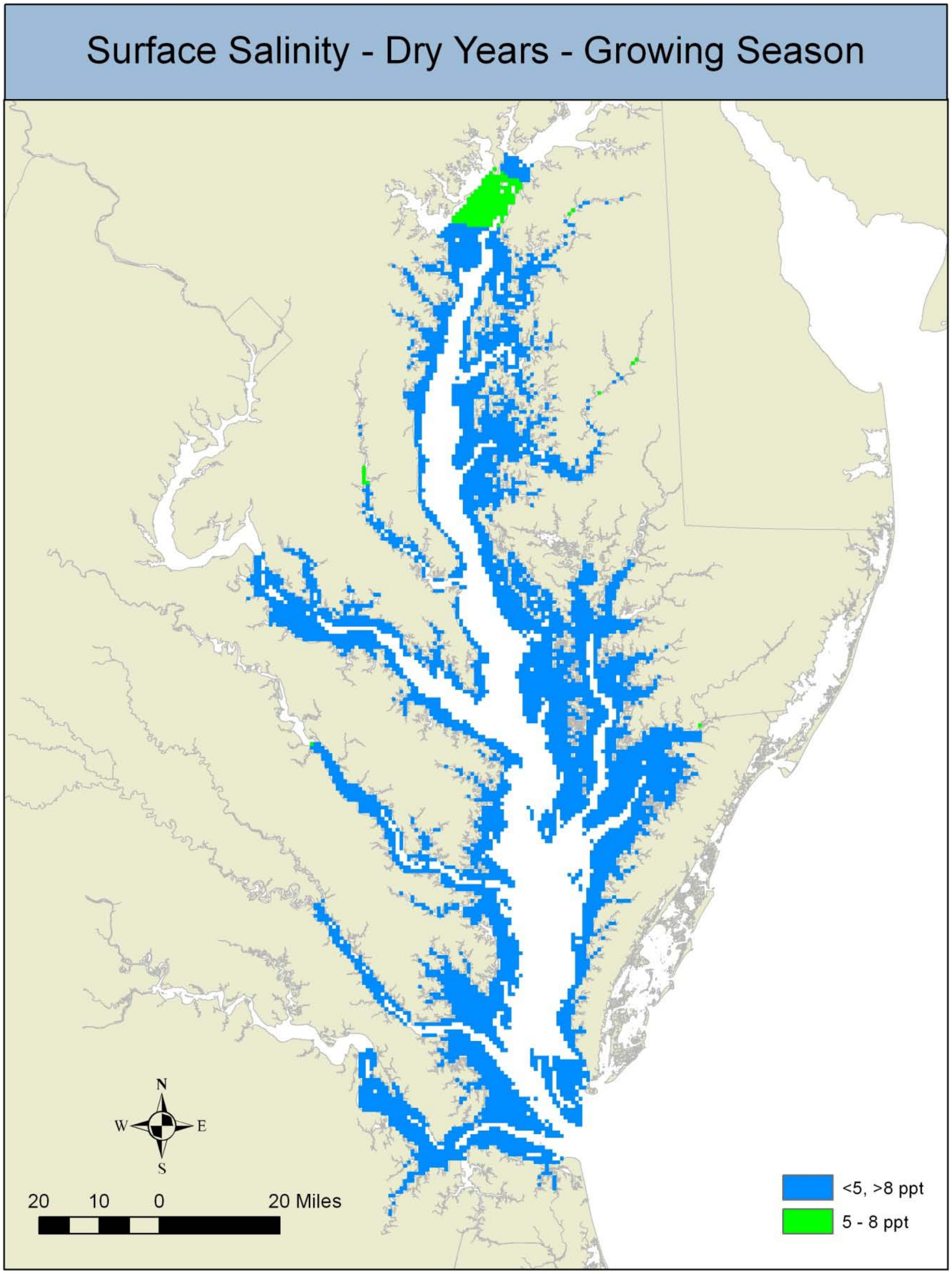


Figure 6. Extent of waters with average growing season surface salinity in dry hydrologic years between 5 and 8 ppt.

Figures 7 and 8 are combined images for bottom and surface salinity for the three hydrologic years, respectively.

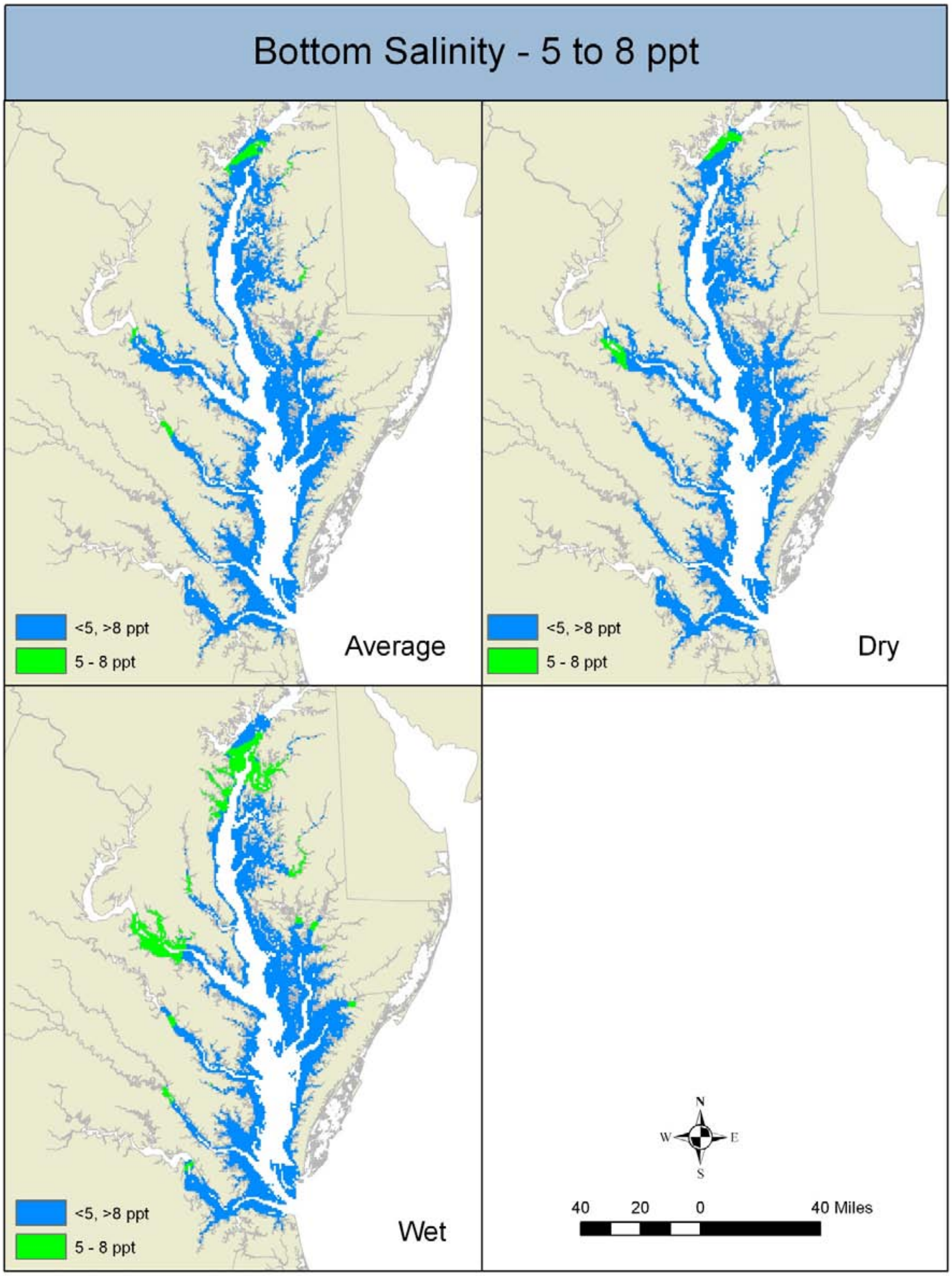


Figure 7. Extent of waters with average growing season bottom salinity 5 and 8 ppt in average, dry, and wet hydrologic years, respectively.

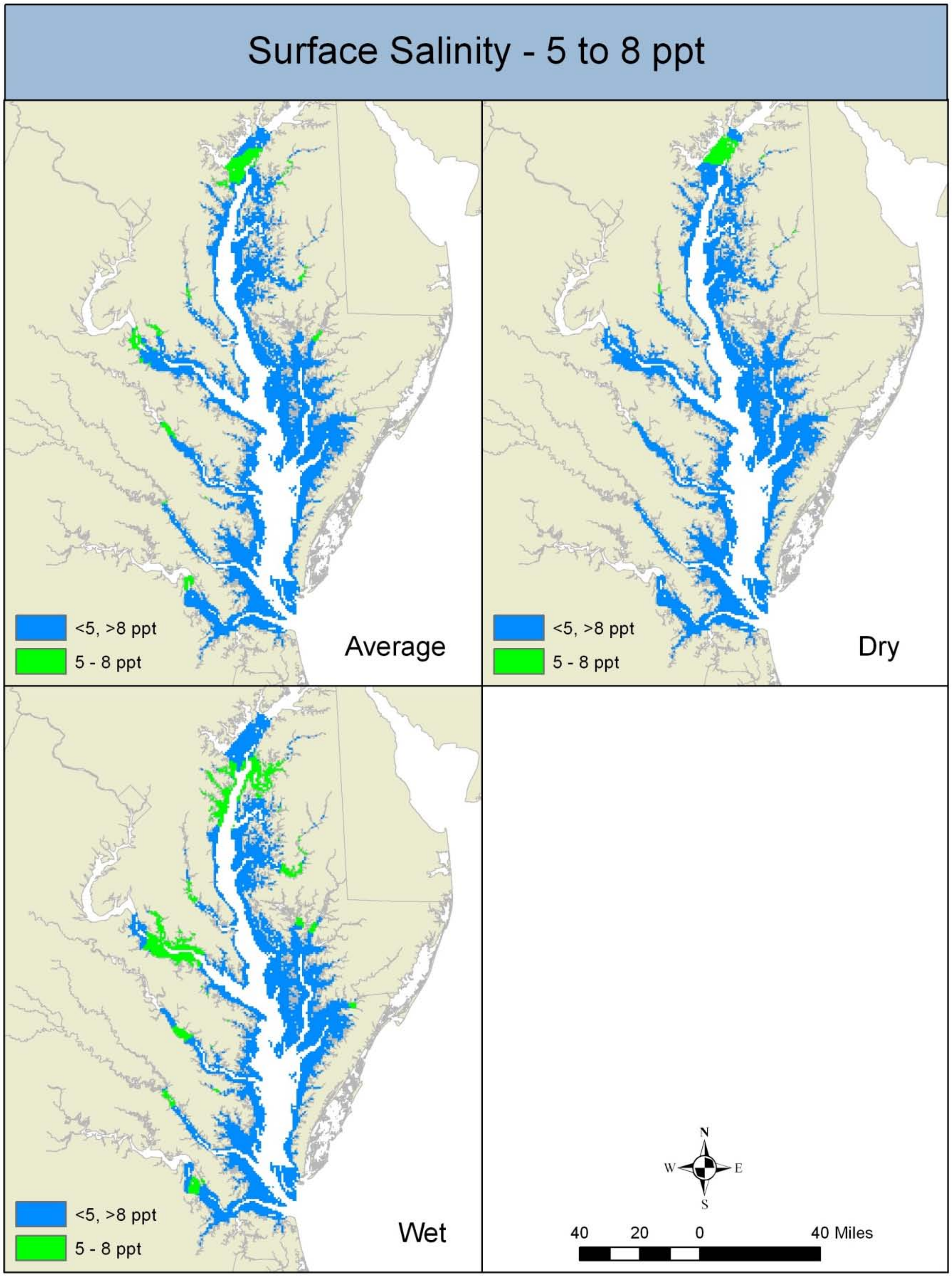


Figure 8. Extent of waters with average growing season bottom salinity 5 and 8 ppt in average, dry, and wet hydrologic years, respectively.

REFERENCES

Amemiya, I. 1926. Notes on experiments on the early development stages of the Portuguese, American and English native oysters, with special reference to the effect of varying salinity. J. Mar. Biol. Assoc. U.K. 14: 161-175.

Andrews, JD, D Haven, and DB Quayle. 1959. Freshwater kill of oysters (*Crassostrea virginica*) in James River, Virginia, 1958. Proc. Natl. Shellfish. Assoc. 49: 29-49.

Arnold. 1868. Oysters in brackish water. Quart. J. Sci. 21: 15-19.

Baird, D., R.R., Christian, C.H. Peterson, and G.A. Johnson. 2004. Consequences of hypoxia on estuarine ecosystem function: Energy diversion from consumers to microbes. Ecological Applications, 14(3), 2004, pp. 805-822.

Baker, S.M. and R. Mann. 1992. Effects of Hypoxia and Anoxia on Larval Settlement, Juvenile Growth, and Juvenile Survival of the Oyster Crassostrea virginica Biological Bulletin, Vol. 182(2): 265-269.

Baker S.M., and R. Mann. 1994. Feeding ability during settlement and metamorphosis in the oyster ***Crassostrea virginica*** (Gmelin, 1791) and the effects of hypoxia on post-settlement ingestion rates. Journal of Experimental Marine Biology and Ecology 181: 239-253.

Barber, B.J., and R. Mann. 1994. Comparative physiology of Eastern oyster, *Crassostrea virginica* (Gmelin, 1791), and Pacific oyster, *Crassostrea gigas* (Thunberg, 1793): Growth, mortality and effects of the parasite, *Perkinsus marinus*. *Journal of Shellfish Research* 13(1):109-114.

Belding, DL. 1912. A report upon the quahaug and oyster fisheries of Massachusetts. Mass. Div. Mar. Fish., Contribution 12: 1-134.

Breitburg, DL. 1990. Near-shore hypoxia in the Chesapeake Bay: patterns and relationships among physical factors. Estuarine, Coastal, and Shelf Science. 30: 593-609.

Breitburg, DL. 1992. Episodic hypoxia in Chesapeake Bay: interacting effects of recruitment, behavior, and physical disturbance. Ecological Monographs 62:525-546.

Breuer, JP. 1962. An ecological survey of the lower Laguna Madre of Texas, 1953-1959. Publications of the Institute of Marine Science 8: 153-183.

Butler, PA. 1949a. An investigation of oyster producing areas in Louisiana and Mississippi damaged by flood waters in 1945. US Fish and Wildlife Serv. Spec. Scientific Rept., Fisheries. 8: 1-29.

Butler, PA. 1949b. The effects of flood conditions on the production of spawn in the oyster. Proc. Natl. Shellfish. Assoc. 1948: 78-81.

Butler, PA. 1949c. Gamategonesis in the oyster under conditions of depressed salinity. Biol. Bull. 96: 263-269.

Butler, PA. 1952. Growth and mortality rates in sibling and unrelated oyster populations. Proc. Gulf Carib. Fish. Inst. 4:71.

Chanley, PE. 1958. Survival of some juvenile bivalves in water of low salinity. Proc. Natl. Shellfish. Assox. 48: 52-65.

Chesapeake Bay Program (CBP). 2007. Dissolved Oxygen. [Accessed 2007] Online at http://www.chesapeakebay.net/do.htm.

Cory, RL, and JM Redding. 1977. Moralities caused by Tropical Storm Agnes to clams and oysters in the Rhode River area of Chesapeake Bay. *In* The Effects of Tropical Storm Agnes on the Chesapeake Bay Estuarine System. The Chesapeake Research Consortium, Inc. Publication #54. Johns Hopkins University Press: Baltimore, 478-487.

Davis, HC. 1958. Survival and growth of clam and oyster larvae at different salinities. Biol. Bull. 114: 296-307.

Davis, HC, and A. Calabrese. 1964. Combined effects of temperature and salinity on development of eggs and growth of larvae of *M. mercenaria* and *C. virginica*. Fish. Bull. 63:643-655.

Dittman, D.E., S.E. Ford, and H.H. Haskin. 1998. Growth patterns in oysters, *Crassostrea virginica*, from different estuaries. *Marine Biology (Berlin)* 132(3):461-469.

Galtsoff, PS. 1964. The American oyster *Crassostrea virginica* Gmelin. Fish. Bull. 64:1-480.

Gunter, G. 1950. Seasonal population changes and distributionsas relatied to salinity, of certain invertebrates of the Texas coast, including the commercial shrimp. Publ. Inst. Mar. Sci. Univ. Texas 1:7-51.

Gunter, G. 1953. The relationship of the Bonnet Carre Spillway to oyster beds in the Mississippi Sound and the Louisiana Marsh with a report on the 1950 opening. Publ. Inst. Mar. Sci. Univ. Texas 3:21-71.

Harlan, NP. 2007. A comparison of the physiology and biochemistry of the eastern oyster, *Crassostrea virginica*, and the Asian oyster, *Crassostrea ariakensis*. University of Maryland: Masters Thesis.

Haven, DS, WJ Hargis, Jr, JG Loesch, and JP Whitcomb. 1977. The effect of Tropical Storm Agnes on oysters, hard clams, soft clams, and oyster drills in Virginia. *In* The Effects of

Tropical Storm Agnes on the Chesapeake Bay Estuarine System. The Chesapeake Research Consortium, Inc. Publication #54. Johns Hopkins University Press: Baltimore, 488-507.

Hopkins, AE. 1932. Chemical stimulation by salts in the oyster, *Ostrea virginica*. J. Exp. Zool. 61: 13-28.

Ingle, RM, and CE Dawson. Jr. 1950a. Variation in salinity and its relation to the Florida oyster. I. Salinity variation in Apalachicola Bay. Proc. Natl. Shellfish. Assoc. (1949): 16-19.

Ingle, RM, and CE Dawson. Jr. 1950b. Variation in salinity and its relation to the Florida oyster. I. Salinity variation in Apalachicola Bay. Proc. Gulf Carib. Fish. Inst. 3:35-42.

Ingle,RM, and CE Dawson, Jr. 1953. A survey of the Cedar Key area. State of Florida Board of Conservation. Technical Series 9:1-27.

Jones, P.D. and A. Moberg. 2003. Hemispheric and large-scale surface air temperature variations: An extensive revision and an update to 2001. Journal of Climate 16: 206-223.

Kemp, W.M., W.R. Boynton, J.E. Adolf, D.F. Boesch, W.C. Boicourt, G. Brush, J.C. Cornwell, T.R. Fisher, P.M. Glibert, J.D. Hagy, L.W. Harding, E.D. Houde, D.G. Kimmel, W.D. Miller, R.I.E. Newell, M.R. Roman, E.M. Smith, and J.C. Stevenson. 2005. Eutrophication of Chesapeake Bay: historical trends and ecological interactions. Marine Ecology Progress Series 303:1-29.

Kennedy, V.S. 1991. 'Eastern Oyster: *Crassostrea virginica*.' In: S.L. Funderburk, S.J. Jordan, J.A. Mihursky, and D. Riley, eds. Habitat Requirements for Chesapeake Living Resources.

Lenihan, HS, and CH Peterson. 1998. How habitat degradation through fishery disturbance enhances impacts of hypoxia on oyster reefs. Ecological Applications 8(1): 128-140.

Loosanoff, VL. 1932. Observations on propagation of oysters in James and Corrotoman Rivers and the seaside of Virginia. Virginia Comm. Fish., Newport News, VA (USA), pp. 1-45.

Loosanoff, VL. 1948. Effects of turbidity on feeding of oysters. Proc. Natl. Shellfish. Assoc. 1947: 40-44.

Loosanoff, VL. 1953. Behavior of oysters in water of low salinities. Proc. Natl. Shellfish. Assoc. 43:135-151.

Mann, R., E.M. Burreson, and P.K. Baker. 1991. The decline of the Virginia oyster fishery in Chesapeake Bay: considerations for introduction of a non-endemic species, *Crassostrea gigas* (Thunberg, 1793). Journal of Shellfish Research 10: 379-388.

Matsche, M. and L. Barker. 2007. Juvenile Oyster Mortality Following Experimental Exposure to Anoxia/Hypoxia - *Crassostrea ariakensis* vs. *C. virginica*. Final Report to Maryland Department of Natural Resources, Fisheries Service.

Menzel, RW, NC Hullings, and RR Hathaway. 1966. Oyster abundance in Apalachicola Bay, Florida in relation to biotic associations influenced by salinity and other factors. Gulf Res. Report 2:73-96.

Moore, HF. 1900. An inquiry into the feasibility of introducing useful marine animals into the waters of the Great Salt Lake. Rept. U.S. Comm. Fish. 25: 229-250.

Prytherch, HF. 1934. The role of copper in the setting, metamorphosis, and distribution of the American oyster. *Ostrea virginica*. Ecol. Monogr. 4:47-107.

Ryder, JA. 1885. A new system of oyster culture. Science 6: 465-467.

Sanford, L. P., K. G. Sellner, and D. L. Breitburg. 1990. Covariability of dissolved oxygen with physical processes in the summertime Chesapeake Bay. Journal of Marine Research 48:567-590.

Seliger, H, JA Boggs, and WH Biggley. 1985. Catastrophic anoxia in the Chesapeake Bay in 1984. Science. 228: 70-73.

Shumway, S.E. 1996. Natural environmental factors. In: Kennedy, V.S., Newell, R.I.E., Eble, A.F. (Eds.), The Eastern Oyster *Crassostrea virginica*. Maryland Sea Grant College, University of Maryland System, College Park, pp. 185-223.

Stickle, WB, MA Kapper, L Liu, E Gnaiger, and S Wang. 1989. Metabolic Adaptations of Several Species of Crustaceans and Molluscs to Hypoxia: Tolerance and Microcalorimetric Studies. Biological Bulletin, Vol. 177(2): 303-312.

U.S. Army Corps of Engineers. 2009. Environmental Impact Statement for Oyster Restoration in Chesapeake Bay Including the Use of a Native and/or Nonnative Oyster.

U.S. Environmental Protection Agency. 2003a. *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries (Regional Criteria Guidance). April 2003*. EPA 903-R-03-002. Region III Chesapeake Bay Program Office, Annapolis, MD.

Wallace, DH. 1966. Oysters in the estuarine environment. A symposium of estuarine fisheries. Amer. Fish. Sco. Spec. Publ. 3:68-73.

Wells, HW. 1961. The fauna of oyster beds, with special reference to the salinity factor. Ecol. Monogr. 31:239-266.

Widdows, J, R. I. E. Newell, and R. Mann. 1989. Effects of Hypoxia and Anoxia on Survival, Energy Metabolism, and Feeding of Oyster Larvae (Crassostrea virginica, Gmelin) Biol. Bull. 177: 154-166.

Physical Characteristics of Individual Reefs White Paper

A. SIGNIFICANCE TO OYSTER RESTORATION AND THE MASTER PLAN

This white paper will focus on the physical characteristics of individual oyster reefs. The following physical characteristics relevant to oyster restoration will be addressed:

- bar morphology, size, and height,
- reef heterogeneity and topography,
- orientation relative to flow, and
- water depth

1. Bar morphology, size, and height

Bar morphology and height has been found to alter flow and ultimately impact growth, recruitment, condition, sedimentation, burial, and mortality. The success of Great Wicomico highlights the importance of sufficient bar height.

2. Reef heterogeneity and topography

Microhabitats such as interstitial space within the reef complex are an important feature of oyster habitat. Interstitial space provides marine organisms with protection from predation, physical stresses, and competitors (Bartol et al. 1999). Heterogeneity is an important feature of the reef complex.

3. Orientation to flow

Proper flow over an oyster reef will maintain a sediment free reef, provide food, and carry away waste products. Again, the master plan should discuss the preferred orientation of a reef, but this factor will be most important when specific tributary restoration plans are being developed.

4. Water depth

Historically, oyster beds were located in shallows and deep waters; today, deep waters are avoided due to issues with hypoxia and anoxia.

B. SCIENTIFIC BASIS AND STATE OF KNOWLEDGE

1. Bar morphology and height

a. Historical bar morphologies, size, and height

Specific to the Chesapeake Bay, two historical reef morphologies have been documented by Woods et al. (2004), a northern and southern. The northern-style was dominant from the Chesapeake Bay north (specifically York River and tributaries to the north). Northern-style reefs exhibited little relief, but were elevated from surrounding soft sediments (Smith et al. 2003). Relief was centered along and parallel to the channel edge (Woods et al. 2004). The southern-style was found in the James River and southward along the Eastern seaboard. Southern-style reefs had significant relief, and although many were shoal-like, they were often emergent

(Woods et al. 2004). The Lower James River reefs were long, fairly wide (reef base), and shoal-like and oriented at right angles to the current. The largest reef stretched 3 km (Woods et al. 2005).

Focused on a beds relationship to the shoreline, Kennedy and Sanford (1999) reviewed various historical reports and determined that three categories of bed morphologies could be identified: (1) string reefs, which extended at right angles to the shore and to tidal currents; (2) fringe reefs, also near shore, but ran in the direction of tidal currents along the shoulders of an axial channel; and (3) patch reefs, which formed away from the shore with an irregular, compact form. Large reefs, at times, displayed characteristics of both string and fringe reefs. Their review determined that bed morphologies were influenced by substrate, salinity, sediment, water circulation, aerial exposure, predation, and larval supply (Kennedy and Sanford, 1999). String reefs included the long transverse reefs identified by Haven and Whitcomb (1983) in the James River, VA (Kennedy and Sanford, 1999). The longitudinal reefs mapped by Winslow (1882) in the Chesapeake Bay were fringe reefs and the pancake reefs of the James River, VA (Haven and Whitcomb, 1983) exemplified patch reefs (Kennedy and Sanford, 1999).

With respect to size and shape of reefs, Winslow (1882) noted that the shape and area of reefs varied but that the length of the bed was usually greater than the width, with the greatest dimension usually in the direction of the current (Kennedy and Sanford 1999). Reefs mapped by Winslow in Tangier Sound ranged in size from 0.168 km^2 (41.5 acres) to 7.043 km^2 (1740.4 acres) in length from 704 m to 8,334 m; and in width from 185 m to 2,315 m (McCormick-Ray 1995). Bed width-to-length ratios of the Tangier Sound beds were all less than 0.4 with the exception of one bed (ranging from 0.03 to 1) indicating that the beds were long and narrow, but that widths vary greatly between and within beds (McCormick-Ray 1998).

Studies by DeAlteris (1988) estimate that Wreck Shoal, in the James River, grew vertically at a rate of 50 cm per century (0.5 cm/yr) until 1855 and that this rate of rise kept pace with both sea level rise and the deposition of new sediment. Harvesting activities over the next 100 years lowered the reef height by 1m (Kennedy and Sanford 1999). Some studies have estimated reduced reef heights of up to several meters by mechanical harvesting over the past century (Marshall 1954, DeAlteris 1988). Woods et al. (2005) identified that Lower James River historically emergent reefs have lost on average 0.47 m of height. Alternatively, Smith et al. (2003) were unable to detect any significant change to bed elevation in Tangier Sound.

b. Current bar morphologies, size, and height

Today, most unrestored reefs within the Bay are flat with little topography. Many are impaired by sediment. Sufficient reef height controls habitat quality (and quantity) indirectly through its effect on flow, which in turn impacts food availability and the reefs susceptibility to DO and sedimentation (Lenihan 1999, Lenihan and Peterson 1998, and Breitburg 1992). Functionally, the presence of soft sediments surrounding elevated oyster reef terrace structures suggests that these lower areas between oyster beds served as sediment traps (Smith et al. 2003).

Recent studies (Schulte et al. 2009) reflect the importance of reef height. In Great Wicomico, the U.S. Army Corps of Engineers Norfolk District restored both high relief reef [HRR, 25-45 cm (9.8-17.7 in)] and low relief reef [(LRR, 8-12 cm (3.1-4.7 in)] (prior to subsidence of 2-6 cm due to settling, on average, of the oyster shell used to build the reefs). This work revealed the following:

- ‘The key mechanism mediating the abundant restored population was the vertical relief of the restored reefs, specifically the height above the river bottom.’
- ‘As the proportion of HRR increased on any particular reef, oyster density rose linearly and sharply from just over 200 oysters per m^2 when a reef was 10 % high relief to over 1000 oysters per m^2 when a reef was 90 % high relief. Thus, for every 10 % increase in the proportion of HRR, oyster density was enhanced by ~ 100 oysters per m^2.
- Oyster size also varied across reef type. Mean size in shell length of*C. virginica* on HRR was 15 % larger than that of oysters on LRR. Thus, oysters were more abundant and larger on HRR than on LRR.
- Recruitment was not only greater on HRR, but it was also more consistently high, compared to the much more variable and lower recruitment on LRR.
- The HRR reefs exhibit both vertical and cohesive growth, in contrast to the pattern of reef degradation typically observed on native oyster restoration projects.
- Sufficient shell accretion occurred on HRR, but not LRR.

Most state-funded shell repletion work has been completed at the patch scale of 1-100m^2 (Eggleston 1999). Eggleston (1999) proposed that oyster density or species diversity on reefs would be highest at an intermediate level of habitat fragmentation and made the following points for consideration in shaping oyster reefs:

- Patch shape: Shape determines perimeter:core ratio (edge effects). That is, long, thin patches have proportionally more edge than square or round patches. This exposes the patch more to detrimental edge effects such as physical stresses and predation pressure, but is beneficial from a recruitment standpoint as there in a higher encounter possibility with settling larvae.
- Patch size: The smaller the patch size, the greater the influence that external factors will likely have (physical stresses, predation). Larger patches have a larger core area that is more isolated from environmental and biotic changes associated with the edges. However, as described for ‘patch shape’ increased perimenter:core ratio of smaller patches may enhance larval recruitment.
- Patch isolation: Isolation may or may not be important for marine species with planktonic larvae, but may impact the spread of disease, predation, and larval recruitment.

Research by Harwell (2004) focused on fragmentation of intertidal oyster reefs in North Carolina (although reefs constructed for the project were not to a scale large enough for restoration). This study identified the importance of fragmentation towards increasing faunal abundance on oyster reefs. It was determined that large fragmented reefs (10.18 m^2 of reef habitat distributed in four equal patches within a 20.14 m^2 area) were preferred by most species in the study compared with small fragmented reefs (5.1 m^2 of reef habitat distributed in four equal patches within a 10.18 m^2 area) or a continuous reef (10.18 m^2). Fragmentation benefited species that prefer edge over interior habitat, but only after a minimum patch size has been reached. Fragmentation decreased predation pressure and increased access to food sources. Harwell (2004) reported that terrestrial systems predict that changes in habitat configurations should begin to influence faunal abundance at a threshold level of 30-50% habitat loss (Andrén 1994, Fahrig 1998). Harwell (2004) supported earlier work by Eggleston (1999) that showed highest biodiversity has been predicted to occur at intermediate levels of habitat fragmentation.

1. Reef heterogeneity and topography

Woods et al. (2004) determined that the Northern-style reef displayed a great deal of heterogeneity at the reef scale (here defined as 'fine scale' in this discussion). This heterogeneity may have been key to the maintenance of viable oyster bars and would have had effects on water column movement and flow characteristics. Southern-style reefs on the other hand exhibited lumps and ridges.

Setting occurs on shell surfaces several inches or more beneath the outer layer of shells. Bartol et al. (1999) showed that interstitial residence space is particularly advantageous for oysters in the mid-intertidal zone. Further, there is clear evidence that interstitial space, to a depth of at least 15 cm, is important in enhancing the survival of new oyster recruits (Luckenbach 2000).

Smith et al. (2003) discussed the importance of reef heterogeneity on a fine scale and suggest that it may be critical to the maintenance of viable oyster habitat. Relief benefits a reef by promoting water column movement and flow (Kennedy and Sanford, 1999). Lenihan (1999) identified the important of reef structural heterogeneity to all stages of oyster development. Smith et al. (2003) focused on the presence of 'lumps' that fringed the main oyster bar terraces and still retained relief. The lumps contained abundant shell and epifauna. The lumps (or mounds) studied ranged from 1 to 12 m in diameter, ringed the terrace, and had elevations similar to the terrace. Smith et al. (2003) proposed that the lumps, unaffected by harvests, exemplified the necessary relief to provide suitable habitat for the oysters and epifauna present on the lump.

2. Orientation to flow

Northern-style reefs were characterized as large patches, often parallel to channel and currents (Woods et al. 2004). Strong currents are important in development of this style of reefs along the edges of channels and tops of upthrusting areas of bottom. It was identified that there exist scouring currents along the scarps that maintained sediment free oysters and likely brought increased food to the bed (Smith et al. 2003). Southern-style reefs were better characterized as biogenic lumps and groin-like ridges perpendicular to current. Woods et al. (2004) proposed that the major controlling factor dictating oyster reef success is water flow.

3. Water depth

Northern-style reefs follow bottom contours. Although typically found in deeper water, along the bottom of rivers in areas of abrupt change in relief, these reefs existed at all depths from a few inches to 15+ fathoms. However, they were most plentiful where depth is from 5 to 30 ft. The greatest abundance exists at mouths of estuaries and in places where there are sudden changes in the depth of bottom (Stevenson 1894). Southern-style reefs were located in shallow water, and often were intertidal. The base of many of the upthrusting oyster reefs in Lower James River were at a depth of 2m in the 1870s (Woods et al. 2005). Seliger and Boggs (1988) determined that oyster reefs typically followed the 6 foot (2m) depth contour and were limited to the 18 foot (6m) depth contour in surveyed areas of the Chester and Choptank Rivers. The mean depth of existing oyster habitat in Maryland's portion of the Bay is 4.2 m, with a range of 1.5 m to 9.7 m (MDNR 2007 as cited in Section 3, PEIS 2009).

C. APPLICATION TO THE MASTER PLAN

1. Bar morphology and height

Based on the success of the Great Wicomico River restoration, the master plan will recommend constructing the first phase of reefs in any given DSS to at least a height of 1ft with some minor variation in height across the reef to create topographic heterogeneity [Lenihan (1999) >1m, NAO (HRR: 25-45 cm (9.5 in-1.5 ft) and LRR: 8-12 cm (3.1-4.7 in), prior to subsidence of 2-6 cm (0.8-2.4 in) due to settling (Schulte et al. 2009]. Within the Chesapeake Bay, one foot of relief is expected to be a sufficient height to promote reef longevity. Following the initial construction phase, the reefs should be evaluated to determine if bar height needs to be adjusted for future reefs constructed in that DSS. Construction methods should continue to be evaluated and improved to fully understand the ability we have to adequately control placement of reef materials.

Approximately, 13 acres of oyster reefs were constructed in the Severn River (MD) using alternate substrates from 2009-2010. These reefs were designed to have a 12 inch base height. Some reefs had elevated plateaus ranging from an additional 1 to 3 feet of height to provide heterogeneity. As the reefs have not been seeded at the time of this white paper's development, the reefs will be monitored and followed over the next years. Lessons learned will be incorporated into future designs.

The size of individual bars will be determined by follow-on tributary plans prior to construction. It is expected that size will vary. There will not be one targeted size. Historical accounts such as Winslow (1882) will be used to guide the decision. Size will depend on historic size, the currently available suitable bottom, and the amount of hard substrate (whether oyster shell or alternate substrate) needed to provide suitable bottom habitat. Winslow (1882) identified that the minimum size of oyster reefs in the Tangier/Pocomoke Sound region was 41.5 ac. It is expected that the size of individual restored bars will likely be smaller in size than historic accounts given current conditions in the Bay and available resources.

Based on the work of Harwell (2004) and Eggleston (1999) fragmentation should be included in reef design. Reefs should not be constructed in large continuous, uniform plots, but rather should allow for channels between restored areas. At this time, science has not provided specific guidance on the size of these channels and fragmented areas. Current construction methods inherently provide some fragmentation to a restored reef, but additional efforts should be made to establish dense plots within a restored area that are separated by defined channels of unrestored bottom. Evidence presented by Harwell (2004) suggests that fragmentation would need to be less than 50%, and would likely promote biodiversity at intermediate levels. Specifically tributary plans will need to address the spatial design of individual reefs for restoration.

2. Reef heterogeneity and topography

Topographic heterogeneity is an important feature to provide when restoring oyster reef. It has been identified that northern style reefs exhibited fine scale heterogeneity while southern style reefs had lumps and ridges. Due to the current construction methods, some degree of fine scale heterogeneity is likely to occur on all constructed reefs because shell and spat are not able to be placed precisely or uniformly. However, the techniques are not available to directly control the creation of fine scale heterogeneity. Placement techniques exist to construct lumps and ridges and these features should be incorporated into specific tributary restoration plans.

In order to provide refuge and promote successful spat sets, interstitial space needs to be incorporated into reef designs. Given that the master plan is proposing to construct reefs at least 1ft in height, these designs should inherently achieve the recommended [6 in (15cm)] shell thickness and provide sufficient interstitial space. However, recognizing the limited shell resources, if alternate substrates are being used for construction, the master plan recommends placing a veneer of clean oyster shell at least 15 cm (6.0 in.) thick upon the alternate substrate core (Jones and Rothschild 2009).

3. Orientation to flow

The master plan should discuss the preferred orientation to flow (Northern-style = parallel, Southern-style = perpendicular). The historic foot print of hard reef base and its orientation to flow should be the true guide for restoration of a specific bar. Recognizing the significance of water flow upon restoration success, this factor should be a focus of tributary specific plans when individual bars are sited.

4. Water depth

Due to concerns with hypoxia and anoxia, it is recommended that restoration be restricted to areas with water depths less than 20 ft of water (CBP 2004).

REFERENCES

Andrén, H. 1994. Effect of habitat fragmentation on birds and mammals in landscapes with different proportions of suitable habitat: a review. Oikos 71: 355-366.

Bartol, I.K., R. Mann, and M. Luckenbach. 1999. Growth and mortality of oysters (*Crassostrea virginica*) on constructed intertidal reefs: effects of tidal height and substrate level. Journal of Experimental Marine Biology and Ecology.

Breitburg, D.L. 1992. Episodic hypoxia in Chesapeake Bay: interacting effects of recruitment, behavior, and physical disturbance. Ecological Monographs 62:525-546.

Chesapeake Bay Program (CBP). 2004. Chesapeake Bay Comprehensive Oyster Management Plan.

DeAlteris, J.T. 1988. The geomorphologic development of Wreck Shoal, a subtidal oyster reef of the James River, Virginia. Estuaries 11:240-249.

Eggleston, D.B. 1999. Application of Landscape Ecological Principles to Oyster Reef Habitat Restoration. *In* M.W. Luckenbach, R. Mann, J.A. Wesson (eds.), Oyster Reef Habitat Restoration: A Synopsis and Synthesis of Approaches. Virginia Institute of Marine Science Press, Gloucester Point, VA, p 213-227.

Fahrig, L. 1998. When does fragmentation of breeding habitat effect population survival? Ecological Modeling 105: 273-292.

Harwell, H.D. 2004. Landscape aspects of oyster reefs: fragmentation and habitat utilization. Master's thesis submitted to the University of North Carolina at Wilmington. Center for Marine Science, University of North Carolina at Wilmington.

Haven, D.S. and Whitcomb, J.P. 1983. The origin and extent of oyster reefs in the James River, Virginia. J. Shellfish Research. 3: 1410151.

Jones, W.P., and B.J. Rothschild. 2009.Maryland's Oyster Redevelopment Program - Sanctuaries and Harvest Reserves. Report to Maryland Department of Natural Resources.

Kennedy, V.S., Sanford, L.P., 1999. Characteristics of relatively unexploited beds of the eastern oyster, Crassostrea virginica, and early restoration programs. In: Luckenbach, M.W., Mann, R., Wesson, J.A. (Eds.), Oyster Reef Habitat Restoration: A Synopsis and Synthesis of Approaches. Proceedings from the Symposium, Williamsburg, Virginia, April 1995. Virginia Institute of Marine Science, Gloucester, Virginia, pp. 25-46.

Lenihan, H.S. 1999. Physical-biological coupling on oyster reefs: How habitat structure influences individual performance. Ecological Monographs. 69(3): 251-275.

Lenihan, H.S., and C.H. Peterson. 1998. How habitat degradation through fishery distruvance enhances impacts of hypoxia on oyster reefs. Ecological Applications. 8(1): 128-140.

Luckenbach, M. 2000. Oyster reef habitat. Abstract [In] Chesapeake Bay Program. 2000 Oyster restoration workshop proceedings and agreement statements. CBP/TRS 238-00.

Marshall N. 1954. Changes in the phsiography of oyster bars in the James River, Virginia. Virgina Journal of Science 5: 173-181.

McCormick-Ray, M.G., 1998. Oyster reefs in 1878 seascape pattern-Winslow revisited. Estuaries 21 (4B), 784-800.

McCormick-Ray, J. 2005. Historical oyster reef connections to Chesapeake Bay- a framework for consideration. Estuarine, Coastal, and Shelf Science. 64: 119-134.

Schulte, D.M, R.P. Burke , and R.N. Lipcius. 2009. Unprecedented restoration of a native oyster metapopulation. Science 325(594): 1124-1128.

Seliger, H.H. and J. A. Boggs. 1988. Evidence for Loss of Suitable Benthic Habitats for Oysters in Tributaries of the Chesapeake Bay. *In*: Understanding the Estuary: Advances in Chesapeake Bay Research. Chesapeake Research Consortium, Publication 129. CBP/TRS 24/88: 111-127.

Smith, G.F., E.B. Roach, and D.G. Bruce. 2003. The location, composition, and origin of oyster bars in mesohaline Chesapeake Bay. Estuarine, Coastal, and Shelf Science. 56:391-409.

Stevenson, C.H. 1894. The Oyster Industry of Maryland. Bulletin of the US Fisheries Commission for 1892. Vol 12, p 203-297.

Winslow, F. 1882. Report on the oyster beds of the James River, Va., and of Tnagier and Pocomoke Sounds, Maryland and Virginia. U.S. Coast and Geodetic Sruvey Report for 1881:1-87.

Woods, H., W.J. Hargis, Jr., C.H. Hershner, and P. Mason. 2004. Improving Siting and Construction Criteria for Oyster Reef Restoration. VIMS Special Report in Applied Marine Science and Ocean Engineering (SRAMSOE) #387. Virginia Institute of Marine Science, Gloucester Point, VA.

Woods, H., W.J. Hargis, Jr., C.H. Hershner, and P. Mason. 2005. Disappearance of the natural emergent 3-dimensional oyster reef system of the James River, Virginia, 1871-1948. Journal of Shellfish Research. 24(1): 139-142.

Physical Characteristics – Population White Paper

A. SIGNIFICANCE TO OYSTER RESTORATION AND THE MASTER PLAN

The following physical characteristics of the Chesapeake Bay oyster population are relevant to oyster restoration and will be discussed in this white paper:

- size and extent of oyster habitat (current and historic), and
- setting within bayscape.

1. Size and extent of oyster habitat

a. Historic oyster population

When commencing a restoration project, it is important to identify the restoration target. In other words, what point in history is the project attempting to achieve? With respect to oysters, what population needs to be restored to provide the ecological services to the Bay that makes the oyster a keystone species? The master plan will target the historical point that is needed to provide a self-sustaining population first within tributaries, and ultimately a connected population throughout the entire Chesapeake Bay.

b. Current oyster population

The current disconnected state of the oyster population means that the master plan not only has to restore oyster biomass but the larval connectivity to achieve a self-sustaining population. Further, oysters provide their own habitat. Given the diminished amount of hard substrate available within the Chesapeake for oysters, the master plan will also need to address habitat limitations.

2. Setting within Bayscape

Prior to water quality impairments, the situation of reefs within the Bayscape was driven by water currents, hydrodynamics, geologic relief, water depth, and suitable substrate. Given today's water quality impairments, dissolved oxygen and salinity play a role.

B. SCIENTIFIC BASIS AND STATE OF KNOWLEDGE

1. Size and extent of oyster habitat

a. Historic oyster populations

Oyster grounds in Chesapeake Bay once encompassed more than 450,000 acres. Reefs existed in the mainstem east of the Gunpowder and Bush Rivers south through the Bay and in all tributaries to the mouth of the Bay. There does not exist a well accepted historic population record for oysters prior to the beginning of commercial harvesting. Commercial harvesting began in the 1800s and peaked in the 1880s. All known surveys were completed after significant harvesting efforts had impacted the oyster population. Winslow (1882) surveyed the oyster beds of the James River as well as Tangier and Pocomoke Sound. He noted that it was the oystermen's general opinion that the original dense oyster rock of Tangier and Pocomoke Sound had been expanded in size by dredging resulting in less dense, scattered oyster reefs. For example, Bird Rock reef in Pocomoke Sound was recorded as being two-thirds larger than when it was first discovered. Structurally, the beds in the two sounds had been altered by harvests. When first worked, 30 years prior, the oysters were in dense clusters, long and thin valved, and very numerous.

The Yates Survey (1913) charted about 215,000 acres (336 mi^2) of historic oyster grounds in Maryland (MDNR 1997). The Baylor Survey (1894) charted 243,000 acres (380 mi^2) of historic oyster grounds in Virginia. Only about half of those historic oyster grounds are believed to have been productive oyster habitat. The original reefs were interlaced with patches of mud and sand and surveys were often influenced by politics; that is, boundaries do not necessarily reflect reef habitat. Stevenson (1894) provided further estimates of total area of MD natural oyster grounds- 355 mi^2, 373 mi^2, (nearly 300 mi^2 (once corrected)) and provided a description of the main oyster areas in MD- Tangier, Choptank, Eastern Bay, and Chester; plus Potomac and Patuxent on Western Shore and 'Western Shore Bay ground', 'Eastern Shore Bay grounds', and Sinepuxent or Chincoteague Bay grounds. 'Bay shore grounds' (Pool Island to Potomac River on Western shore and from Worton Point to Smith Island on Eastern shore) was described as an almost continuous reef along the shore and at some places 2.4 km (1.5 mi) in width (Stevenson 1894). Eggleston (1999) described oyster habitat as individual clumps arranged into discrete patches that typically range from one to more than 100m diameter. Oyster patches, in turn, are arranged into reefs that extend over kilometer-wide areas.

Concerns existed as early as the mid to late 1800s that the oyster resources of Chesapeake Bay were being mismanaged. Winslow's surveys of the late 1870s recognized that some beds were no longer profitable to work. It recorded that beds in some areas that had been discovered just 30 years prior and had been exposed to heavy harvest pressure were becoming unproductive. The oystermen also stated that the number of oysters on the beds had been very materially diminished.

b. Current oyster populations

It is often cited that current populations are 1% of the historic population, or currently 3.5 billion (Newell 1988, USACE 2009). However, as discussed above, historic population levels prior to heavy disturbance are not known. Oyster populations have been decimated by overharvesting, disease, and loss of habitat. Oysters can still be found in most areas, but reefs are scarce and typically have very low oyster density. Oysters are often scattered rather than in dense assemblages. However, some areas of Virginia such as the Lynnhaven and Great Wicomico have local thriving populations. There are also oyster aquaculture operations, a few in Maryland and a thriving industry in Virginia, that contribute to the wild populations and to water quality improvement.

2. Setting within Bayscape

Northern-style reefs had terrace tops, channel edges, and geologic relief. Reefs followed the bottom contours (Woods et al. 2004). Reefs developed primarily on terrace scarps (terrestrial land submerged as paleochannels flooded) that could provide the substrate and support for the oyster bar. Often they were ringed by 1 to 12 m (in diameter) lumps (convex mounds) of similar elevation to that of the associated terrace. Smith et al. (2003) viewed their existence as ephemeral (susceptible to sedimentation), and succession occurred potentially rapidly, where the chance exposure of hard terrace was the overriding criterion. Stevenson (1894) identified that MD reefs at the time occur mainly on sides of channels in Chesapeake Bay as well as its tributaries and extend usually in the direction of the current. The greatest abundance of reefs was at the mouths of estuaries and in places where there are sudden changes in the depth of bottom. Southern-style reefs often extend from near-shore to channel edge (Woods et al. 2004). Seliger and Boggs (1988) identified that remaining viable oyster reefs were located in areas with steep bathymetric gradients (where $dz/dr \times 10^3 \geq 20$). They proposed that the steep bathymetric gradients are areas where tidal shear fronts maintain a silt-free environment that enable oyster reefs to remain viable.

C. APPLICATION TO THE MASTER PLAN

1. Size and extent of oyster habitat

There are no surveys of historic oyster grounds or historic population size prior to impacts from commercial harvesting. Therefore, the Yates and Baylor surveys have been selected as the most comprehensive early oyster surveys. Since it is recognized that these two surveys overestimated the amount of oyster reef habitat for various reasons, the master plan will estimate the true extent of oyster habitat by using the Yates and Baylor surveys in conjunction with the Winslow and Moore Surveys, respectively. These comparisons will provide an estimate of the percent of the historic surveys (Yates and Baylor) that actually held oyster reef. See scale white paper for further details.

In order to restore concentrated populations of oysters with the greatest likelihood of achieving self-sustainability, the master plan will focus on restoring a critical distribution and density of oysters within selected tributaries. See scale white paper for further details. The master plan will identify the acreage that needs to be restored in each tributary in order to establish the critical spatial distribution and the restoration goal. Subsequent studies that focus on targeted tributaries will investigate the appropriate location of individual bars.

Investigations into the gene flow of oysters within the Chesapeake Bay identified that local gene flow predominates with the Chesapeake Bay (Rose et al. 2006). The average squared dispersal was determined to be 472 km^2, approximately 4% of the entire Chesapeake Bay or the area within a large tributary. Their estimate defined a geographic scale encompassing the bulk of dispersal from a central point source, implying that recruitment of oysters in CB is local within tributaries or regional subestuaries. Further, Rose et al. (2006) proposes that at higher oyster densities characteristic of the Chesapeake Bay before 1900, their data indicates a smaller average squared dispersal. This implies that larval behavior may be as important as hydrography, making local recruitment the rule, not a tributary-specific phenomenon. With respect to distance between restored reefs, restoration studies of other sessile benthic invertebrates (red sea urchins) have recommended establishing multiple sanctuaries which are spaced at a distance less than the average larval dispersal distance of the target species (Smith et al. 1999). North et al. (2008) investigated larval transport in the Chesapeake Bay and determined that the average dispersal distance of all particles (representative of larvae) modeled during all hydrologic years was 9.0 km, but this distance is variable between tributaries.

The master plan will recommend providing a network of multiple reefs within the average distance of 9 km to restored reefs. The master plan also recommends considering the dispersal distance of individual tributaries when developing specific tributary plans.

The increased establishment of oyster aquaculture operations in conjunction to reefs restored for ecosystem restoration will additionally contribute to recruitment of larvae, water quality improvements, a sustainable seafood production source, and job creation at no additional investment by parties funding ecosystem restoration.

3. Setting within Bayscape

The location of reefs within the Bayscape will not likely be a major concern for the master plan, but will be very important when developing specific tributary restoration plans on the scale of individual reefs. Benthic mapping will be utilized to identify hard bottom and remnant bars that would be able to support additions of hard substrate. Incorporating historic hard features into plans will assist in restoring reefs to their historic place in the bayscape: along terrace scarps, on the sides of channels, in areas where there is a sudden change in water depth, and at the mouths of rivers. Bathymetric gradients should be considered in helping to identify suitable locations.

REFERENCES

Baylor, J.B. 1894. Method of defining and locating natural oyster beds, rocks and shoals. Oyster Records (pamphlets, one for each Tidewater, VA county, that listed the precise boundaries of the Baylor Survey). Board of Fisheries of Newport News, Virginia.

Eggleston, D.B. 1999. Application of Landscape Ecological Principles to Oyster Reef Habitat Restoration. *In* M.W. Luckenbach, R. Mann, J.A. Wesson (eds.), Oyster Reef Habitat Restoration: A Synopsis and Synthesis of Approaches. Virginia Institute of Marine Science Press, Gloucester Point, VA, p 213-227.

Maryland Department of Natural Resources (MDNR). 1997. Maryland's Historic Oyster Bottom: A Geographic Representation of the Traditional Named Oyster Bars.

Newell, R.I.E. 1988. Ecological changes in Chesapeake Bay: Are they the result of overharvesting the eastern oyster (*Crassostrea virginica*). *In* M.P. Lynch and E.C. Krome, editors. Understanding the Estuary: Advances in Chesapeake Bay Research. Solomons, Maryland: Chesapeake Research Consortium Publication 129. CBP/TRS 24/88. pp 536-546.

North, E. W., Z. Schlag, R. R. Hood, M. Li, L. Zhong, T. Gross, and V. S. Kennedy. 2008. Vertical swimming behavior influences the dispersal of simulated oyster larvae in a coupled particle-tracking and hydrodynamic model of Chesapeake Bay. Marine Ecology Progress Series 359: 99-115.

Rose, CG, KT Paynter, and MP Hare. 2006. Oyster, *Crassostrea virginica*, in Chesapeake Bay. Journal of Heredity 97(2): 158-170.

Rothschild, BJ, JS Ault, P Goulletquer, and M Heral. 1994. Decline of the Chesapeake Bay oyster population: a century of habitat destruction and overfishing. Marine Ecology Progress Series. 111: 29-39.

Seliger, H.H. and J. A. Boggs. 1988. Evidence for Loss of Suitable Benthic Habitats for Oysters in Tributaries of the Chesapeake Bay. *In*: Understanding the Estuary: Advances in Chesapeake Bay Research. Chesapeake Research Consortium, Publication 129. CBP/TRS 24/88: 111-127.

Smith, GF, KN Greenhawk, and DL Jensen. 1999. Oyster Bottom: Surface Geomorphology and Twentieth Century Changes in the Maryland Chesapeake Bay. 47- in M.W. Luckenbach, R. Mann, J.A. Wesson (eds.), Oyster Reef Habitat Restoration: A Synopsis and Synthesis of Approaches. Virginia Institute of Marine Science Press, Gloucester Point, VA.

Smith, G.F., E.B. Roach, and D.G. Bruce. 2003. The location, composition, and origin of oyster bars in mesohaline Chesapeake Bay. Estuarine, Coastal, and Shelf Science. 56:391-409.

Stevenson, C. H. 1894. The Oyster Industry of Maryland. Bulletin of the US Fisheries Commission for 1892. Vol 12, p 203-297.
Woods et al. 2004.

United States Army Corps of Engineers. 2009. Final Programmatic Environmental Impact Statement for Oyster Restoration in Chesapeake Bay Including the Use of a Native and/or Nonnative Oyster .

Winslow, F. 1882. Report on the oyster beds of the James River, Va., and of Tnagier and Pocomoke Sounds, Maryland and Virginia. U.S. Coast and Geodetic Survey Report for 1881:1-87.

Woods, H, WJ Hargis, Jr., CH Hershner, and P Mason. 2004. Improving Siting and Construction Criteria for Oyster Reef Restoration. VIMS Special Report in Applied Marine Science and Ocean Engineering (SRAMSOE) #387. Virginia Institute of Marine Science, Gloucester Point, VA.

Woods, H, WJ Hargis, Jr., CH Hershner, and P Mason. 2005. Disappearance of the natural emergent 3-dimensional oyster reef system of the James River, Virginia, 1871-1948. Journal of Shellfish Research. 24(1): 139-142.

Yates, CC. 1913. Summary of survey of oyster bars in Maryland, 1906-1913. US Department of Commerce, Washington, DC.

Physical Characteristics – Hydrodynamics White Paper

A. SIGNIFICANCE TO OYSTER RESTORSTION AND THE MASTER PLAN

The following physical characteristic relevant to oyster restoration will be addressed by this white paper:

- hydrodynamics/currents.

1. Hydrodynamics/Currents

Each tributary will have its own unique hydrodynamics and currents that are driven by tides, tributary shape and size, freshwater input, benthic structures, and winds. These forces influence oyster larval transport within and between tributaries, as well as local flows over an individual reef. The hydrodynamics and currents control the delivery rate and retention of planktonic oyster larvae and suspended food material to suspension-feeding oysters, as well as sediment, thereby affecting the recruitment, growth, and survival of oysters, and oyster reef habitat quality (Lenihan 1999). Further, alteration of flow speed by marine benthic habitat (such as oyster reefs) influences rates of larval settlement, recruitment, feeding, growth, predation, and community composition of benthic organisms.

B. SCIENTIFIC BASIS AND STATE OF KNOWLEDGE

As summarized by Powers et al. (2009), "With oysters now so depleted in most estuaries of the Atlantic coast of the U.S.A. (Kirby 2004), restoration strategies must be based on knowledge of hydrodynamics so as to concentrate reef restorations in areas of larval retention and seeded by sufficient spawning stock biomass to insure sustained recruitment (Lipcius et al. 2008). For North Carolina's northern Pamlico Sound and the Maryland portion of Chesapeake Bay, spatial strategies of rebuilding of oyster stocks may be necessary, first establishing core retention areas of high spawning stock biomass and then subsequently extending oyster reef restorations further and further from the margins of these already restored areas."

Hydrodynamics also plays a role in source/sink dynamics. It has been shown that within metapopulations, oyster reefs can serve either as source and sinks with respect to larval transport (Lipcius et al. 2008, North et al. 2008). Source reefs provide larvae to reef habitat in both source and sink habitats to maintain the populations. Sink reefs receive larvae, but do not contribute a significant amount of larvae to the population.

The relationship of the oyster larval period needs to be considered when evaluating hydrodynamics of a region for restoration. Within 48 hours of fertilization, an oyster enters a pelagic larval life stage which lasts two to three weeks (likely between 13 and 25 days) depending on temperature and food conditions (Galtsoff 1964, Carriker 1996, Kennedy 1996, Shumway 1996, Thompson et al. 1996, North et al. 2006). During the pelagic larval stage (veliger and pediveliger), larvae are moved within the estuary actively by swimming and passively by tides and current. Oyster larvae typically swim vertically. Active horizontal movement is less common (Thompson et al. 1996). Swimming speeds of *C. virginica* are influenced by size and vary from 0 to approximately 3 mm s^{-1} during the development to pediveligers ready to settle (Kennedy 1996, Newell et al. 2005). Newell et al. (2005) showed that *C. virginica* typically swim up in the presence of a halocline. Hidu and Haskin (1978) also demonstrated that in laboratory experiments salinity gradients caused behavioral changes in *C. virginica* larvae. In general, as larvae age, they are found closer to the bottom.

Thompson et al. (1996) summarized that the planktonic nature of oyster larvae, their presence in the water column for up to three weeks, their small size, and their relatively weak swimming ability likely result in the larvae being carried away from the parent reef on which they were spawned. It is unknown with any certainty how far larvae are distributed from a parent reef. North et al. (2008) investigated larval transport in the Chesapeake Bay and determined that the average dispersal distance of all particles (representative of larvae) modeled during all hydrologic years was 9.0 km, but this distance is variable between tributaries. Median dispersal distances are provided in North et al. (2008) for major tributaries. Although flow and wind contributed to dispersal, the only significant relationship to dispersal was habitat. A significant negative relationship was found to exist between habitat coverage in a basin and the dispersal distance of particles.

Hydrodynamics has important effects on individual reefs (Lenihan 1999) as well as to the connectivity of a metapopulation of oysters with respect to larval transport (Lipscius et al. 2008, North et al. 2008). On the individual reef scale, flow speed affects recruitment, growth, condition, and mortality (Lenihan 1999). Local flow speed increased with reef height and elevation on the reef. Variation in flow speed affected recruitment, growth, and condition of oysters. Recruitment was typically highest at the front base of the reef where flow speed was lowest. Flow speed was positively related to growth and condition of oysters. Both growth and condition were greatest where the flows were greatest, at the crests of reefs >1m. Flow impacts sedimentation and burial of the reef habitat. Sedimentation and burial contributes to mortality, which was greatest on the front bases of reefs where sedimentation and burial were the greatest (Lenihan 1999).

C. APPLICATION TO THE MASTER PLAN

Hydrodynamics are primarily important to the master plan with respect to identifying systems with retentive properties. Selecting sites with good larval retention is a key component of bay oyster restoration. There are a number of small embayments and/or tributaries to the mainstem of the Chesapeake Bay that have low tidal exchange rates, and as a result, tend to retain the planktonic larvae at much higher rates than areas with higher tidal flushing rates. Other hydrodynamic features in much larger river systems, such as the tidal intrusion front in the lower James River have been identified as important mechanisms for the retention of larval organisms. This frontal system, together with a cyclonic gyre in Hampton Roads, is thought to be at least partially responsible for retention of bivalve larvae in the lower James River (Shen, et al, 2008; Mann, 1988). Such waters are called "trap estuaries" and allow restored oyster habitat areas within them a much higher chance to auto recruit and become self-sustaining than waters in more open systems. Given the sparse spatial extent and size of suitable hard habitat in the Chesapeake Bay currently, initial restoration efforts will be targeted in tributaries with a high degree of retentiveness to achieve dense concentrations of spawning stock mass, to promote the development of disease resistance, and to ensure that larvae produced from restored bars is not completely lost to unrestored or unproductive areas of the Chesapeake. Once dense populations and sustained recruitment are achieved in a sufficient number of tributaries, subsequent sites (regardless of their retentiveness) will be selected for restoration that is aimed at restoring the connectivity of the oyster population throughout the Bay.

Source and sink dynamics are also important to consider. Identification of source verses sink habitats will enable placement of reefs to achieve desired goals. That is, ecological restoration will initially focus on source habitats to provide larvae to and retain larvae within the targeted restoration area. Locating sink habitats is key for the placement of shell and will serve to promote fisheries restoration. Source and sink dynamics will be a major consideration of the detailed tributary restoration plans that follow the master plan.

With respect to local hydrodynamics on individual bars (as opposed to system hydrodynamics on reef systems), external currents (up to 10 cm/s) enhance internal feeding currents, and improve rate of particle capture (Lenihan 1999). This information will be more important when designing individual tributary plans.

The master plan will evaluate hydrodynamics of tributary systems as a secondary criterion following GIS analysis of the absolute criteria. There is no available analysis of hydrodynamics for all tributaries of interest in the Chesapeake Bay. Therefore, the master plan has compiled and considered all available information focused on tributary hydrodynamics and larval transport and will use this knowledge to provide a hydrodynamic rating to each tributary. Large tributaries are divided into sub-basins and rated as such while small tributaries are rated in their entirety. This permitted the rating of hydrodynamically distinct sub-segments (DSS) regardless of size.

When detailed tributary plans are being developed, hydrodynamics should be studied in detail using available modeling tools in order to identify sink and source bars on the local scale and to fully understand metapopulation connections.

The following sources of information were used to compile hydrodynamic information and determine a rating for the tributaries:

- **Scientific Literature**

  A number of studies were referenced in the literature that focused on retention times in various Chesapeake Bay tributaries. Shen and Wang (2007) investigated the age of water of the Rappahannock, Potomac (106-214 d), York (32-136 d), and James (50-108 d) Rivers. Shen and Lin (2006) estimated mean residence time of the James River at 95 d. Shen and Haas (2004) likewise estimated the mean residence time of the York River at 100 d. Breitburg et al. (2003) looked at the hydrodynamics of the Patuxent River as it impacts dissolved oxygen patterns. Also for the Patuxent River, Hagy et al (2000) estimated mean residence time at 68 d. The Patuxent was also the focus of Testa and Kemp (2000). This study looked at physical transport processes within the river. Manning and Whaley (1954) focused on the hydrodynamics and larval transport processes of the St. Mary's River. Their work identified three distinct regions of the river based on circulation, larval abundance, and spatfall. Larval retention and hydrodynamics of Broad Creek was studied in Boicourt (1982) and Seliger et al. (1982). Zones of spawning, transport, and larval setting were identified. Lipcius et al (2008) investigated the hydrodynamics and metapopulations of the Lynnhaven River and identified larval source and sink areas.

None of these analyses used similar methods making it difficult to compare results. From the few available sources of residence time estimates made for large tributaries and the estimates from Wazniak et al. (2009) for small tributaries it takes a much longer time for water to exit the larger systems compared to the smaller tributaries (Shen and Wang 2007, Shen and Haas 2004, Gay and O'Donnell 2009, and Shen and Lin 2006). It is evident that the large and small tributaries have retentive properties on different scales.

- **Historic Spat Sets**

Historic spat set data provides information on the larval production of a tributary or region prior to recent oyster population degradation. MD historic oyster spat set data was compiled by Krantz and Meritt (1977) for the period 1939 to 1975. This work provided an average spat set by region for 1939 -1965 and 1966-1975. The average spat set for 1939-1965 was selected as representative of historic oyster spat set. Although, harvesting was already impacting oyster populations at this time and older data may be available for some areas, this was the most comprehensive data available for Maryland. Historic spat set data for Virginia was compiled from the VIMS archives by VIMS, but was limited in spatial coverage. Average spat sets were calculated to be comparable to MD data. However, VA spatset data was only available starting in 1947. Table 4.6 provides the average spat set for each DSS.

Tributaries were scored by this metric using the following criteria: High: >100 spat per bushel, Medium: 50-99, and Low: <50.

- **Current restoration activities**

NAO has been actively restoring oyster resources in Lynnhaven and Great Wicomico Rivers. Research and monitoring in these two tributaries have identified the retentive properties of these two systems. The restoration achieved in these two tributaries was considered in determining the final ratings of the Lynnhaven and Great Wicomico (Schulte et al. 2009; Lipcius et al. 2008).

- **Best Bar Identification by Maryland Department of Natural Resources and Historical Spat Set Data**

Jones and Rothschild (2009) evaluated MDNR Fall Survey Data from 1985 to 2007 in various forms. This effort identified the most productive bars or 'Best Bars' as those with market oyster abundance in the top 10% (>70 market oysters per bushel) of all bars surveyed in four or more years over the study period (1996-2007). Tributary production in terms of spat set was also evaluated.

The master plan took into consideration whether tributaries contain a 'Best Bar', and if so, how many. Also, the master plan valued the tributaries that had the highest spat sets over the period of record. (The tributaries that are identified in Table 2 as a 'Top 10 Tributary for Spat Set' fell in the top 10 for all metrics compiled in Jones and Rothschild (2009). Those that fell within the Top 10 for some metrics of Jones and Rothschild (2009), but not others were noted as 'ranked high for spat sets' in the matrix.)

Comparable recent bar ratings were not available for Virginia oyster bars.

- **Small Tributary Flushing Times**

The residence time of small tributaries was evaluated by Wazniak et al. (2009) specifically for the master plan. This exercise focused on small tributaries and used the flushing time as a measure of retention. The retention of oyster larvae in a system depends upon the flushing rate (or residence time) of the water in the system as well as the amount of suitable settlement habitat. For small tributaries an estimate of the flushing time was developed using the adjusted intertidal volume method. This method takes into account surface area, volume, and depth, as well as tidal forcing. The analysis was limited to small tributaries that do not have significant freshwater input or a well-defined gravitational circulation. The size of the large tributaries violated the assumptions made to perform the small tributary analyses and therefore prohibited an identical analysis. Significant freshwater flow into the large tributary induces density-driven (gravitational) circulation. The small tributary analysis assumed that tidally-driven circulation is the main component of the tributaries flow patterns (Wazniak et al. 2009).

A “tidal flushing index” (T_f in days) was determined for each of the 36 small tributaries considered. Flushing times for each tributary were scored using the following criteria: High:T_f>5, Medium:T_f 3-5, and Low:T_f<3

- **Geomorphology of Small Tributaries**

The methodology used to estimate the Small Tributary Flushing Times did not take into consideration the shape of the tributary and therefore, in cases of long and/or branched tributaries, the retentiveness was underestimated. For tributaries exposed to large fetches and therefore, wind-driven flushing, the method tends to overestimate flushing time.

Shape was qualitatively considered along with the flushing time scores in the master plan analysis. Tributaries with long and/or branched morphology were noted. It is expected that these tributaries would likely have flushing times greater than that calculated. Tributaries with wide, open configurations would likely have reduced flushing times.

- **Larval Transport Modeling- Self-recruitment metric of large tributaries**

Analyses of larval transport were made for the Maryland Department of Natural Resources (MDNR)-funded Programmatic Environmental Impact Statement (PEIS) and can be used as a proxy for the influence hydrodynamics on larval transport (North et al. 2008). The greater the retention of larvae in a tributary in which larvae were produced was used to signify greater retentive hydrodynamic properties. This is not a perfect proxy for hydrodynamics because the amount of settlement in a system is dependent on hydrodynamics and on the amount of habitat within a system, which varied between systems. The extent of current habitat is not known and therefore had to be estimated (Greenhawk 2005), introducing uncertainty in model results. Additionally, the larval transport model only accounted for mortality due to a larva’s inability to encounter a suitable site for settlement, and no other biology was considered to determine if the spat would survive once settled. Because the larval transport model does not include sources of biological mortality that vary by salinity regime, the model should simply be considered a robust proxy for the influences of circulation patterns on larval transport, and should not be expected to incorporate the impacts of salinity on juveniles Despite these uncertainties, the model provides the best and most consistent knowledge available of larval transport and hydrodynamics for all of the large tributaries in the Chesapeake Bay.

The master plan used the self-recruitment metric compiled by North et al. (2008). This metric represents the percent of successfully settled particles that settled within the basin of origin and is based only on particles that successfully settled. Tributaries were scored by this metric using the following criteria: High: $\geq$80 Medium: 50-79, and Low: <50.

- **Larval Transport Modeling- self-recruitment of sub-basins**

North and Wazniak (2009) prepared a companion document for the master plan entitled "Larval Transport Maps" to provide additional information about larval transport on the sub-basin scale. A self-recruitment metric was determined. In this paper, the metric indicates the percentage of all released particles that successfully settled within the same basin in which they originated. Self-recruitment scores were calculated for sub-basins. The values calculated for this self-recruitment are lower than those determined by North et al. (2008) because the North and Wazniak (2009) metric was based on 'all released particles' rather than 'all successfully settled particles'.

Tributaries were scored by this metric using the following criteria: High: >60, Medium: 40-59, and Low: <40.

- **Larval Transport Modeling: Particle Accumulation Zones**

North and Wazniak (2009) and North et al. (2006) investigated the spatial accumulation of particles as modeled by the larval transport model and identified accumulation zones. The accumulation zones represent areas where it would be expected that the greatest density of larvae would collect. They defined two zones representing the densest concentrations: 1) particle concentrations greater than the 75th percentile of all particle concentration values and 2) particle concentrations greater than the 90th percentile of all particle concentration values. For restoration purposes, these accumulation zones provide an estimate of locations where habitat structure should be placed to provide settlement structure for the larvae. These zones also suggest where hydrodynamic properties may be working to retain larvae. The master plan focused on the 90th percentile accumulation zones as most likely estimates of where high densities of larvae may concentrate. The GIS coverage of 90th percentile accumulation zones was used to compute the area within a DSS that was estimated to be a 90th percentile zone. This allowed the percent coverage of a DSS that was estimated to be a 90th percentile zone to be calculated.

Tributaries were scored by this metric using the following criteria: High: $\geq$20% of a DSS's area was projected to be a 90th percentile accumulation zone, Medium: $\geq$10-19, and Low: <10.

In determining the qualitative ratings, any available data including the historic spat set, MDNR Best Bar analysis, current restoration activities, and retention documented by scientific literature was given the greatest weight, followed by the modeling analyses (self-recruitment metric and accumulation zones of North and Wazniak (2009) because they were calculated at the sub-basin scale, and then the self-recruitment metric of North et al. (2008)). The flushing rate determination (Wazniak et al. 2009) was given lowest priority because of recognized short-comings, but was still valuable for some tributaries that had no other available information.

The hydrodynamic ratings were initially assigned by the master plan to each hydrodynamically DSS as:

- high (H)- A high rating is justified by a high self-recruitment score as identified by North and Wazniak (2009), documented (in the scientific literature) retention, monitoring data or specific modeling for a DSS that has identified retention, high historical spat sets, or a combination of these indicators.

- medium-high (MH)- A medium-high rating is justified by 1) strong larval transport model (LTM) indicators of high or medium (North et al. 2008) in conjunction with historical records such as spat set or the presence of ‘Best Bar, or 2) a high flushing time (Wazniak et al. 2009) supported by geomorphology or the presence of a ‘Best Bar’.

- medium (M)- A medium rating is assigned to DSS with 1) medium LTM self-recruitment scores by North and Wazniak (2009), 2) historic evidence of strong spat sets and presence of ‘Best Bars’ but LTM does not support retention, 3) a medium flushing time (Wazniak et al. 2009) supported by historic information or geomorphology, or 4) a low flushing time supported by both historic information and geomorphology.

- medium-low (ML)- A medium-low rating is assigned to tributaries with 1) a medium LTM self-recruitment score by North et al. (2008) that is not supported by historic or monitoring information, or a low LTM self-recruitment score by North et al. (2008) supported by historic or monitoring data, or 2) a low flushing time supported by either geomorphology or historic data.

- low (L)- DSS receiving a low rating is characterized by 1) a low LTM self-recruitment score (North and Wazniak, 2009), or 2) a low flushing time (Wazniak et al. 2009) without preferred geomorphology and unsupported by historic data.

After further discussions these nine data sets were compressed into 3 hydrodynamic qualitative rating (high (H), medium (M), and low (L)) (Table 1). When considering the the compiled information, the greatest weight was given to data produced from monitoring, survey, and other scientific investigations over information produced from modeling. General rating guidelines were:

- A DSS was assigned a 'High' if they had data and modeling that showed high retention or multiple ‘High” data sources that provided evidence to support 'Medium' modeling ratings.

In the absence of any data sources, DSS with some combination of high and medium modeling scores are assigned a 'High'.

- A DSS was assigned a 'Medium' if there was one data set supporting retention but low or medium modeling or if 'High' modeling scores that had 'Low data or other 'Low' modeling scores.

- A DSS was assigned a 'Low' for 'Low' data scores or for 'Low' or 'Medium' modeling scores in conjunction with 'Low' or no data scores.

Table 1: Rating Scheme used to determine Qualitative Hydrodynamic Rating

		H	M	L
Data Produced from Monitoring, Survey, and Scientific Investigations	**Scientific Literature**	documented retention	NA	NA
	Current Restoration Activities (Monitoring Data/Modeling)	documented retention	NA	NA
	Presence of MD Best Bar	Y	Yes but not supported by LTM modeling	N with exception of mainstem segments
	Historic Spat Sets	H	M	L
	Geomorphology of small tributaries	Y	possible	N
Data Produced from Modeling	**Small trib flushing time score (Wazniak et al. 2009)**	H, or M if other data	M, or L with historical and geomorphology	L
	Self-recruitment of sub-basins (North and Wazniak 2009. Table 3)	H, or M if other data	M	L
	Self-recruitment metric of large tributaries (North et al. 2008. Table 5)	H, or M if other data	M	L
	Accumulation Rating (North and Wazniak 2009)	H, or M if other data	M	L

All scores and the final qualitative retention rating are compiled in Table 2.

REFERENCES

Airoldi L., and Beck M.W. 2007. Loss, status and trends for coastal marine habitats of Europe. Oceanogr Mar Biol Ann Rev 45:345-405.

Andrews, J.D. 1947. Weekly oyster spatfall on shellbags, 1947 in the James River seed area. Virginia Institute of Marine Science. Gloucester Point, Virginia 23062.

Andrews, J.D. 1949. Weekly oyster spatfall on shellbags, 1948 & 1949 in the James River seed area. Virginia Institute of Marine Science. Gloucester Point, Virginia 23062.

Andrews, J.D. 1950. Weekly oyster spatfall on shellbags, 1950 in the James River seed area. Virginia Institute of Marine Science. Gloucester Point, Virginia 23062.

Andrews, J.D. 1951. Seasonal patterns of oyster setting in the James River and Chesapeake Bay. Ecology 32:752-758.

Andrews, J.D. (1952) Weekly oyster spatfall on shellbags, 1951 & 1952 in the James River seed area. Virginia Institute of Marine Science. Gloucester Point, Virginia 23062.

Andrews, J.D. (1954) Setting of oysters in Virginia. Proc Nat Shellfish Ass 45:38-46.

Andrews, J.D.1979. Pelecypoda: Ostreidae. In: AC Giese and JS Pearse, editors. Reproduction of Marine invertebrates. New York, NY: Academic Press, 293-341.

Andrews, J.D. 1988. Epizootiology of the disease caused by the oyster pathogen *Perkinsus marinus* and its effects on the oyster industry. Amer Fish Soc Spec Pub 18:47-63.

Austin, H.M., D.A Evans, and D.S. Haven. 1996. A retrospective time series analysis of oyster, *Crassostrea virginica*, recruitment (1946-1993) J Shellfish Res 15(3):565-582.

Austin, H.M., D.S. Haven, and M.S. Moustafa. 1993. The relationship between trends in a condition index of the American oyster, *Crassostrea virginica*, and environmental parameters in three Virginia estuaries. Estuaries 16(2):362-374.

Baker, S., F.H. Harris, and C.E. Moody. 1977. A benefit-cost analysis of the Virginia oyster industries: An historical appraisal and proposals for the future. A report to the Marine Resources Commission, Commonwealth of Virginia. Department of Economic. The College of William & Mary. Williamsburg, Virginia 23187.

Bartol, I.K., R. Mann, and M. Luckenbach. 1999. Growth and mortality of oysters (*Crassostrea virginica*) on constructed intertidal reefs: effects of tidal height and substrate level. Journal of Experimental Marine Biology and Ecology.

Beck, M.B., R.D. Brumbaugh, L. Airoldi, A. Carranza, L.D. Coen, C. Crawford, O. Defeo, G.J. Edgar, B. Hancock, M. Kay, H. Lenihan, M.W. Luckenbach, C.L. Toropova, and G.

Zhang. 2009. Shellfish reefs at risk: A global analysis of problems and solutions. The Nature Conservancy, Arlington VA. 52 pp.

Boicort, W.C.. 1982. Estuarine larval retention mechanisms on two scales. *In* Estuarine Comparison. Kennedy, V. (ed). Academy Press: New Yor, 445-457.

Breitburg, D.L, A. Adamack, K. A. Rose, S. E. Kolesar, M. B. Decker, J. E. Purcell, J. E. Keister, J. H. Cowan, Jr. 2003. The Pattern and Influence of Low Dissolved Oxygen in the Patuxent River, a Seasonally Hypoxic Estuary Estuaries, Vol. 26, No. 2, (Part A: Dedicated Issue: From Ecology to Economics: Tracing Human Influence in the Patuxent River Estuary and Its Watershed): 280-297.

Burke, R.P.2010. Alternative substrates as a native oyster (*Crassostrea virginica*) reef restoration Strategy in Chesapeake Bay. Ph.D. Dissertation. Virginia Institute of Marine Science, The College of William & Mary. 286 pp.

Burreson, E.M., and J.D. Andrews.1988. Unusual intensification of Chesapeake Bay oyster diseases during recent drought conditions. Proc Oceans 88:799-802

Butler, P.A. 1949. Gametogenesis in the oyster under conditions of depressed salinity. Biol Bull 96:263-269.

Carlsson, J., R.B. Carnegie, J.F. Cordes, M.P. Hare, A.T. Leggett, and K.S. Reece. 2008. Evaluating recruitment contribution of a selectively bred aquaculture line of the oyster, *Crassostrea virginica* used in restoration efforts. J Shellfish Res 27(5):1117-1124

Carnegie, R.B., and E.M. Burreson. 2008. Gametogenesis and spawning in *Crassostrea virginica* from disease-intense waters of Virginia, USA. 11th International Conference on Shellfish Restoration, Charleston, South Carolina 29401.

Carnegie, R.B., and E.M. Burreson. 2009. Status of the major oyster diseases in Virginia 2006-2008: A summary of the annual oyster disease monitoring program. Virginia Institute of Marine Science. Gloucester Point, Virginia 23062.

Carriker, M. R.. 1996. The shell and ligament. In: Kennedy, V. S., R. I. E. Newell, and A. E. Eble, eds. The Eastern Oyster: *Crassostrea virginica*. Maryland Sea Grant College, College Park, Maryland. 734 pp.

Choi, K.S., E.A. Wilson, D.H. Lewis, E.N. Powell, and S. M. Ray. 1989. The energetic cost of *Perkinsus marinus* parasitism in oysters: quantifications of the thioglycollate method. J Shellfish Res 8(1):125-131.

Cleveland, W.S. 1979. Robust locally weighted regression and smoothing scatterplots. J Amer Stat Assoc 74:829-836.

Coen, L.D., and R.E. Grizzle. 2007. The importance of habitat created by molluscan shellfish to managed species along the Atlantic Coast of the United States. Atlantic States Marine Fisheries Commission Habitat Management Series #8.

Commission of Fisheries of Virginia (1931) Thirty-third annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1931. Richmond, Virginia

Commission of Fisheries of Virginia (1932) Thirty-fourth annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1932. Richmond, Virginia

Commission of Fisheries of Virginia (1933) Thirty-fifth annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1933. Richmond, Virginia

Commission of Fisheries of Virginia (1934) Thirty-sixth annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1934. Richmond, Virginia

Commission of Fisheries of Virginia (1935) Thirty-seventh annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1935. Richmond, Virginia

Commission of Fisheries of Virginia (1936) Thirty-eighth annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1936. Richmond, Virginia

Commission of Fisheries of Virginia (1937) Thirty-ninth annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1937. Richmond, Virginia

Commission of Fisheries of Virginia (1939) Fortieth and forty-first annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1938 and June 30, 1939. Richmond, Virginia

Commission of Fisheries of Virginia (1941) Forty-second and forty-third annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1940 and June 30, 1941. Richmond, Virginia

Commission of Fisheries of Virginia (1943) Forty-fourth and forty-fifth annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1942 and June 30, 1943. Richmond, Virginia

Commission of Fisheries of Virginia (1945) Forty-sixth and forty-seventh annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1944 and June 30, 1945. Richmond, Virginia

Commission of Fisheries of Virginia (1947) Forty-eighth and forty-ninth annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1946 and June 30, 1947. Richmond, Virginia

Commission of Fisheries of Virginia (1949) Fiftieth and fifty-first annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1948 and June 30, 1949. Richmond, Virginia

Commission of Fisheries of Virginia (1951) Fifty-second and fifty-third annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1950 and June 30, 1951. Richmond, Virginia

Commission of Fisheries of Virginia (1953) Fifty-fourth and fifty-fifth annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1952 and June 30, 1953. Richmond, Virginia

Commission of Fisheries of Virginia (1955) Fifty-sixth and fifty-seventh annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1954 and June 30, 1955. Richmond, Virginia

Commission of Fisheries of Virginia (1957) Fifty-eighth and fifty-ninth annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1956 and June 30, 1957. Richmond, Virginia

Commission of Fisheries of Virginia (1959) Sixtieth and sixty-first annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1958 and June 30, 1959. Richmond, Virginia

Commission of Fisheries of Virginia (1961) Sixty-second and sixty-third annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1960 and June 30, 1961. Richmond, Virginia

Commission of Fisheries of Virginia (1963) Sixty-fourth and sixty-fifth annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1962 and June 30, 1963. Richmond, Virginia

Commission of Fisheries of Virginia (1965) Sixty-sixth and sixty-seventh annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1964 and June 30, 1965. Richmond, Virginia

Commission of Fisheries of Virginia (1967) Sixty-eighth and sixty-ninth annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1966 and June 30, 1967. Richmond, Virginia

Commission of Fisheries of Virginia (1969) Seventieth and seventy-first annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1968 and June 30, 1969. Richmond, Virginia

Commission of Fisheries of Virginia (1971) Seventy-second and seventy-third annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1970 and

June 30, 1971. Richmond, Virginia

Commission of Fisheries of Virginia (1973) Seventy-fourth and seventy-fifth annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1972 and June 30, 1973. Richmond, Virginia

Commission of Fisheries of Virginia (1975) Seventy-sixth and seventy-seventh annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1974 and June 30, 1975. Richmond, Virginia

Commission of Fisheries of Virginia (1977) Seventy-eighth and seventy-ninth annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1976 and June 30, 1977. Richmond, Virginia

Commission of Fisheries of Virginia (1979) Eightieth and eighty-first annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1978 and June 30, 1979. Richmond, Virginia

Commission of Fisheries of Virginia (1980) Eighty-second annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1980. Richmond, Virginia

Commission of Fisheries of Virginia (1982) Eighty-third and eighty-fourth annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1981 and June 30, 1982. Richmond, Virginia

Ford, S.E., and A.J. Figueras. 1998. Effects of sublethal infection by the parasite *Haplosploridium nelsoni* (MSX) on gametogenesis, spawning, and sex ratios of oysters in Delaware Bay, USA. Dis Aquat Org 4:121-133.

Galtsoff, P.S.. 1964. The American oyster, *Crassostrea virginica*, Gmelin. Fish. Bull., US Fish and Wildlife Service. 64:1-480.

Gay, P., and J. O'Donnell, 2009. Comparison of the salinity structure of the Chesapeake Bay, the Delaware Bay and Long Island Sound using a Linearly Tapered Advection-Dispersion Model. Estuaries and Coasts 32: 68-87.

Greenhawk, K. 2005. Development of a potential habitat layer for Maryland oyster bottom. Maryland Department of Natural Resources, Fisheries Division Report. August 4, 2005.

Hagy J.D., Boynton, W.R., Sanford, L.P. 2000. Estimation of net physical transport and hydraulic residence times for a coastal plain estuary using box models. Estuaries. 23(3): 328-340.

Hargis, W.H., and D.S. Haven. 1998. A reprint of the precarious state of the Chesapeake public oyster resource. Contribution No. 1965 of the Virginia Institute of Marine Science, Gloucester Point, VA 23062.

Hargis W.J., and D. S. Haven. 1999. Chesapeake oyster reefs, their importance, destruction and guidelines for restoring them. p. 329-358. *In*: (eds) MW Luckenbach, R Mann, and JA Wesson. Virginia Institute of Marine Science Press, Gloucester Point, Virginia.

Haven, D. 1960. Seasonal cycle of condition index of oysters in the York and Rappahannock Rivers. Proceedings of the National Shellfisheries Association. 51:42-66.

Haven, D. 1969. Annual summary for 1969: Oyster spatfall on shellstrings in Virginia rivers. Marine Resource Information Bulletin. Virginia Institute of Marine Science, Gloucester Point, Virginia 23062. 1(4):5-17.

Haven, D. 1970. Annual summary for 1970: Oyster spatfall on shellstrings in Virginia rivers. Marine Resource Information Bulletin. Virginia Institute of Marine Science, Gloucester Point, Virginia 23062. 2(15):1-11.

Haven, D. 1971a. Annual summary for 1970: Oyster spatfall on shellbags in Virginia rivers. Marine Resource Information Bulletin. Virginia Institute of Marine Science, Gloucester Point, Virginia 23062. 3(5):1-6.

Haven, D. 1971b. Annual summary for 1971: Oyster spatfall on shellstrings in Virginia rivers. Marine Resource Information Bulletin. Virginia Institute of Marine Science, Gloucester Point, Virginia 23062. 3(18):1-12.

Haven, D., and P. Kendall. 1973. 1972 Annual summary: Oyster spatfall on shellstrings in Virginia rivers. Marine Resource Information Bulletin. Special Report. Virginia Institute of Marine Science, Gloucester Point, Virginia 23062. 15 pp.

Haven, D., and P. Kendall. 1974. 1973 Annual summary: Oyster spatfall on shellstrings in Virginia rivers. Marine Resource Information Bulletin. A Sea Grant Advisory Service Special Report. Virginia Institute of Marine Science, Gloucester Point, Virginia 23062. 15 pp.

Haven, D., and P. Kendall. 1977. 1977 Spatfall summary. Marine Resource Information Bulletin. Virginia Institute of Marine Science, Gloucester Point, Virginia 23062. p. 7.

Haven, D., and P. Kendall. 1982. 1981 Annual summary: Oyster spatfall in Virginia rivers. Marine Resource Special Report. Virginia Institute of Marine Science, Gloucester Point, Virginia 23062. 14 pp.

Haven, D.S., W.J. Hargis, and P.C. Kendall. 1978. The oyster industry of Virginia: its status, problems and promise. VIMS special papers in marine science, Virginia Institute of Marine Science, Gloucester Point, VA.

Haven, D.S., W.J. Hargis, J.G. Loesch, J.P. Whitcomb. 1974. The effect of tropical storm Agnes on oysters, hard clams, soft clams, and oyster drills. In: AM Andersen and ML Wass, editors. Reports on the effects of tropical storm Agnes on the Chesapeake Bay estuarine system. Ches Res Consortium Pub No. 34, D169-D208.

Haven, D.S., and L.W. Fritz. 1985. Setting of the American oyster *Crassostrea virginica* in the James River, Virginia, USA: temporal and spatial distribution. Mar Biol 86:271-282.

Haven, D.S., J.P. Whitcomb, and P.C. Kendall. 1981. The present and potential productivity of the Baylor Grounds in Virginia. Special Report in Applied Marine Science and Ocean Engineering No. 243. Virginia Institute of Marine Science, Gloucester Point, VA 23062.

Herberich, D. 2006. Estimated return to harvest due to the Maryland Department of Natural Resources repletion activities 1990-2006. College Park, MD 20742.

Hidu, H., and H. H. Haskin. 1978. Swimming speeds of oyster larvae *Crassostrea virginica* in different salinities and temperatures. *Estuaries* 1: 252-255.

Ingersoll, E. 1881. 10th Census of the United States, the history and present condition of the fishery industries. The oyster industry. 251 pp.

Jones, P.W., and B.J .Rothschild. 2009. Maryland's Oyster Redevelopment Program- Sanctuaries and Harvest Reserves. Report to Maryland Department of Natural Resources.

Kennedy, V. S. 1996. Biology of larvae and spat. In: Kennedy, V. S., R. I. E. Newell, and A. E. Eble, eds. The Eastern Oyster: *Crassostrea virginica*. Maryland Sea Grant College, College Park, Maryland. 734 pp. Kirby,M. X. 2004. Fishing down the coast: Historical expansion and collapse of oyster fisheries along continental margins. *Proc. Nat. Acad. Sci.*, **101**: 13096–13099.

Kirby, M.X. 2004. Fishing down the coast: Historical expansion and collapse of oyster fisheries along continental margins. *Proc. Nat. Acad. Sci.*, **101**: 13096–13099.

Krantz, G.E., and D.W. Meritt. 1977. An analysis of trends in oyster spat set in the Maryland portion of the Chesapeake Bay. Proceedings of the National Shellfisheries Association, 67: 53-59.

Lawless, A.S. 2008. Effects of shoreline development and oyster reefs on benthic communities in Lynnhaven, Virginia. Master's Thesis. The College of William & Mary. Gloucester Point, Virginia 23062

Lenihan, H.S. 1999. Physical-biological coupling on oyster reefs: How habitat structure influences individual performance. Ecological Monographs. 69(3): 251-275.

Lipcius, R.N., D.B. Eggleston, S.J. Schreiber, R.D. Seitz, J. Shen, M. Sisson, W.T. Stockhausen, and H.V. Wang. 2008. Importance of Metapopulation Connectivity to Restocking and Restoration of Marine Species. Reviews in Fisheries Science. 16(1-3):101-110.
Mann 200- from Non-native EIS.

Lotze, H.K., H.S. Lenihan, B.J. Bourque, R.H. Bradbury, R.G. Cooke, M.C. Kay, S.M. Kidwell, M.X. Kirby, C.H. Peterson, and J.B.C. Jackson. 2006. Depletion, degradation, and recovery potential of estuaries and coastal seas. Science 312:1806-1809.

Luckenbach, M.W., and P.G. Ross. 2009. Recruitment, substrate quality and standing stock monitoring in support of NOAA-ACOE oyster restoration projects in the Great Wicomico, Rappahannock, Piankatank and Lynnhaven River Basins 2004-2006. VIMS ESL GIS-based Summary of Native Oyster Monitoring, Grant #NA06NMF4570303.

McCormick-Ray, A.G. 1998. Oyster reefs in 1878 seascape pattern-Winslow revisited. Estuaries, Vol. 21, No. 4B, pp. 784-800.

Mann, R. 1988. Distribution of bivalve larvae at a frontal system in the James River, Virgiina. Marine Ecology Progress Series 50: 29 - 44.

Mann, R., and D.A. Evans. 1998. Estimation of oyster, *Crassostrea virginica*, standing stock, larval production and advective loss in relation to observed recruitment in the James River, Virginia. J Shellfish Res 17(1):239-254.

Mann, R., and R. Morales-Alamo. 1994. The status of Virginia's public oyster resource 1993. Molluscan ecology program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 33 pp.

Mann, R., M. Southworth, J.M. Harding, and J.A. Wesson. 2009. Populations studies of the native eastern oyster, *Crassostrea virginica*, (Gmelin, 1791) in the James River, Virginia, USA J Shellfish Res 28(2):193-220.

Manning, J.H., and H.H. Whaley. 1954. Distribution of oyster larvae and spat in relation to some environmental factors in a tidal estuary. Proceedings of the National Shellfisheries Association. 45: 56-65.

Map of Mobjack Bay (2010) www.chesapeakeboating.net

Medcof , J.C. 1939. Larval life of the oyster (*Ostrea virginica*) in Bideford River. J Fish Res Bd Canada 4:287-301.

Morales-Alamo, R., and R. Mann. 1995. The status of Virginia's public oyster resource 1994. Molluscan ecology program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 37 pp.

Morales-Alamo R, and R. Mann. 1996. The status of Virginia's public oyster resource 1995. Molluscan ecology program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 45 pp.

Morales-Alamo R, and R. Mann. 1997. The status of Virginia's public oyster resource 1996. Molluscan ecology program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 48 pp

Morales-Alamo R, and R. Mann. 1998. The status of Virginia's public oyster resource 1997. Molluscan ecology program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 51 pp

Munch, S.B., M.R. Walsh, and D.O. Conover. 2005. Harvest selection, genetic correlations, and evolutionary changes in recruitment: one less thing to worry about? Can J Fish Aquat Sci 62:802-810.

Newell, R.I.E., and B.J. Barber. 1990. Summary and recommendations of oyster recruitment and standing stock monitoring workshop held at Horn Point Environmental Laboratories, November 6 and 7, 1990. Funded by Maryland Department of Natural Resources

Newell, R. I. E., V. S. Kennedy, J. L. Manuel and D. Meritt. 2005. Behavioral responses of *Crassostrea ariakensis* and *Crassostrea virginica* larvae to environmental change under spatially realistic conditions. Final report to Maryland Department of Natural Resources, May 2005.

North, E. W., Z. Schlag, R. R. Hood, L. Zhong, M. Li, and T. Gross. 2006. Modeling dispersal of *Crassostrea ariakensis* oyster larvae in Chesapeake Bay. Final Report to Maryland Department of Natural Resources, July 31, 2006. 55 p.

North, E. W., Z. Schlag, R. R. Hood, M. Li, L. Zhong, T. Gross, and V. S. Kennedy. 2008. Vertical swimming behavior influences the dispersal of simulated oyster larvae in a coupled particle-tracking and hydrodynamic model of Chesapeake Bay. Marine Ecology Progress Series 359: 99-115.

North, E.W., and T. Wazniak. 2009. Larval Transport Maps. Report to U.S. Army Corps of Engineers.

Maryland Oyster Advisory Commission (OAC). 2008. Maryland Oyster Advisory Commission 2008 Report: Concerning Maryland's Chesapeake Bay Oyster Management Program. Available online at: http://www.dnr.state.md.us/fisheries/oysters/

Powers, S.P., C.H. Peterson, J.H. Grabowski and H.S. Lenihan. 2009. Success of constructed oyster reefs in no-harvest sanctuaries: implications for restoration. Marine Ecology Progress Series. 389:159-170.

Santopietro, G.D., K. Stephenson, V.A. Satyal, and J. Wesson. 2009. A bioeconomic analysis of management plans for the public oyster grounds of the Rappahannock River. J Shellfish Res 28(2):235-241.

Schulte, D.M. 2003. Final Decision Document Amendment, Section 704B as Amended, Chesapeake Bay Oyster Recovery Phase III, Great Wicomico River, Virginia. Norfolk District – United States Army Corps of Engineers. Norfolk, Virginia 23510-1096

Schulte, D.M., R.P. Burke, and R.N. Lipcius. 2009. Unprecedented Restoration of a native oyster metapopulation. Science. 325(5944): 1124-1128.

Schulte, D.M., M, Cleland, and K. Groth. 2006. Final Decision Document Amendment, Section 704B as Amended, Chesapeake Bay Oyster Recovery Phase IV, Lynnhaven River, Virginia. Norfolk District – United States Army Corps of Engineers. Norfolk, Virginia 23510-1096.

Seliger, H.H., J.A. Boggs, R.B. Rivken, W.H. Biggley, and K.R.H. Aspden. 1982. The transport of oyster larvae in an estuary. Marine Biology 71: 57-72.

Shen, J. and L. Haas. 2004. Calculating age and residence time in the tidal York River using three-dimensional model experiments. Estuarine, Coastal and Shelf Science 61: 449-461.

Shen, J., and J. Lin, 2006. Modeling study of the influences of tide and stratification on age of water in the tidal James River. Estuarine, Coastal and Shelf Science 68: 102-112.

Shen, J., and H. V. Wang. 2007. Determining the age of water and long-term transport timescale of the Chesapeake Bay. Estuarine Coastal and Shelf Science 74:585–598.

Shen, J., Wang, T., Herman, J., Mason, P., Arnold, G.L. 2008. Hypoxia in a Coastal Embayment of the Chesapeake Bay: A Model Diagnostic Study of Oxygen Dynamics. *Estuaries and Coastal*, 31,652-663

Shumway, S. E. 1996. Natural environmental factors. In: Kennedy, V. S., R. I. E. Newell, and A. E. Eble, eds. The Eastern Oyster: *Crassostrea virginica*. Maryland Sea Grant College, College Park, Maryland. 734 pp.

Smith, G.F., D.G. Bruce, E.B. Roach, A. Hansen, R.I.E. Newell, and A.M. McManus. 2005. Assessment of recent habitat conditions on eastern oyster *Crassostrea virginica* bars in mesohaline Chesapeake Bay. North American Journal of Fisheries Management 25: 1569-1590.

Smith, G.F., K.N. Greenhawk, and D.L. Jensen. Oyster Bottom: Surface Geomorphology and Twentieth Century Changes in the Maryland Chesapeake Bay. 47- in M.W. Luckenbach, R. Mann, J.A. Wesson (eds.), Oyster Reef Habitat Restoration: A Synopsis and Synthesis of Approaches. Virginia Institute of Marine Science Press, Gloucester Point, VA.

Southworth, M. and R. Mann. 1998. Oyster reef broodstock enhancement in the Great Wicomico River, Virginia. Journal of Shellfish Research. 17(4):1101-1114.

Southworth, M., J.M. Harding, and R. Mann. 1999. The status of Virginia's public oyster resource 1998. Molluscan ecology program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 42 pp

Southworth, M., J.M. Harding, and R. Mann. 2000. The status of Virginia's public oyster resource 1999. Molluscan ecology program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 44 pp

Southworth, M., J.M. Harding, and R. Mann. 2001. The status of Virginia's public oyster resource 2000. Molluscan ecology program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 49 pp

Southworth, M., J.M. Harding, and R. Mann. 2002. The status of Virginia's public oyster resource 2001. Molluscan ecology program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 53 pp

Southworth, M., J.M. Harding, and R. Mann. 2003. The status of Virginia's public oyster resource 2002. Molluscan ecology program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 51 pp

Southworth, M., and R. Mann. 2004. Decadal scale changes in seasonal patterns of oyster recruitment in the Virginia sub estuaries of the Chesapeake Bay. J Shellfish Res 23(2):391-402

Southworth, M., J.M. Harding, and R. Mann. 2004. The status of Virginia's public oyster resource 2003. Molluscan ecology program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 55 pp

Southworth, M., J.M. Harding, and R. Mann. 2005. The status of Virginia's public oyster resource 2004. Molluscan ecology program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 51 pp

Southworth, M., J.M. Harding, and R. Mann. 2006. The status of Virginia's public oyster resource 2005. Molluscan ecology program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 49 pp

Southworth, M., J.M. Harding, and R. Mann. 2007. The status of Virginia's public oyster resource 2006. Molluscan ecology program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 49 pp

Southworth, M., J.M. Harding, and R. Mann. 2008. The status of Virginia's public oyster resource 2007. Molluscan ecology program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 49 pp

Southworth, M., J.M. Harding, and R. Mann. 2009. The status of Virginia's public oyster resource 2008. Molluscan ecology program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 53 pp

Southworth, M., J.M. Harding, and R. Mann. 2010. The status of Virginia's public oyster resource 2009. Molluscan ecology program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 52 pp

Testa, J.M. and W. M. Kemp. 2008. Variability of biogeochemical processes amd physical transport in a partially stratified estuary: a box-modeling analysis. Marine Ecology Progress Series. 356: 63-79.

Thompson, R. J., R. I. E. Newell, V. S. Kennedy, and R. Mann. 1996. Reproductive processes and early development. In: Kennedy, V. S., R. I. E. Newell, and A. E. Eble, eds. The Eastern Oyster: *Crassostrea virginica*. Maryland Sea Grant College, College Park, Maryland. 734 pp.

United States Army Corps of Engineers (USACE). 2009. Final programmatic environmental impact statement for oyster restoration in Chesapeake Bay including the use of a native and/or nonnative oyster.

Virginia Marine Resources Commission. 1984. Official Minutes of the Virginia Marine Resources Commission, January-December 1983. Newport News, Virginia 23607.

Virginia Marine Resources Commission. 1985. Official Minutes of the Virginia Marine Resources Commission, January-December 1984. Newport News, Virginia 23607.

Virginia Marine Resources Commission. 1986. Official Minutes of the Virginia Marine Resources Commission, January-December 1985. Newport News, Virginia 23607.

Virginia Marine Resources Commission. 1987. Official Minutes of the Virginia Marine Resources Commission, January-December 1986. Newport News, Virginia 23607.

Virginia Marine Resources Commission. 1989. Official Minutes of the Virginia Marine Resources Commission, January-December 1988. Newport News, Virginia 23607.

Virginia Marine Resources Commission. 1990. Official Minutes of the Virginia Marine Resources Commission, January-December 1989. Newport News, Virginia 23607.

Virginia Marine Resources Commission. 1991. Official Minutes of the Virginia Marine Resources Commission, January-December 1990. Newport News, Virginia 23607.

Virginia Marine Resources Commission. 1992. Official Minutes of the Virginia Marine Resources Commission, January-December 1991. Newport News, Virginia 23607.

Virginia Marine Resources Commission. 1993. Official Minutes of the Virginia Marine Resources Commission, January-December 1992. Newport News, Virginia 23607.

Virginia Marine Resources Commission. 1994. Official Minutes of the Virginia Marine Resources Commission, January-December 1993. Newport News, Virginia 23607.

Virginia Marine Resources Commission. 1995. Official Minutes of the Virginia Marine Resources Commission, January-December 1994. Newport News, Virginia 23607.

Virginia Marine Resources Commission. 1996. Official Minutes of the Virginia Marine Resources Commission, January-December 1995. Newport News, Virginia 23607.

Virginia Marine Resources Commission. 1997. Official Minutes of the Virginia Marine Resources Commission, January-December 1996. Newport News, Virginia 23607.

Virginia Marine Resources Commission. 1998. Official Minutes of the Virginia Marine Resources Commission, January-December 1997. Newport News, Virginia 23607.

Virginia Marine Resources Commission. 1999. Official Minutes of the Virginia Marine Resources Commission, January-December 1998. Newport News, Virginia 23607.

Virginia Marine Resources Commission. 2000. Official Minutes of the Virginia Marine Resources Commission, January-December 1999. Newport News, Virginia 23607.

Virginia Marine Resources Commission. 2001. Official Minutes of the Virginia Marine Resources Commission, January-December 2000. Newport News, Virginia 23607.

Virginia Marine Resources Commission. 2002. Official Minutes of the Virginia Marine Resources Commission, January-December 2001. Newport News, Virginia 23607.

Virginia Marine Resources Commission. 2003. Official Minutes of the Virginia Marine Resources Commission, January-December 2002. Newport News, Virginia 23607.

Virginia Marine Resources Commission. 2004. Official Minutes of the Virginia Marine Resources Commission, January-December 2003. Newport News, Virginia 23607.

Virginia Marine Resources Commission. 2005. Official Minutes of the Virginia Marine Resources Commission, January-December 2004. Newport News, Virginia 23607.

Virginia Marine Resources Commission. 2006. Official Minutes of the Virginia Marine Resources Commission, January-December 2005. Newport News, Virginia 23607.

Virginia Marine Resources Commission. 2007. Official Minutes of the Virginia Marine Resources Commission, January-December 2006. Newport News, Virginia 23607.

Virginia Marine Resources Commission. 2008. Official Minutes of the Virginia Marine Resources Commission, January-December 2007. Newport News, Virginia 23607.

Virginia Marine Resources Commission. 2009. Official Minutes of the Virginia Marine Resources Commission, January-December 2008. Newport News, Virginia 23607.

Virginia Marine Resources Commission. 2010. Official Minutes of the Virginia Marine Resources Commission, January-December 2009. Newport News, Virginia 23607.

Wazniak, T. W. Boicourt, and E. North. 2009. Residence Times of Small Chesapeake Bay Tributaries. Report to USACE.

Whitcomb, J . 1984. 1983 Annual summary: Oyster spatfall in Virginia rivers. Marine Resource Special Report. Virginia Institute of Marine Science, Gloucester Point, Virginia 23062 21 pp.

Whitcomb, J. 1987. 1987 Annual summary: Oyster spatfall in Virginia rivers. Marine Resource Special Report. Virginia Institute of Marine Science, Gloucester Point, Virginia 23062 20 pp.

Whitcomb, J.P. and D.S. Haven.1987. The physiography and extent of public oyster grounds in Pocomoke Sound, Virginia. Journal of Shellfish Research. 6: 55-65.

Attachment 1-A: Hydrodynamic Rating Assignments by DSS

MARYLAND	
Magothy River	The **Magothy River** has a high (5.95) small tributary flushing time score combined with a relatively narrow and branched shape that suggests retention. No data are available for historical spat sets (low rating). Possibly the system was and is broodstock limited. No portion (low) of the Magothy was estimated to be in a 90% accumulation zone. The Magothy is assigned a *MEDIUM* hydrodynamic rating because the system has a high modeling score with low data and another low modeling score.
Severn River	The **Severn River** received the highest (most retentive) small tributary flushing time score (8.51). Its shape is long and narrow promoting retention. Although historical spat sets were low (16.9 spat/bu), the Severn contains one Maryland Best Bar. The Severn had 7% of its area (low) estimated to be in the 90% accumulation zone. The Severn was assigned a *HIGH* because it had a high data score and a high modeling score.
South River	The **South River** received a high (5.98) rating for small tributary flushing time. It shape is long and narrow promoting retention. Although historical spat sets were low (19.9 spat/bu), the South contains one Maryland Best Bar. The South had 2% of its area (low) estimated to be in the 90% accumulation zone. The South was assigned a *HIGH* because it had a high data score and a high modeling score.
Rhode River	The **Rhode River** was scored as a medium (3.8) for small tributary flushing time and has a shape that could possibly promote retention. Historical spat sets were low (19.9 spat/bu). No portion (low) of the Rhode was estimated to be in a 90% accumulation zone. The Rhode was assigned a *LOW* because it had low and medium modeling scores in conjunction with a low data score.
West River	The **West River** was scored as a medium (3.2) for small tributary flushing time and has a shape that could possibly promote retention (forked with wide mouth). Historic spat sets were low (19.9 spat/bu). No portion (low) of the West was estimated to be in a 90% accumulation zone. The West was assigned a *LOW* because it had low and medium modeling scores in conjunction with a low data score.
Chester River	The **Chester River** received a high (81) self recruitment score for large tributaries. The upper and lower Chester each were scored as a medium (50.9 and 54.5, respectively) for the self-recruitment of sub-basins. The Chester had 27% of the lower area (high) and 19% of the upper area (medium) estimated to be in the 90% accumulation zone. The lower sub-basin self-recruitment scores compared with that of the entire Chester suggests that the upper and lower sections are linked and contribute to the greater modeled retention with the full Chester River. The Chester River has historically low spat sets (12.4 spat/bu in lower and 13.4 spat/bu in upper), but has two best bars, one in the lower portion and one in the upper. The Chester River was assigned a *HIGH* hydrodynamic rating because it had a high data score supported by high and medium modeling ratings. The lower Chester River was assigned a *HIGH* rating while the upper Chester was assigned a *MEDIUM* rating.
Corsica River	The **Corsica River** received a medium (3.87) small tributary flushing time score supported by shape (long and narrow) that suggests retention. Historically, the Corsica has low spat set (10-25 spat/bu). No portion (low) of the Corsica was estimated to be in a 90% accumulation zone. The Corsica was assigned a *LOW* because it had low and medium modeling scores in conjunction with a low data score.
Eastern Bay	**Eastern Bay** received a medium (62.5) self recruitment score for large tributaries. Upper and lower Eastern Bay were scored as a medium (48.1) and low (15.4), respectively for the self-recruitment of sub-basins. Eastern Bay had 21% of the upper area (high) and 16% of the lower area (medium) estimated to be in the 90% accumulation zone. Eastern Bay contains two best bars. In addition, two of its tributaries, the Wye River and Miles River, each contain a best bar. Historically, Eastern Bay had high spat sets (113.6 spat/bu in upper and 122.4 spat/bu in lower). Eastern Bay was identified as a region of high consistent spat sets by Kimmel et al. (in review) and contained two prime bars. A number of Eastern Bay is assigned a *HIGH* hydrodynamic rating because it has high data scores (best bar and historical spat sets) and a high modeling score (accumulation zone). Both the lower and upper Eastern Bay sub-segments were rated as *HIGH* based on historical spat sets and the presence of best bars.
Choptank River	The **Choptank River** received a medium (77.2) self recruitment score for large tributaries. The upper and lower Choptank each were scored as a high (68.3) and medium (42.8), respectively for the self-recruitment of sub-basins. The Choptank had 13% of the upper area (medium) and 29% of the lower area (high) estimated to be in the 90% accumulation zone. The Choptank River does not contain any best bars, but two of its tributaries, Broad and Harris Creek, are the sites of best bars. Historically, the upper Choptank had low spat sets (26.8 spat/bu) and the lower Choptank at medium spat sets (71.1 spat/bu). Seliger et al. (1982) project a tidally pumped, upstream flow (from the mouth) of Choptank bottom waters containing oyster larvae. The larval transport modeling scores suggest retention, particularly within the upper Choptank. However, the accumulation zone modeling and the higher historical spat sets in the lower Choptank suggest that this portion of the Choptank has more abundant oyster resources. Kimmel et al.

	(in review) identified the Choptank (focus on lower mainstem and lower tributaries) as a region with consistently high spat sets and the location of a prime bar. The Seliger et al. (1982) study provides strong support for retention within the Choptank system. Due to the documentation of retentive forces by Seliger et al (1982), the presence of best bars in its tributaries, the analyses performed by Kimmel et al. (in review) and the high modeling scores, the Choptank River was assigned a *HIGH* hydrodynamic rating. Both sub-segments of the Choptank were also rated *HIGH* due to the investigations by Seliger et al. (1982) and the inability of the available data to distinctly separate the two sub-segments. Further investigations should be undertaken to better understand the connection between the upper and lower segments of the river before any restoration actions are undertaken in either segment.
Harris Creek	**Harris Creek** received a medium (4.26) small tributary flushing time score, but has a shape that could possibly promote higher retention (narrow with many small tributaries, but a wider mouth). Historically, Harris Creek had high spat set (203.6 spat/bu). Harris Creek contains one best bar and had 19% (medium) of its area estimated to be in a 90% accumulation zone. Harris Creek was identified as part of the region of the Eastern Shore that receives consistently high spat sets by Kimmel et al. (in review). Harris Creek is assigned a *HIGH* hydrodynamic rating because it has high data scores (best bar and historical spat set) that support medium modeling scores.
Broad Creek	**Broad Creek** received a medium (4.1) small tributary flushing time score, but has a shape that promotes higher retention (forked). Historically, Broad Creek had high spat set (160.5 spat/bu). Broad Creek contains three best bars and has 20% (high) of its area estimated to be in a 90% accumulation zone. Seliger et al. (1982) identified zones of spawning, transport, and setting. Broad Creek was identified as part of the region of the Eastern Shore that receives consistently high spat sets by Kimmel et al. (in review). Broad Creek is assigned a *HIGH* hydrodynamic rating because it has high data scores (documented hydrodynamics, high best bar and historical spat set) plus high and medium modeling scores.
Little Choptank River	The **Little Choptank River** received a low (37.3) self recruitment score for large tributaries, a low (29.2) for the self-recruitment of sub-basins, and a medium (4.01) small tributary flushing time score. The Little Choptank had 13% of its area (medium) estimated to be in the 90% accumulation zone. The Little Choptank contains four best bars, the most of any tributary. The larval transport modeling suggests that a significant portion of the larvae produced in the system are exported to the mainstem of the Bay, but little retention. There is no evidence in the larval transport model that the Little Choptank is a sink area for larvae from other tributaries. However, the Little Choptank was identified as part of the region of the Eastern Shore that receives consistently high spat sets and holds one prime bar (Kimmel et al. (in review). Given the presence of four best bars, a prime bar, and high historical spat sets (136.8 spat/bu), those larvae that do remain in the system must thrive. The Little Choptank is assigned a *HIGH* based on high data scores (the presence of four best bars and historical spats sets).
Honga River	The **Honga River** received a medium (3.01) small tributary flushing time score, but is not supported by a shape that suggests retention. Historically, the Honga River has high spat set (166.9 spat/bu) and does contain a prime bar (Kimmel et al., in review). A low portion (7%) of the Honga was estimated to be in a 90% accumulation zone. The Honga was assigned a *MEDIUM* because it had low and medium modeling scores supported only by one high data score (historical spat set) suggesting that the Honga River serves more as a sink than a source.
Potomac River	The **Potomac River** received a high (93.7) self recruitment score for large tributaries. Shen and Wang (2007) identified an age of water in the Potomac between 106 and 214 days depending on discharge. However, when the segments of the Potomac River are evaluated, hydrodynamic scores are reduced. The self-recruitment of sub-basins scores for the upper, middle, and lower segments were medium (43.4), medium (40.1), and low (19.8), respectively. Historical spat sets were low for the upper (8.2 spat/bu), low for the middle (36 spat/bu), and high for the lower (106.3 spat/bu). The Potomac had 8% of the upper area (low), 16% of the middle area (medium), and 17% of the lower area (medium) estimated to be in the 90% accumulation zone. Larval transport modeling suggests some retention in the upper and middle portions of the Potomac, but the historical spat sets identify the lower Potomac as having much better oyster resources than the upper two segments. There is a prime bar located near the mouth of the Potomac (Kimmel et al., in review). This suggests that the lower portion was supplied with larvae from the upstream Potomac or that possible larvae were introduced from the Bay mainstem. The relatively long retention time estimated by Shen and Wang (2007) is likely due to the large size of the Potomac River system. The Potomac is assigned a *MEDIUM* hydrodynamic rating. The Potomac had one data set supporting retention (high spat set in lower segment), but low and medium modeling, plus one high modeling score (large tributary self-recruitment) combined with low data scores for the other segments with low and medium modeling scores for the segments. It is suspected that the sheer size of the Potomac produced the high large tributary self-recruitment score. The greatest retention within a sub-segment was identified in the lower Potomac based on historical spatset data. Therefore, the lower sub-segment was assigned a *MEDIUM* rating based on the high data rating mixed with low and medium modeling scores. The middle and upper sub-segments were assigned *LOW* ratings.

St. Mary's River	The **St. Mary's River** received a high (6.17) small tributary flushing time score. Its shape is long and forked promoting retention. St. Mary's had 10% of its area (medium) estimated to be in the 90% accumulation zone. St. Mary's had high historical spat set (150.7 spat/bu). Manning and Whaley (1954) identified zones of spawning, transport, and setting within St. Mary's. The St. Mary's River is assigned a *HIGH* hydrodynamic rating due to the documented hydrodynamics of Manning and Whaley (1954), high data score (historical spat set), and a high modeling score.
Tangier Sound	**Tangier Sound** received a high (96.7) self recruitment score for large tributaries. Upper and lower Tangier Sound were each scored high (74.8 and 68.6, respectively) for self-recruitment of sub-basins. Tangier Sound had 16% (medium) of its area estimated to be in the 90% accumulation zone. Historically, upper Tangier Sound had high spat sets (108.9 spat/bu) and lower Tangier Sound had low spat sets (47.7 spat/bu). However, Kimmel et al. (in review) identified two prime bars within Tangier Sound. The larval transport modeling indicates high retention. Although there are no best bars in Tangier Sound, the area historically had and still has to some extent abundant oyster resources. Tangier Sound is assigned a *HIGH* hydrodynamic rating because of high data and modeling scores. The upper and lower sub-segments were each assigned a *HIGH* score based on the information documented for Tangier Sound as a whole, the modeling data, and the rating of Tangier Sound as a 'Top 10' for production of spat set (Jones and Rothschild 2009).
Fishing Bay	**Fishing Bay** was scored as a low (2.79) for small tributary flushing time and does not have a shape that suggests higher retention. Historical spat sets were medium (55.9 spat/bu). A high portion (20%) of Fishing Bay was estimated to be in a 90% accumulation zone. Fishing Bay also had high larval transport modeling scores from North and Wazniak (2009) and North et al. (2008) where is was modeled as part of Tangier Sound. Fishing Bay was assigned a *MEDIUM* because it had a high modeling scores, but low and medium data scores.
Nanticoke River	**Nanticoke River** was included as part of Tangier Sound in the larval transport modeling (North et al. 2008, North and Wazniak 2009) and scored high (96.7 and 74.8) for both. Historical spatsets were low (33.3spat/bu), but the Nanticoke appears to have geomorphology that does support retention. Nanticoke River was assigned a *MEDIUM* because it had high modeling scores supported by a low data score.
Monie Bay	**Monie Bay** was scored as a low (2.05) for small tributary flushing time and does not have a shape that suggests higher retention. Historical spat sets were low (33.3 spat/bu). A low portion (3%) of Monie Bay was estimated to be in a 90% accumulation zone. Monie Bay was assigned a *LOW* because it low modeling and data scores.
Manokin River	The **Manokin River** was scored as a low (1.88) for small tributary flushing time and does not have a shape that suggests higher retention. Historical spat sets were high (108.8 spat/bu). The Manokin has 13% of its area (medium) estimated to be in the 90% accumulation zone. The Manokin was included with the Tangier in larval transport modeling by North et al. (2008) and received a high self-recruitment score as part of the Tangier system. The Manokin holds one prime bar (Kimmel et al., in review). Given the high historical spat sets, high rating for current spat sets and high (but limited) modeling data, there appears to be some degree of retention and connectivity to the Tangier system. The Manokin is assigned a *HIGH* based on high data scores and its position in the Tangier Sound system.
Big Annemessex River	The **Big Annemessex River** was scored as a low (2.03) for small tributary flushing time and does not have a shape that suggests higher retention. Historical spat sets were medium (78.1 spat/bu). The Big Annemessex has 7% of its area (low) estimated to be in the 90% accumulation zone. The Big Annemessex was assigned a *MEDIUM* because it had a medium data score (historical spat set) supported by low modeling scores.
Little Annemessex River	The **Little Annemessex River** was scored as a low (1.71) for small tributary flushing time and does not have a shape that suggests higher retention. Historical spat sets were low (46.8 spat/bu). The Little Annemessex has 14% of its area (medium) estimated to be in the 90% accumulation zone. The Little Annemessex was assigned a *LOW* because it had a low data score (historical spat set) supported by low and medium modeling scores.
Patuxent River	The **Patuxent River** received a medium (67.2) self recruitment score for large tributaries. The upper and lower Patuxent River were each scored low (19 and 22.1, respectively) for self-recruitment of sub-basins. The upper and lower Patuxent had 0% (low) and 28% (high) of its area, respectively, estimated to be in the 90% accumulation zone. Historically, the upper and lower Patuxent had low spat sets. Hagy et al. (2000) report a residence time of 68 d for the Patuxent River. The lower portion of the Patuxent is assigned a high modeling score based on the 90% accumulation zone. The other larval transport indicators indicate low retention suggesting that the particles accumulating in the lower Patuxent may originate outside the Patuxent. Based on the larval transport modeling there is likely connectivity between the upper and lower segments of the Patuxent. The retention time determined by Hagy et al. (2000) suggests that the full Patuxent has a moderately high residence time compared with other large tributaries. The Patuxent River is assigned a *MEDIUM* based on the high modeling score supported by low data scores and additional medium and low modeling scores. For the same reason, the lower Patuxent was assigned a *MEDIUM* rating. The upper Patuxent was assigned a *LOW* rating based on low modeling scores.

Mainstem-Upper	The **Upper Mainstem** received a high (84.7) self recruitment score for large tributaries, but a low (24.3) for the self-recruitment of sub-basins. The Upper Mainstem had 18% of its area (medium) estimated to be in the 90% accumulation zone. Historically, the Upper Mainstem had low (23.9 spat/bu) spat sets. The modeling that estimated the self-recruitment score of large tributaries evaluated the entire Maryland mainstem as one segment. Therefore, it is likely that the high self-recruitment score for large tributaries is due mainly to the large size of this segment, is not indicative of retentive properties, and is therefore not given strong influence in determining the hydrodynamic rating. The Upper Mainstem is assigned a *LOW* hydrodynamic rating because of a low data score supported by medium and low modeling scores.
Mainstem-Middle West	The **Middle West Mainstem** received a high (84.7) self recruitment score for large tributaries, but a low (21.4) for the self-recruitment of sub-basins. The Middle West Mainstem had 29% of its area (high) estimated to be in the 90% accumulation zone. Historically, the Middle West Mainstem had low (7.7 spat/bu) spat sets. The modeling that estimated the self-recruitment score of large tributaries evaluated the entire Maryland mainstem as one segment. It is likely that the high self-recruitment score for large tributaries is due mainly to the large size of this segment, is not indicative of retentive properties, and is therefore not given strong influence in determining the hydrodynamic rating. The middle west mainstem is assigned a *MEDIUM* hydrodynamic rating because of a low data score supported by high and low modeling scores.
Mainstem-Middle East	The **Middle East Mainstem** received a high (84.7) self recruitment score for large tributaries, but a low (29.4) for the self-recruitment of sub-basins. The Middle East Mainstem had 17% of its area (medium) estimated to be in the 90% accumulation zone. Historically, the Middle East Mainstem had medium (92.3 spat/bu) spat sets. The Middle East Mainstem contains one best bar. The modeling that estimated the self-recruitment score of large tributaries evaluated the entire Maryland mainstem as one segment. It is likely that the high self-recruitment score for large tributaries is due mainly to the large size of this segment, is not indicative of retentive properties, and is therefore not given strong influence in determining the hydrodynamic rating. The Middle East Mainstem is assigned a *MEDIUM* hydrodynamic rating because of a medium data score and one best bar supported by medium and low modeling scores. The presence of the best bar might have led to a high score if evaluating the same scores in a tributary, but due to the openness and size of the mainstem segments and location of the best bar at the mouth of Eastern Bay, a medium rating is assigned.
Mainstem-Lower West	The **Lower West Mainstem** received a high (84.7) self recruitment score for large tributaries, but a low (11.4) for the self-recruitment of sub-basins. The Lower West Mainstem had 20% of its area (high) estimated to be in the 90% accumulation zone. Historically, the upper mainstem had low (40.4 spat/bu) spat sets. The modeling that estimated the self-recruitment score of large tributaries evaluated the entire Maryland mainstem as one segment. It is likely that the high self-recruitment score for large tributaries is due mainly to the large size of this segment, is not indicative of retentive properties, and is therefore not given strong influence in determining the hydrodynamic rating. The Lower West Mainstem contains one best bar. The Lower West Mainstem is assigned a *MEDIUM* hydrodynamic rating because of a low data score supported by high and low modeling scores. The presence of the best bar would have led to a high score if evaluating the same scores in a tributary, but due to the openness and size of the mainstem segments and location of the best bar at the mouth of the Potomac, a medium rating is assigned.
Mainstem-Lower East	The **Lower East Mainstem** received a high (84.7) self recruitment score for large tributaries, but a low (35.1) for the self-recruitment of sub-basins. The Lower East Mainstem had 8% of its area (low) estimated to be in the 90% accumulation zone. Historically, the Lower East Mainstem had high (209.3 spat/bu) spat sets. The modeling that estimated the self-recruitment score of large tributaries evaluated the entire Maryland mainstem as one segment. It is likely that the high self-recruitment score for large tributaries is due mainly to the large size of this segment, is not indicative of retentive properties, and is therefore not given strong influence in determining the hydrodynamic rating. The Lower East Mainstem is assigned a *MEDIUM* hydrodynamic rating because of a high data score (historical spat set) supported by low modeling scores and the openness and size of the segment.

VIRGINIA	
Mainstem-Virginia	The **Virginia Mainstem** received a medium (72.7) self recruitment score for large tributaries, but a low (5.4) for the self-recruitment of sub-basins. The Virginia Mainstem had 6% of its area (low) estimated to be in the 90% accumulation zone. The Virginia Mainstem is assigned a *LOW* due to low and medium modeling scores.
Little Wicomico River	The **Little Wicomico** was scored as a low (2.87) for small tributary flushing time, but does have a shape (narrow and long with many branches) that suggests higher retention. The Little Wicomico had 1% of its area (low) estimated to be in the 90% accumulation zone. The Little Wicomico River was assigned a *LOW* hydrodynamic rating based on low modeling scores.
Cockrell Creek	**Cockrell Creek** received a medium small tributary flushing time score (4.05), and does have a shape (narrow, long, and branched) that suggests higher retention. Cockrell Creek had no area designated within the 90% accumulation zone. Cockrell Creek was assigned a *LOW* hydrodynamic rating based on low and medium modeling scores that had no further supporting data.
Great Wicomico River	The **Great Wicomico River** received a low (12.1) score for the self-recruitment of sub-basins. The Great Wicomico had a high (5.56) small tributary flushing time score with a shape that appears to promote retention (narrow and branched). The Great Wicomico had 10% of its area (medium) estimated to be in the 90% accumulation zone. The flushing time rating suggests retentive properties. The Virginia Oyster Atlas identifies the Great Wicomico as having trap estuary properties (VIMS 2002). The larval transport modeling results suggest that little is retained within the system to settle, however, restoration efforts by USACE-Norfolk have demonstrated retention and suitability of the area for oysters (Schulte et al. 2010). The Great Wicomico River is assigned a *HIGH* hydrodynamic rating based on current restoration activities and documented retention (Schulte et al., 2010; VIMS, 2002) combined with a high modeling score.
Rappahannock River	The **Rappahannock River** received a high (92.1) self recruitment score for large tributaries. The self-recruitment of sub-basins scores for the upper, middle, and lower segments were high (68.7), medium (49.2), and low (34.3), respectively. The Rappahannock had 32% of the upper area (high), 40% of the middle area (high), and 35% of the lower area (high) estimated to be in the 90% accumulation zone. Shen and Wang (2007) estimated that of the four major Virginia tributaries (others are Potomac, York, and James), the Rappahannock had the greatest age of water (approximately 110-193 days depending on discharge). Based on larval transport modeling the greatest retention appears to be in the upper segment of the Rappahannock. The Rappahannock is assigned a *HIGH* hydrodynamic rating based on multiple high modeling scores and the results of the investigation by Shen and Wang (2007). The individual sub-segments were each assigned a *HIGH* rating for the same reasons. The available information suggests that the greatest retention exists in the upper Rappahannock and the least in the lower.
Corrotoman River	The **Corrotoman River** had a high (5.3) small tributary flushing time score with a shape that appears to promote retention (narrow and branched). The Corrotoman had 5% of its area (low) estimated to be in the 90% accumulation zone. The Virginia Oyster Atlas identified the Corrotoman as having significant historical spat sets (VIMS 2002). The Corrotoman River is assigned a *HIGH* hydrodynamic rating based on a high historical spat set, geomorphology that appears to promote retention, and high and low modeling score.
Piankatank River	The **Piankatank River** received a medium (69.4) self recruitment score for large tributaries, a medium score (40.6) for the self-recruitment of sub-basins, and a high (5.62) small tributary flushing time score. The shape of the Piankatank (long and narrow, with a tight bend near the mouth) would promote retention. The Piankatank had 16% of its area (medium) estimated to be in the 90% accumulation zone. Historically, the Piankatank River was one of two primary seed producing areas in Virginia. The Piankatank historically supported a very productive reef system (VIMS 2002; Bartol et al. 1999). The Virginia Oyster Atlas identified the Piankatank as a trap type estuary. The Piankatank River is assigned a *HIGH* hydrodynamic rating based on its historical productivity, documented trap estuary properties, and high and medium modeling scores.
Mobjack Bay	**Mobjack Bay** received a high (92.3) self recruitment score for large tributaries, a medium score (45.4) for the self-recruitment of sub-basins, and a medium (3.73) small tributary flushing time score. The shape of Mobjack Bay is forked but wide, suggesting that the shape may be limited in enhancing retention. Mobjack Bay had 14% of its area (medium) estimated to be in the 90% accumulation zone. Larval transport modeling shows that nearly all of the settled particles stay within Mobjack Bay, but only about half of them settle successfully. Mobjack Bay is assigned a *HIGH* hydrodynamic rating based on high and medium modeling scores.

Severn River	The **Severn River** received a low (2.34) small tributary flushing time score, but does have a shape (narrow and forked with many branches) that suggests higher retention. The Severn River had 9% of its area (low) estimated to be in the 90% accumulation zone. The Severn River was assigned a *LOW* hydrodynamic rating based on low modeling scores.
York River	The **York River** received a high (93.7) self recruitment score for large tributaries. The upper and lower York sub-segments were scored as a high (81.3) and low (18), respectively for the self-recruitment of sub-basins. The York had 38% of the upper area (high) and 17% of the lower area (medium) estimated to be in the 90% accumulation zone. Shen and Hass (2004) estimated a residence time of 100 d. Shen and Wang (2007) determined an age of water ranging from 21 to 136 days depending on discharge. This age of water was less than that of the Rappahannock and Potomac, but greater than the age of water for the James River. Larval transport modeling suggests high retention in the upper York. The lower York does not appear to be as retentive. The York River is assigned a *HIGH* hydrodynamic rating based on high modeling scores and the analyses by Shen and Wang (2007) and Shen and Haas (2004). The upper York also has indicators to justify a *HIGH* rating. The lower York River has low and medium modeling scores. However, when considered with the indicators for the full York River, retention in the lower York is not clear. The lower York, therefore, maintained the *HIGH* designation assigned the full York River. It is highly recommended that larval transport, retention, and circulation should be further investigated in the York River to better understand how the two sub-segments interact prior to large scale restoration. Restoration actions should only be undertaken if future investigations confirm the high retention in the lower York.
Poquoson River	The **Poquoson River** received a low small tributary flushing time score (1.61), and does have a shape (narrow, forked, and branched) that suggests higher retention. The Poquoson River had 3% of its area designated within the 90% accumulation zone. Cockrell Creek was assigned a *LOW* hydrodynamic rating based on low modeling scores.
Back River	The **Back River** received a low small tributary flushing time score (1.23), and does have a shape (forked, and branched) that suggests higher retention. The Poquoson River had 1% of its area designated within the 90% accumulation zone. The Poquoson River was assigned a *LOW* hydrodynamic rating based on low modeling scores.
Pocomoke/Tangier Sound	The **Pocomoke/Tangier Sound** was assigned a high (68.7) self-recruitment of sub-basins score. Pocomoke/Tangier Sound had 15% (medium) of its area designated within the 90% accumulation zone. Historically, the area held abundant oyster resources. The Pocomoke River contains one prime bar as identified by Kimmel et al. (in review). Pocomoke/Tangier Sound was assigned a *HIGH* hydrodynamic rating based on the high and medium modeling results supported by the work of Kimmel et al. (in review).
Onancock Creek	**Onancock Creek** received a low small tributary flushing time score (1.56), and does have a shape (narrow and branched) that suggests higher retention. Onancock Creek had no area designated within the 90% accumulation zone. Onancock Creek was assigned a *LOW* hydrodynamic rating based on low modeling scores.
Puncateague Creek	**Puncoteague Creek** received a low small tributary flushing time score (1.33), and does have a shape (narrow and forked) that suggests higher retention. Puncoteague Creek had no area designated within the 90% accumulation zone. Puncoteague Creek was assigned a *LOW* hydrodynamic rating based on low modeling scores.
Nandua Creek	**Nandua Creek** received a low small tributary flushing time score (1.4). The shape of Nandua Creek (wider at the mouth) does not suggest a retentive system. Nandua Creek had no area designated within the 90% accumulation zone. Nandua Creek was assigned a *LOW* hydrodynamic rating based on low modeling scores.
Occohannock Creek	**Occohannock Creek** received a low small tributary flushing time score (1.44), and does have a shape (narrow) that suggests higher retention. Occohannock Creek had no area designated within the 90% accumulation zone. Occohannock Creek was assigned a *LOW* hydrodynamic rating based on low modeling scores.
Nassawaddox Creek	**Nassawaddox Creek** received a low small tributary flushing time score (1.07), and does have a shape (narrow and branched) that suggests higher retention. Nassawaddox Creek had no area designated within the 90% accumulation zone. Nassawaddox Creek was assigned a *LOW* hydrodynamic rating based on low modeling scores.

Hungars Creek	**Hungars Creek** received a low small tributary flushing time score (0.87). It is unclear whether the shape of Hungars Creek would promote retention (mouth appears restricted, but mainstem wider). Hungars Creek had no area designated within the 90% accumulation zone. Hungars Creek was assigned a *LOW* hydrodynamic rating based on low modeling scores.
Cherrystone Inlet	**Cherrystone Inlet** received a low small tributary flushing time score (1.03). The shape of Cherrystone Inlet (wide) does not suggest a retentive system. Cherrystone Inlet had no area designated within the 90% accumulation zone. Cherrystone Inlet was assigned a *LOW* hydrodynamic rating based on low modeling scores.
Old Plantation Creek	**Old Plantation Creek** received a low small tributary flushing time score (0.57). It is unclear whether the shape of Old Plantation Creek would promote higher retention. Old Plantation Creek had no area designated within the 90% accumulation zone. Old Plantation Creek was assigned a *LOW* hydrodynamic rating based on low modeling scores.
James River	The **James River** received a high (98.4) self recruitment score for large tributaries. The upper and lower James were scored as a medium (47.8 and 49.7, respectively) for the self-recruitment of sub-basins. The James had 34% of the upper area (high) and 35% of the lower area (high) estimated to be in the 90% accumulation zone. The abundant resources of the James River, particularly the lower portion, have long been recognized. Along with the Piankatank, the James River is one of two primary seed producing areas in Virginia. The Craney Island investigation by Boon et al. (2001) documents retention between the upper and lower James segments. Shen and Lin (2006) estimated a residence time of 95 days in the James River. Shen and Wang (2007) calculated the age of water in the James between 50 and 108 days depending on discharge. Of the four major Virginia rivers investigated, this was the shortest age (Rappahannock>Potomac>York>James). The James River is assigned a *HIGH* hydrodynamic rating based on historical information, documented retention, and high and medium modeling scores. Subsequently, the lower and upper sub-segments were both assigned *HIGH* ratings for the same reasons.
Elizabeth River	The **Elizabeth River** received a medium (4.98) small tributary flushing time score, narrowly missing the 5 cut-off to qualify for a high rating. The shape of the Elizabeth River (narrow and forked) appears to promote retention and supports the argument that the Elizabeth has higher retentive properties than evident from a medium flushing time score. The Elizabeth River had 2% of its area (low) designated within the 90% accumulation zone. No historical spat data was available. The Elizabeth has been closed to shellfish harvesting because due to pollution and bacteria since the mid-1900s. Current anecdotal accounts suggest oysters are present and setting on available hard substrates. The Elizabeth River was assigned a *HIGH* hydrodynamic rating based on its geometry and its flushing time score, combined with current spat set information.
Nansemond River	The **Nansemond River** received a low (1.54) small tributary flushing time score. The shape of the Nansemond (narrow) appears to promote retention. The Nansemond River had 14% of its area (medium) designated within the 90% accumulation zone. The Nansemond River was assigned a *LOW* hydrodynamic rating based on medium and low modeling scores that had no further supporting data.
Lynnhaven Bay	**Lynnhaven Bay** received a low (0.71) small tributary flushing time score, but the shape of Lynnhaven Bay (forked and branched) suggests higher retention. Lynnhaven Bay had no area (low) designated within the 90% accumulation zone. Lipcius et al. (2008) documented the hydrodynamics of Lynnhaven Bay and identified source and sink areas of larval transport. Lynnhaven Bay historically had abundant oyster resources. Although Lynnhaven Bay received low modeling scores, it is assigned a *HIGH* hydrodynamic rating due to its historical oyster resources and the work of Lipcius et al. (2008).

Attachment 1-B: Historic Maryland Spatfall Data

Data from Krantz and Meritt (1977)

	Spat/bushel			Rank	
Region	**1939-1965**	**1966-1975**	**% Decline Since 1965**	**1939-1965**	**1966-1975**
Big Annemessex	78.1	9	88	18	34
Broad Creek	160.5	50.9	68	9	8
Fishing Bay	55.9	18.7	67	27	26
Harris Creek	203.6	37.3	82	6	13
Honga	166.9	56.1	66	8	7
Little Annemessex	35	4.5	87	37	44
Little Choptank	136.8	23.7	83	12	21
Lower Chester	12.4	3.3	73	49	49
Tred Avon	42.2	7	83	33	39
Lower Choptank	68.3	20.9	69	22	24
Middle Choptank	35.6	23.7	83	36	22
Lower Patuxent	20.7	18	23	41	27
Middle Patuxent	16.6	14.3	14	45	28
Lower Potomac	71.1	33	54	21	18
Smith Creek	141.5	42	70	10	10
Middle Tangier Sound	48.5	31.3	34	30	19
Lower Tangier Sound	46.8	12.6	73	31	30
Magothy	No Data	0	No Data	55	55
Lower Bay East	179.6	0	100	7	54
Holland Straits	223.8	48.6	78	4	9
Kedges Straits	315.4	71.9	77	1	1
Tar Bay	118.3	4	97	13	46
Lower Calvert Shore	44.8	9	80	32	35
St. Mary's Shore	36	33.8	6	35	17
Talbot Shore	66	35	47	23	15
Poplar Is. Narrows	38.4	20.7	46	34	25
Trippes Bay	53.5	3.5	93	28	48
Dorchester Shore	250.6	59.1	76	3	4
Lower Anne Arundel Shore	6	2.7	55	52	51
Upper Anne Arundel Shore	4.7	4.8	2	53	43
Upper Calvert Shore	12.3	10.3	16	50	32
Upper Bay East	15.4	9.8	36	46	33
Upper Bay West	3.1	7.2	232	54	38
Kent Shore	53.1	5.6	89	29	42
Manokin	108.8	21.1	81	14	23

	Spat/bushel			Rank	
Region	**1939-1965**	**1966-1975**	**% Decline Since 1965**	**1939-1965**	**1966-1975**
Middle Potomac	14.2	2.8	80	47	50
St. Clements-Breton Bays	30.1	2.4	92	39	52
Wicomico (Potomac)	63.7	63.4	1	25	2
Pocomoke Sound	71.5	10.8	85	20	31
Severn	16.9	3.7	78	44	47
South-Rhode	19.9	8.3	58	42	37
Lower St. Mary's	95.7	37.6	61	17	12
St. Georges Creek	63.9	34.7	46	24	16
Upper St. Mary's	292.4	57	81	2	6
Eastern Bay South	106	39	63	15	11
Eastern Bay North	138.8	60.3	57	11	3
Miles	96	26.1	73	16	20
Upper Chester	13.4	4.4	67	48	45
Upper Choptank	26.8	6	78	40	41
Upper Patuxent	18.2	6.5	64	43	40
Upper Potomac	8.2	0.6	93	51	53
Hooper Straits	218.6	58.2	73	5	5
Upper Tangier Sound	74.9	8.3	89	19	36
Nanticoke-Wicomico	33.3	13.6	59	38	29
Wye	56.2	35.4	37	26	14

Attachment 1-C: Historic Spatfall Data – Virginia

Analysis of Annual Oyster Spatfall in the Tributaries of Chesapeake Bay, VA- and Virginia Spatfall Records from 1947-2009- Russell Burke (2010)

FINAL REPORT

Analysis of Annual Oyster Spatfall in the Tributaries of Chesapeake Bay, Virginia

Russell P. Burke, Ph.D.

Virginia Institute of Marine Science
The College of William & Mary

Funded under a contract to:

Romuald N. Lipcius, Ph.D.
(Principal Investigator)

Virginia Institute of Marine Science
The College of William & Mary

from:

U.S. Army Corps of Engineers, Norfolk District

3 December 2010

INTRODUCTION

Oyster reefs in most ecoregions where they historically occurred are in poor condition and at risk of extirpation as functional ecosystems (Kirby 2004, Lotze et al. 2006, Airoldi and Beck 2007, Coen and Grizzle 2007, Beck et al. 2009). The Chesapeake Bay's oyster (*Crassostrea virginica*) population decline is amongst the most dramatic globally at less than 1% of its historic abundance. The United States Army Corps of Engineers (USACE) has risen to the challenge of large-scale ecological oyster restoration in Chesapeake Bay as part of their Master Oyster Plan. In Virginia, the Norfolk District (NAO) transitioned the federal oyster restoration program from repletion-dominant activities and token sanctuary construction to large-scale sanctuary shell reef production in the Great Wicomico River – GWR (Schulte 2003) and the Lynnhaven River System – LRS (Schulte et al. 2006). This transition was supported by independent (Baker et al. 1977, Haven et al. 1978, Herberich 2006, Oyster Advisory Commission 2008, Santopietro et al. 2009) and in-house (NAO *unpublished report*) economic analyses of harvest grounds, relative to the federal benefit-to-cost standard of 1:1 (3:1 preferred) for fifty years post-construction; each analysis supports the conclusion that the harvest/managed ground construction strategy is not in the federal (or state's – VA and MD) interest. Thus, ecological restoration was adopted as the sole oyster restoration strategy by the USACE and the National Oceanic and Atmospheric Administration (NOAA) – a fact confirmed in the Virginia Oyster Restoration Review Workshop in Williamsburg, VA (31 March 2010).

Since their construction, the GWR and LRS sanctuary oyster reef projects have shown encouraging signs of sustainability. The GWR reefs were constructed in late 2004 and subsequently recruited millions of oysters that have grown into a thriving, complex metapopulation (Schulte et al. 2009). The LRS reefs were constructed in late 2007 and 2008. Observations with oyster hand tongs and underwater videography conducted with a remotely-operated vehicle (ROV) confirm the persistence of the LRS reefs with the presence of multiple oyster age classes, including large (>5 inches in shell height) oysters that have grown out from spat-on-shell plantings coordinated by the USACE, the City of Virginia Beach, and the Virginia Marine Resources Commission (Linkhorn Bay in 2007 and 2008). The collaborative nature of the LRS project – large-scale restoration in a highly-urbanized watershed – garnered the attention of the administration of President Barack H. Obama. On 14 January 2010, team members were presented the 2009 Coastal America Award – the only White House award for Ecology. This award followed two other major Chesapeake Bay oyster-related milestones:

1) President Obama released Executive Order 13508, Chesapeake Bay Protection and Restoration (12 May 2009), declaring Chesapeake Bay a "national treasure" and calling for:

> "a renewed commitment to controlling pollution from all sources as well as protecting and restoring habitat and living resources, conserving lands, and improving management of natural resources, all of which contribute to improved water quality and environmental Health. The Federal Government ***should*** lead this effort."

2) The release of the Final Programmatic Environmental Impact Statement for Oyster Restoration in Chesapeake Bay (USACE 2009) which concluded that the introduction of a non-native oyster to Chesapeake Bay waters was NOT a viable Bay recovery strategy. Instead, Alternative 8a was selected:

> “a combination of alternatives that involves only the native Eastern oyster, is the preferred approach for restoring the Chesapeake Bay oyster population.”

The release of these two landmark decisions, which both acknowledged the GWR and LRS projects as the best examples of large-scale oyster restoration success in Chesapeake Bay, stimulated the USACE to move forward with their Master Oyster Plan. As part of this plan, “Tier 1 Tributaries” have been identified as the top candidate VA sub-estuaries in which federal oyster restoration projects will be considered. This list includes the Great Wicomico, James, Lynnhaven, Piankatank, Rappahannock, and York Rivers, as well as Mobjack Bay and Tangier/Pocomoke Sound. In order to estimate the scale and extent of restoration possible in any one tributary, it is critical to understand how oyster recruitment has historically been influenced by: oyster broodstock, availability of quality habitat/substrate (Smith et al. 2005), short- (annual) and long-term (decadal oscillations) weather patterns (temperature, rainfall, etc.), hydrodynamic retentiveness, overharvesting (Table 1), disease, etc. This report addresses these influences on historic and modern VA sub-estuary oyster populations, and includes information collected from peer-reviewed literature, grey literature, unpublished reports (Virginia Institute of Marine Science –VIMS – archives), and other, recently-collected unpublished data. The primary goal of this report is to inform federal oyster restoration implementation plans prior to formulation and subsequent construction within any given Virginia sub-estuary.

The time and energy invested in preparing this report as a “historical reconstruction” of Virginia’s oyster reefs was committed, in part, to avoid federal and state managers from falling victim to “shifting baseline syndrome.” The shifting baseline, in this case, would be considering the period immediately preceding MSX and Dermo outbreaks consisted of natural oyster populations existing in a „natural state’ and that harvests of that pre-disease period were sustainable. We offer the following excerpts (circa 1930) that explain, in detail, that state of public rocks in all of Virginia’s Tier 1 Tributaries as „depleted’ or „practically exhausted’ and hope the remainder of this report be evaluated with these statements in mind.

The State of Virginia’s Oyster Stocks, Ca 1930

The following excerpts were taken from the 33rd Annual Report of the Commission of Fisheries of Virginia, June 30, 1931:

> “According to the United States Bureau of Fisheries, the average annual production of marketable oysters from all sources from 1901 to 1912, inclusive, was 6,240,264 bushels. According to the same authority the production of marketable oysters in the year 1929 from the public rocks of the State [Virginia] was 838,219 bushels, and from private grounds 1,556,421 bushels, a total of 2,395,340 bushels. A comparison of the above statistics clearly shows that the quantity of oysters coming from the public rocks has shown a marked decrease and the greater part of the supply of marketable oysters are, at this time produced on leased grounds.

Table 1. Effects of overharvesting on oyster populations and reefs (Hargis and Haven 1998).

MARKET OYSTERS[1] (With culling: No culling exacerbates damaging effects)	SEED OYSTERS[1] (No culling)	OYSTER SHELLS[2]
Removes larger, older mature oysters, reducing Broodstock and overall fecundity and lowering recruitment.	Removes young, leaving fewer to grow to adulthood and breeding or market size. Lowers fecundity.	Removal of oyster shells from reefs reduces self-renewing capacity of reefs. It also reduces shell surface available for spatfall.
Often kills attached spat	Removes attached spat	Removes attached spat.
Reduces overall population	Removes attached market oysters.	Eventually reduces number of living oysters the reef can support.
Probably alters sex ratios of remaining populations toward younger, smaller males by "selective" removal of larger, older females	Reduces overall population.	Reduces reefs in height, extent, volume and surface area – damaging or destroying habitat.
Removes faster-growing, surviving individuals thus reducing genetic quality of surviving populations	Removes shell. Also, reduces shell replacement ability of reef.	Diminution of reefs puts remaining shells and surviving and future oysters closer to bottom, thus increasing stress, availability to predators and chances of damage to remaining living oysters and of reef, itself, by siltation and sanding.
Setting is better on reefs with living oysters. Reduction of living oysters can, therefore, reduce spatfall.	Reduces reefs in height, extent, volume and surface area damaging or destroying habitat.	
Reduces reefs in height, extent, volume and surface area, damaging habitat	Reduces filtering capacity of reef population and altering filtration-associated ecological effects.	Reduced reef's attractiveness of reef finfish and its carrying capacity for same.
Removes larger shell-producing adults, damaging self-maintenance ability of entire reef.	Reduces reef's attractiveness to finfish, and their carrying capacity for same.	Continued removal allows depleted reefs to silt over.
Reduces filtering capacity of reef population thereby reducing filtration-associated ecological effects.		
Reduces reef's attractiveness to finfish and their carrying capacity for same.		

[1] Harvesters avoid culling whenever possible. They also avoid culling in areas being harvested to reduce chances of relifting same shells and other rejecta. In either case, reef being harvested is reduced. Reduction of reefs alters biogeophysical properties of reefs and fields.

[2] Though purposeful, removal of shells, themselves, for use in road building, lime production and poultry grit, once commonplace, is no longer officially permitted, shells continue to be removed by harvesting of mature and seed oysters, and shell replacement capabilities of oyster beds are reduced.

The decline in the production of oysters from the natural rocks may be attributed to two principal causes: first, natural depletion, due to the constant tonging without adequate rest and any replenishment of shells which are necessary for the natural propagation of oysters, and second, to the natural enemy of young oyster commonly called the borer, or drill. Comparing the present productiveness of the natural oyster rocks of the State with that of even a few years ago, all of them may be said to be depleted. In order, however, to be more specific in describing their present condition, we will refer to those areas in which there are sufficient quantities of shells to serve as cultch for self-rehabilitation as "barren"; and to those which still produce a sufficient quantity of marketable oysters every year to afford the tonger a reasonable daily wage, as "productive."

A survey of the natural oyster rocks on the ocean side of Accomac and Northampton Counties shows that thousands of acres of oyster bottoms, as defined by the Baylor Survey, have become entirely barren. On the bay side of the above named counties the only natural rocks which can be called productive are a few of those lying in Pocomoke Sound. The natural rocks in Virginia tributaries of the Potomac, including the Yeocomico and Coan Rivers, have become depleted to such an extent that, with a few exceptions, they may be said to be now practically exhausted. The same conditions prevail in the Great Wicomico and York Rivers, in Mobjack Bay and its tributaries, and to a modified extent in the James River below the seed line. Some of the rocks in the Rappahannock and Piankatank Rivers are still comparatively productive, but many of the rocks in these rivers have either become much smaller in area or are now totally barren. These conditions easily explain the falling off in the production from the natural rocks.

The principal cause of depletion is, however, due to the gradual wearing away of the rocks from the constant fishing of them which has been going on for many years. This condition is not due entirely to the removal of shells and young oysters from the rocks by the tongers, but is mainly due to the fact that, in the process of culling, the shells are eventually broken into small particles which sink into the mud or are covered with silt washed down from the head waters of our tidal streams. The natural rocks were formed by nature through the centuries by the process of spawn attaching to the shells of oysters which had died. With the disappearance of the shells, either by removal or the other causes mentioned, there is nothing left for the oyster spawn to adhere to. It is manifest from what has been said that the question to be determined by the State is whether it will undertake a constructive repletion program by the planting of shells or seed oysters, or both, on the natural rocks, or whether it will continue the policy pursued in the past."

Repletion Program Initiated to Replenish Virginia's Oyster Stocks, Ca 1930

The following excerpts were taken from the 33rd Annual Report of the Commission of Fisheries of Virginia, June 30, 1931:

"The last session of the General Assembly appropriated on-half of the tonging licenses, and also the revenues derived from the two-cent bushel tax, after $25,000.00 thereof had been deducted for the use of the State Board of Health, to be set up as a fund for repletion of the natural oyster beds of the State. While the experiments being conducted under the supervision of the marine biologist and the planting of oysters and shells in various sections, as above noted, will be of great value in furnishing information as to what can be done, the Commission is of the opinion that unless further funds are provided to carry out a repletion program, as based upon information gained by the studies and experimental work which is now being undertaken, it will be of no practical benefit to further proceed with the repletion program which has been inaugurated by the Legislature and is now being conducted by the Commission. In this connection, attention might be called to what is being done by our sister State, Maryland, in repleting the natural oyster rocks of that State. During the past two seasons Maryland has planted on natural oyster rocks approximately 900,000 bushels of shells each year. The policy of that state is to plant shells only on live and productive oyster bottoms. After a careful study and consideration of this policy, this Commission is convinced that it is the only practical repletion plan to pursue.

The planting of shells on barren grounds, and then closing the areas on which they are planted until there is a sufficient catch of oysters of marketable size, as the statute now provides, will not, in the opinion of the Commission, produce satisfactory results for the reasons, that there is frequently a failure to obtain a catch of young oysters on such grounds, and when they are once thrown open to the public the repleted areas soon become as barren as they were before the shells were planted. Furthermore, the cost of restoring the natural rocks on barren bottoms in Virginia would be too great to be considered. On the other hand with shells planted on the live, productive rocks, and the cull law enforced, there is not only a better chance to obtain a catch of young oysters on the shells year by year, but they would afford a continual means of production.

In the report of the Commission appointed by Governor Byrd, commonly known as "The Spratley Commission," submitted to the General Assembly in January, 1928, it is well said:

> „If the State permits, year after year, the matured oyster and the seed oyster to be taken from the bottoms, and does not require even shells to be thrown back, depletion is naturally to be expected on the public rock. No seed oysters are being planted; no shells are being thrown back; except in culling to supply a cultch, or fastener, for the oyster to catch on or for additional lime to feed the growing oyster. In addition to selling the seed oyster to the planters in and out of Virginia, the shells have been used for road-building purposes; ground up for poultry food, for agricultural lime; many have been sold to an adjoining state where they are being replanted on depleted rocks.'

While private planting should unquestionably be encouraged, in the opinion of the Commission, the State should adopt a policy to increase the production of oysters from the public rocks by a repletion program such as outlined above in order to increase the oyster supply from both sources and thereby rehabilitate the entire industry."

Given the historic context provided by these excerpts, it is clear that specific questions need to be addressed including (Newell and Barber 1990):

1) What are the historic trends in relative abundances of market oysters?
2) How do these trends compare with landings?
3) What are the historic trends in spatfall?
4) Is there any correlation between spatfall and subsequent market harvest?
5) Is there any correlation between "yearling" abundance and subsequent market harvest?
6) Is there any correlation between spatfall on collectors and spatfall on bottom?

A number of these questions were addressed, in detail, nearly 15 years ago by Austin et al. (1993, 1996) for the James, Rappahannock and York Rivers, and more recently for the Great Wicomico and Piankatank Rivers (Southworth and Mann 2004). As part of this report, we have summarized those findings where appropriate. We then took the next step and used a combination of spatfall, shell/seed planting, and harvest (public/private) data to draw similar conclusions for all Virginia tributaries (Tier 1) of interest.

MATERIALS AND METHODS

Oyster spatfall data (See Digital Appendix with raw data) collected in Chesapeake Bay's tributaries (Fig. 1) as part of the VIMS Shellstring Survey (1946-Present) were sought through all possible means, including, but not limited to, a librarian-assisted search of all oyster spatfall reports held by the VIMS Hargis Library, the VIMS Molluscan Ecology Program website, a thorough search of DS Haven's archived records, and a direct request of spatfall data held (but not collected) by Dr. Roger Mann; that request was denied. Thus, gaps in data may be the result of: 1) lack of spatfall survey data for a given tributary, 2) inability to locate certain annual oyster spatfall reports (1974-1977), or 3) an unwillingness to remit publicly-owned data collected (1950s and 1960s) (Mann *pers comm*). However, the aforementioned review of relevant literature should neutralize any attempt to thwart the progress of ecological oyster restoration.

Oyster shellstrings (Fig. 2) were used to monitor oyster spatfall. A shellstring consists of twelve oyster shells of similar size (~3 inches in length) drilled through the center and strung on heavy gauge wire. Throughout the monitoring period, shellstrings were usually replaced after a one-week exposure and the number of spat that attached to the smooth underside of the middle ten shells was counted under a dissecting microscope. To obtain the mean number of spat per shell for the corresponding time interval, the total number of spat observed was divided by the number of shells examined. Although shellstring collectors at most stations were deployed for seven-day periods, there were some weather related deviations such that shellstring deployment periods ranged from 7 to 21 days. These periods did not always coincide among the different rivers and areas monitored. Therefore, spat counts for different deployment dates and periods were standardized to correspond to the 7-day periods; standardized weekly periods allow comparison of spatfall trends over the course of the season between the various stations in a river as well as between data for different years. The cumulative spatfall for each station was computed by adding the standardized weekly values of spat per shell for the entire season. This value represents the average number of spat that would fall on any given shell if allowed to remain at that station for the entire sampling season. Spat-per-shell values were categorized for comparison purposes as follows: 0.10-1.00, light; 1.01-10.00, moderate; and 10.01 or more, heavy (Southworth et al. 2009).

Note that spatfall estimates from a shellstring survey are more reliable than spat-per-bushel data gathered by sampling of public grounds or reefs – these grounds/reefs often contain substrate (shell) of variable quality, often with surfaces occluded or impaired which makes said substrate less attractive to oyster larvae. They may be silted over, fouled with tunicates, hydroids, or barnacles, or may be deteriorated by boring sponge or by years of slow dissolution. Thus, spatfall data from shellstring surveys (when available) are preferable to those collected via bottom surveys, typically conducted with dredges – devices that are qualitative, at best).

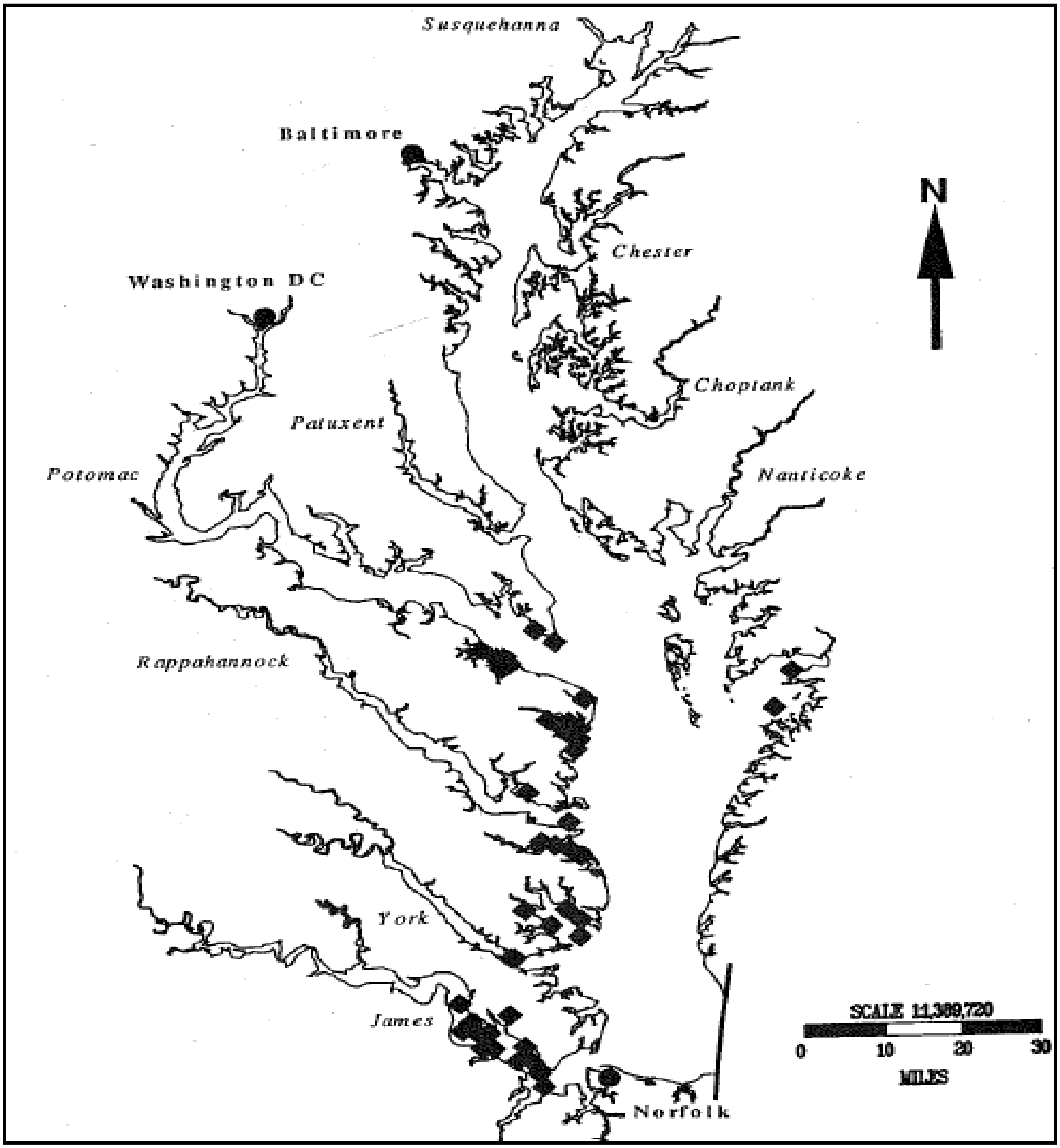


Figure 1. Map of shellstring survey stations in the tributaries of Chesapeake Bay, Virginia (Newell and Barber 1990).

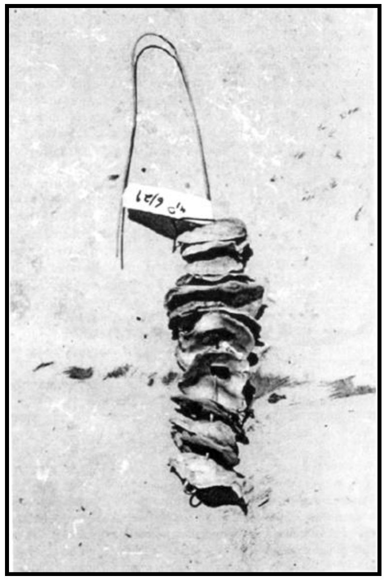


Figure 2: Picture of a typical shellstring used in the VIMS annual oyster spatfall survey, 1946 to present (Southworth and Mann 2004).

Oyster shell and seed planting records in Virginia's Bay tributaries (Fig. 3) were collected from the Annual Reports of the Marine Resources Commission (1931-1982) and from the official minutes of the Virginia Marine Resources Commission – VMRC, (1983-2010). Seed transplant records can assist in identifying reefs or regions of reliable oyster growout (priority broodstock areas – source reefs). Shell plant records can similarly identify areas of consistently high spatset (priority recruitment areas – sink reefs). Analysis of these and other related data helped produce the recommendations made in this report.

RESULTS AND DISCUSSION

Factors Influential in Oyster Population Recovery:

Case Study – Great Wicomico, James and Piankatank Rivers

Each Tier 1 Tributary was investigated using the annual spatfall, shell plant, and seed oyster transplant data for that system. However, we first noted the frequency and scale of recruitment, shell planting and seed oyster transplanting within three Virginia Bay tributaries that were well-known historically for their seed oyster production and grow-out to market size on leased grounds (Table 2) – the Great Wicomico, James, and Piankatank Rivers (Fig. 4). The James River was historically the world's largest seed-producing river system (Commission of Fisheries 1931) and has been closely monitored for more than 60 years (Mann et al. 2009). Oyster settlement in the Great Wicomico (337 km^2) and Piankatank (575 km^2) River watersheds and the health of their resident oyster populations has become increasingly important over the last 15 years, primarily due to increasing restoration efforts in these smaller systems (Southworth and Mann 2004). Both rivers have been termed trap-type estuaries by Andrews (1979) and are characterized by gyre-like circulation in their lower reaches. For these reasons, the modern annual spatfall survey (Mann and Morales-Alamo 1994, Morales-Alamo and Mann 1995-1998, Southworth et al. 1999-2009) still focuses on these three river systems.

Table 2. Virginia public seed production (Virginia Bushels), 1965-1981 (Commission of Fisheries 1982).

Season	Great Wicomico River	James River	Piankatank River
1965-66	232,739	611,167	99,275
1966-67	146,103	532,569	60,090
1967-68	88,513	483,690	71,704
1968-69	50,776	486,536	3,848
1969-70	98,380	264,203	3,581
1970-71	212,953	458,637	27,024
1971-72	70,765	381,250	40,113
1972-73	--	396,169	--
1973-74	--	372,537	102,236
1974-75	8,310	317,003	34,269
1975-76	9,585	446,121	53,123
1976-77	--	420,403	16,708
1977-78	--	350,418	30,625
1978-79	--	419,465	13,336
1979-80	--	310,062	--
1980-81	--	201,992	--

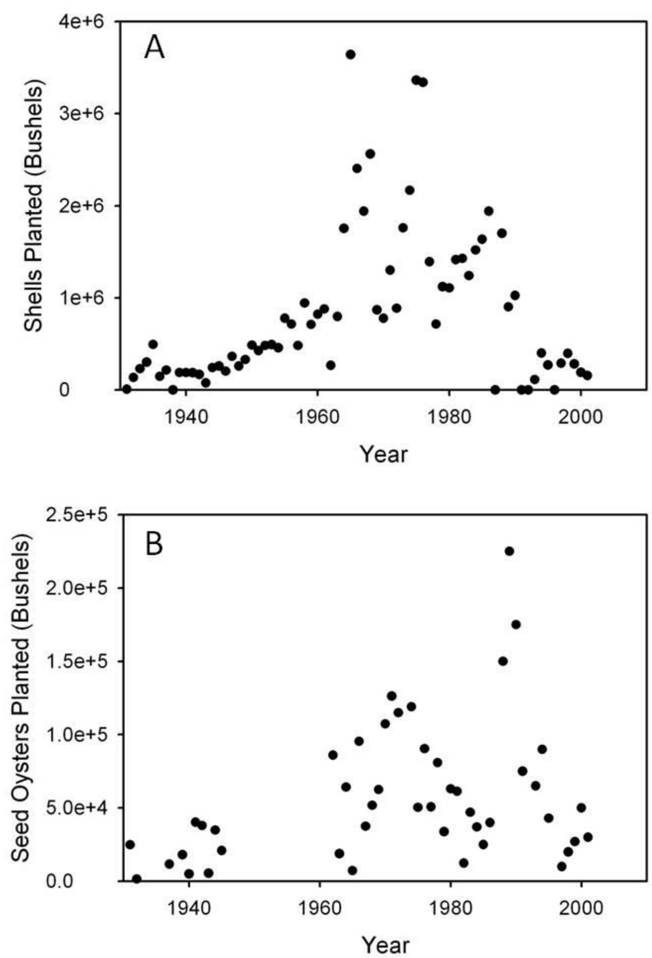
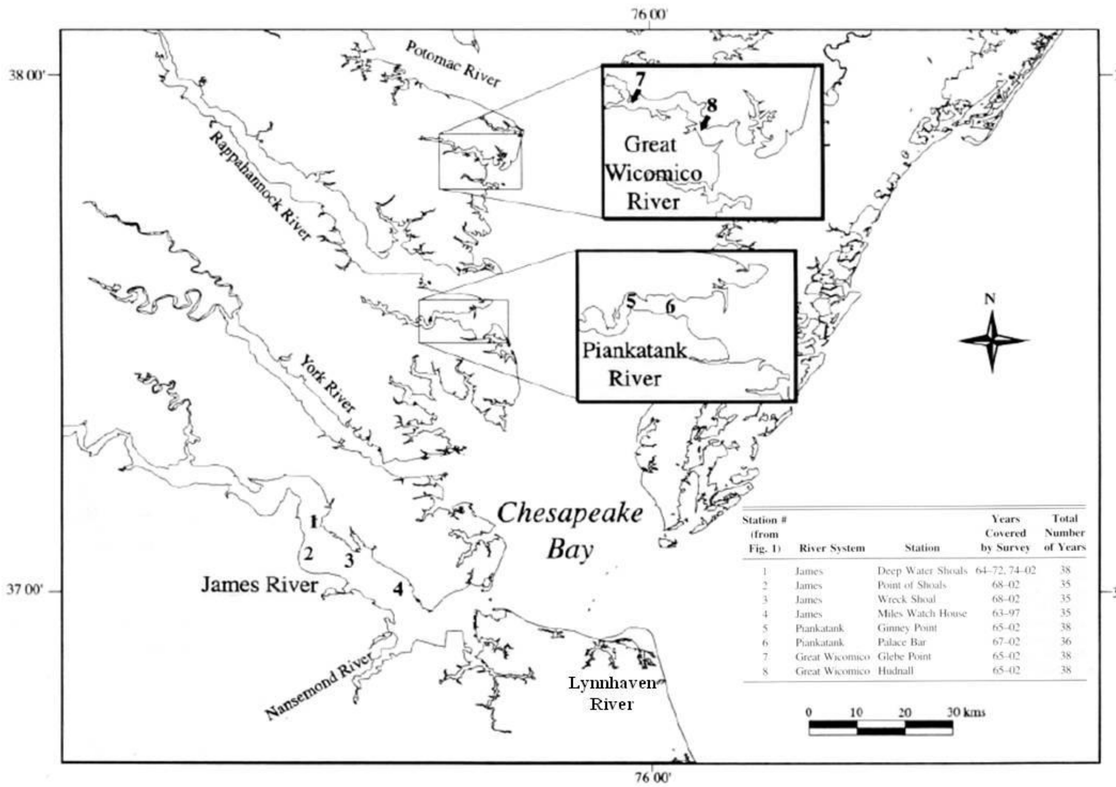


Figure 3. Virginia totals (1931-2009) for (A) oyster shells planted, and (B) seed oysters transplanted (Data Sources: Commission of Fisheries 1931-1982; VMRC Official Minutes, 1983-2009).



Station # (from Fig. 1)	River System	Station	Years Covered by Survey	Total Number of Years
1	James	Deep Water Shoals	64–72, 74–02	38
2	James	Point of Shoals	68–02	35
3	James	Wreck Shoal	68–02	35
4	James	Miles Watch House	63–97	35
5	Piankatank	Ginney Point	65–02	38
6	Piankatank	Palace Bar	67–02	36
7	Great Wicomico	Glebe Point	65–02	38
8	Great Wicomico	Hudnall	65–02	38

Figure 4. Map of the Chesapeake Bay showing the locations of the James, Piankatank, and Great Wicomico Rivers and the location of the 8 study sites: (1) Deep Water Shoal, (2) Point of Shoal, (3) Wreck Shoal, (4) Miles Watch House, (5) Ginney Point, (6) Palace Bar, (7) Glebe Point, (8) Hudnall, including an inset table of the years covered by the VIMS Shellstring Survey (Southworth and Mann 2004).

In a thorough analysis of these rivers, Southworth and Mann (2004) acknowledge the environmental parameters such as temperature (Medcof 1939), salinity (Butler 1949), and biologic (food) parameters that influence oyster reproductive periodicity. River discharge (Fig. 5; Austin et al. 1996), harvest pressure (Commission of Fisheries 1931, Hargis and Haven 1998, 1999, Munch 2005), disease stress (Ford and Figuereas 1988, Choi et al. 1989), major storm events (Haven et al. 1974) and location of broodstock in a system (Haven and Fritz 1985, Carlsson et al. 2008) also have the potential to affect both the timing and magnitude of oyster settlement (Southworth and Mann 2004). There was a wide range in X_0 (day of the year when 50% of the total settlement had occurred) over the 40-year period; in fact, there was as much as a 60 to 90 day difference in the timing of oyster settlement between years and between river systems (Fig. 6a). Long-term trends in these data (Fig. 6b) were elicited through a technique called *Loess* smoothing (Cleveland 1979). In addition, a 45-year survey of the James River reefs upriver and downriver of Wreck Shoal reef reveals interannual spatial variability of oyster broodstock (Fig. 6c), a direct effect of disease mortality associated with Dermo and MSX (Southworth and Mann 2004, Carnegie and Burreson 2009, Mann et al. 2009). Aside from the early years (through 1970) in the James River, settlement timing between sites within the same river was similar (usually within 1 week of each other). The Great Wicomico River showed the largest variation in timing, whereas the Piankatank River was fairly consistent in terms of settlement timing.

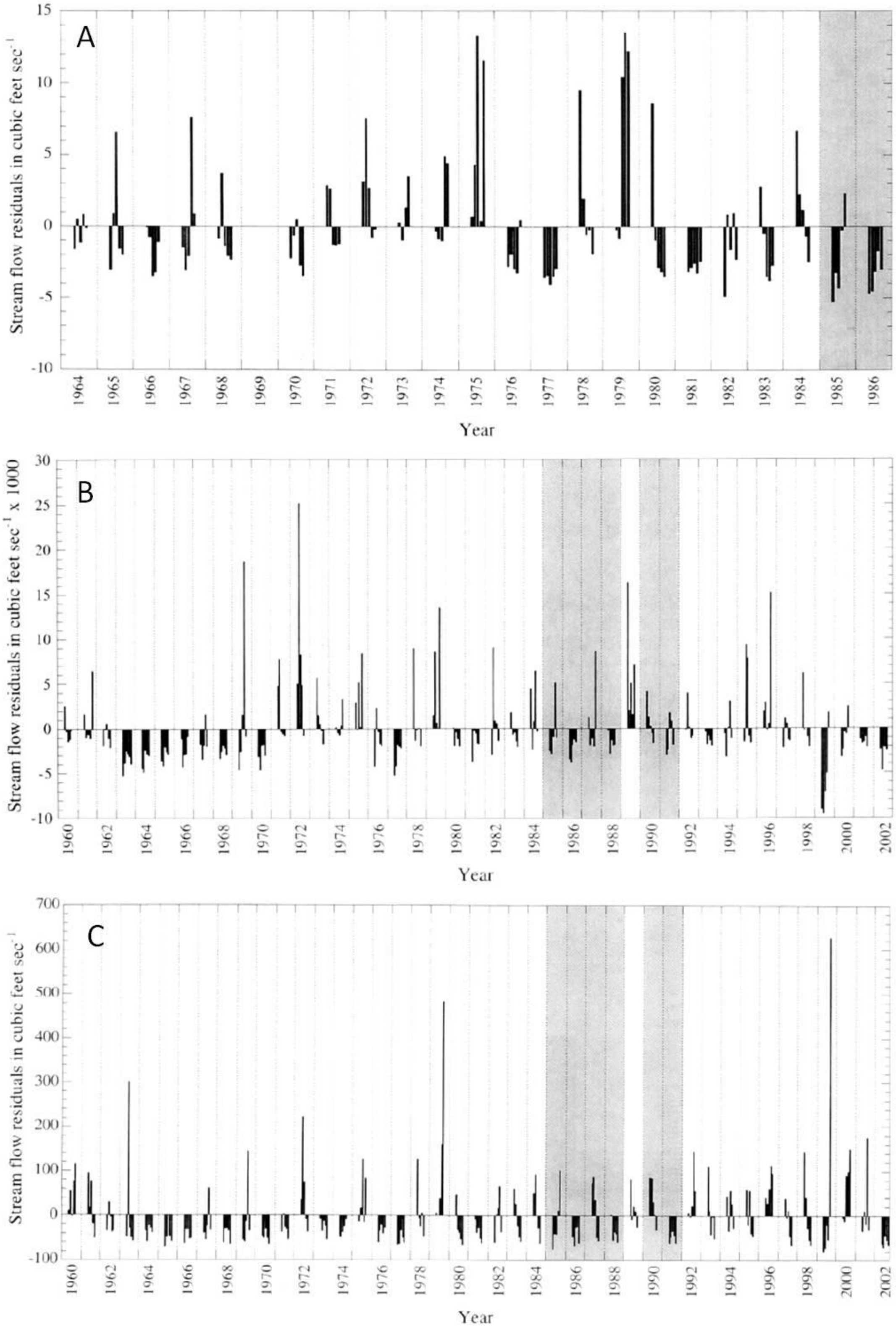


Figure 5. Average monthly stream flow residuals (monthly average minus long-term average) from May through September from USGS records for the (A) Great Wicomico, (B) James, and (C) Piankatank Rivers, where shaded regions represent dry years (Southworth and Mann 2004).

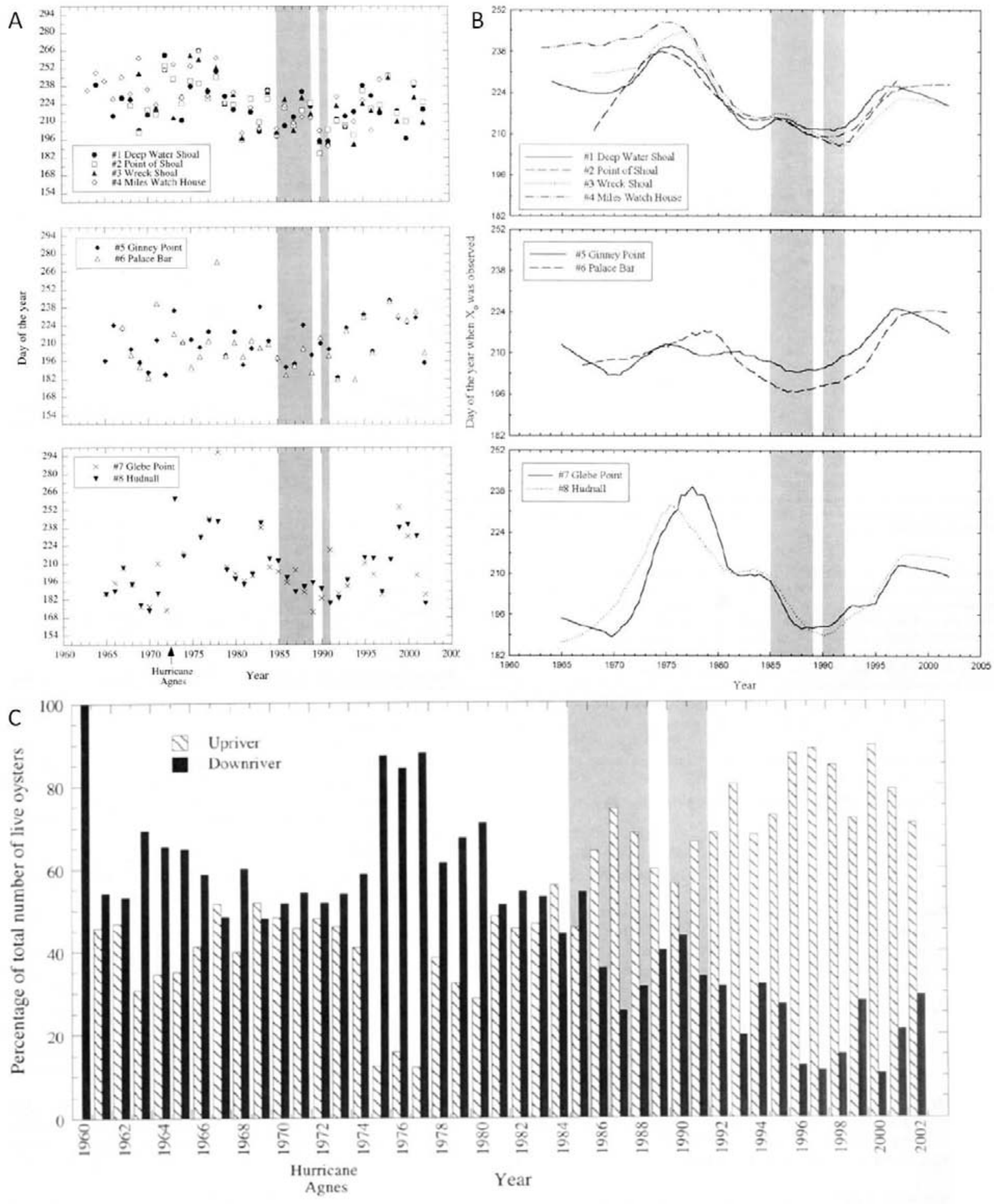


Figure 6. (A) Plot of X_0 (day of the year when 50% of the total settlement has occurred), and (B) cumulative recruitment (X_0) data (smoothed with the *Loess* technique in relation to year – similar to Austin et al. 1996) for the James (top), Piankatank (middle) and Great Wicomico Rivers. (C) Broodstock location in the James River from the VIMS annual dredge survey from 1960 to 2002: sites upriver of Wreck Shoal (#3) versus sites downriver of Wreck Shoal (Southworth and Mann 2004).

Temperature: Temperature and salinity affect every aspect of an oyster's biology, including gonadal development and timing of spawn (Southworth and Mann 2004). Temperature in particular is viewed as the single most important factor controlling when oysters spawn in Chesapeake Bay. Several studies have found that the rate of temperature change can be as important in inducing spawning oysters as some "critical" level being obtained (Medcof 1939, Butler 1949). The Great Wicomico River is, on average, warmer than the James River whereas the Piankatank River is, on average, cooler than the James River. The difference in temperature between the three systems may explain several aspects of the observed settlement trends. Throughout the observed time span, spawning in the Great Wicomico tended to occur 1 to 2 weeks earlier than in the other two systems; this trend, combined with the overall higher temperatures obtained throughout the spawning season may explain the earlier settlement observed. The Piankatank River seems to warm at a similar rate to the Great Wicomico early in the spawning season, but may take longer to reach that "critical" termperature necessary to induce spawning (Southworth et al. 2004).

Salinity: Salinity can also affect gametogenesis, especially in flood conditions. Butler (1949) found that gametogenesis delayed in salinities less than 6 ppt. Laboratory examination of gonads from field-collected animals from May to August showed a 2-month lag in gametogenic development in about 90% of the oysters from a low salinity site (0-6 ppt) when compared with a higher salinity site (6-15 ppt; Butler 1949). In fact, most oysters failed to produce gametes until salinity rose above 8 ppt (Butler 1949).

River Discharge and Drought: River flow has been shown to have an inverse relationship with salinity (Mann and Evans 1998). Run-off in the Piankatank and Great Wicomico Rivers (Fig. 5) is in the 10s to 100s of cubic feet sec^{-1} whereas the James is in the 1000s to 10,000s cubic feet sec^{-1}, at least two orders of magnitude higher. Major storms can be accompanied by high rainfall, creating freshets that can drop the salinity so low that there is a massive oyster die-off and/or system-wide oyster recruitment failure (Haven et al. 1974). Alternatively, slow-moving, late summer tropical storms can sometimes cause the cessation of tidal due to wind-forcing. If larvae are present in the water column during these events, there is an increased potential of their settlement on substrate located within their tributary-of-origin, as opposed to the common fate of a percentage of larvae – being washed out into Chesapeake Bay proper, where few remaining reefs persist and little to no substrate is present. This scenario unfold in late summer/early fall 2006 when a tropical storm and a northeaster passed through Hampton Roads within a few weeks of each other. Tidal flushing was inhibited by prevailing winds as described above and resulted in an augmented setting of oyster larvae in the Lynnhaven River System (Burke 2010).

For the drought conditions of the late 1980s and early 1990s, the oysters from all three systems spawned earlier in the year than during wetter years (Southworth and Mann 2004). Furthermore, low river discharge equates to increased residence time of larvae-containing water and higher settlement within the retentive portions of these systems. This enhanced recruitment has been documented in the Great Wicomico River in 1997 (Southworth and Mann 1998, Southworth et al. 1998) and in Lynnhaven River in 2006 (Luckenbach and Ross 2009, Burke 2010).

Detecting complex trends between organisms and their environments can be complex, especially when there is a biological lag. Austin et al. (1996) found that spatfall showed a significant cross-correlation with yearlings a year later in all Virginia rivers, suggesting that the "yearling" designation is accurate and that spat counts may be used to predict yearling abundance (no apparent lag). In addition, the relation of spat to later seed was significant for the James River at 2 (Fig. 7a) and 3 years (Fig. 7b), but none was found between spat and market oyster. This relationship suggests that seed oysters grow large enough to reproduce and contribute to the next generation of seed oysters, but may not survive to market size as consistently.

However, Austin et al. (1996) detected a significant relation between spat count and the Palmer Drought Index – PDI (a combination of rainfall, soil type, and evapotranspiration). When the period of the greatest change in the drought index was correlated with spatfall, there was found to be a significant 2- to 4-year lag (Fig. 7c). Austin et al. (1996) suggest that this reflects a response by the ecosystem to changing environmental conditions, whereby if one considers the period of greatest PDI change, that period when the environment passes from one temperature/precipitation regime to another, it makes biologic sense that the populations, after a lag, will begin to show change; then, change will occur rapidly as the population shifts toward equilibrium with the "new" environment (Fig. 7d). The cyclic nature of the physical (PDI) results in rapid and cyclic changes in spatfall; only during the extended drought of the early- to mid-1980s did the spatfall rates have a chance to equilibrate (Austin et al. 1996).

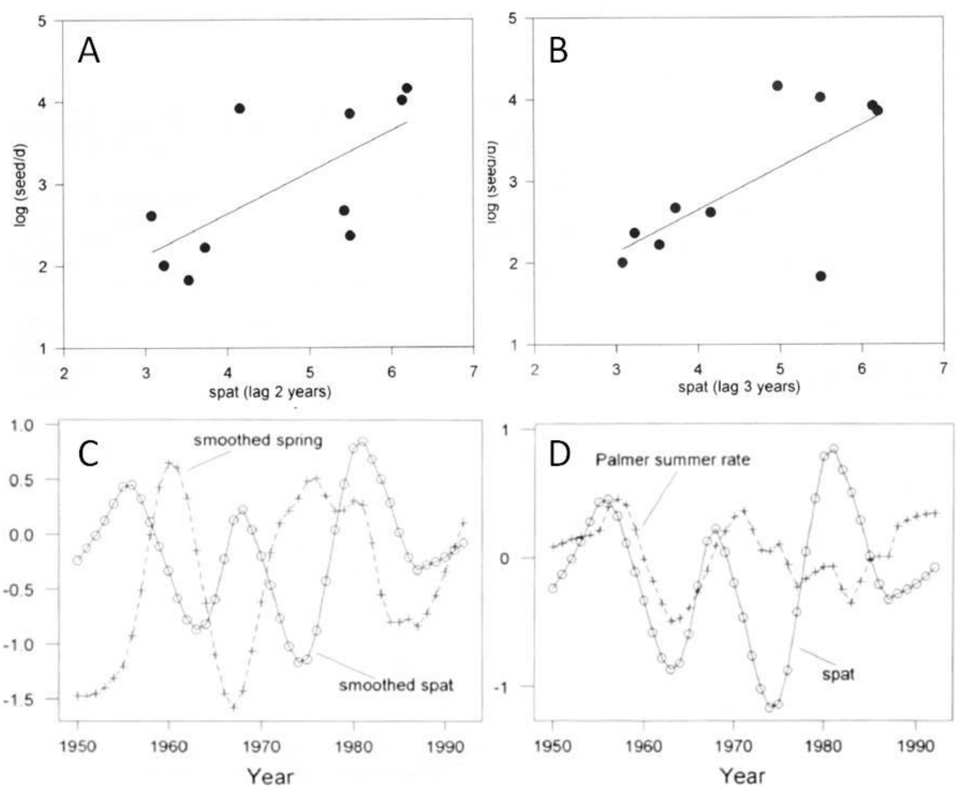


Figure 7. (A) Regression for James River spat, lagged 2 and (B) 3 years. (C) Detrended, smoothed upriver James spatfall and detrended, smoothed spring Palmer Drought Index (PDI), and (D) detrended, smoothed summer period of maximum rate of change in PDI, respectively (Austin et al. 1996).

Disease: Oyster disease – Dermo and MSX – distribution and abundance is primarily controlled by salinity with requirements of 12 and 15 ppt, respectively (Andrews 1988, Burreson and Andrews 1988). Since the aforementioned drought conditions (late 1980s and early 1990s) *P. marinus* has persisted in the upper James River and throughout the Piankatank and Great Wicomico Rivers even though salinities returned to normal during the mid to late 1990s (Southworth and Mann 2004). Beginning in May 2007 and continuing through most of 2008, streamflows were depressed and salinities elevated. As in the late 1980s/early 1990s and a similar period from 1999 to 2002, these conditions favored intensified *P. marinus* activity, particularly in the upper parts of the major rivers, where lower salinities normally inhibit *P. marinus*. Exacerbating the salinity effects was the extended period of elevated water temperatures, from the summer of 2007 through most of 2008. The relatively warm winter of 2007/8 in particular allowed *P. marinus* to overwinter at a relatively high level, which is thought to contribute to intensified disease the following summer. These conditions favored the intensification of *H. nelsoni* activity as well. However, a season-long study in 2008 of oysters in the Lynnhaven River in Virginia Beach, where salinities always favor *H. nelsoni*, and thus where selection for resistance to MSX disease is likely more intense, revealed that there is no refuge from MSX disease and oysters susceptible to the disease have probably been purged from that system (Carnegie and Burreson 2009). This finding is the most prominent example of a trend that has emerged from the long-term data – *C. virginica* is adapting to intense parasitism by both *H. nelsoni* and *P. marinus* (Carnegie and Burreson 2009). Comprehensive disease monitoring of James River oysters at Wreck Shoal has revealed generally decrease in *H. nelsoni* infection levels since the early 1990s (Carnegie and Burreson 2009). Similar trends in *P. marinus* have been identified in the Great Wicomico (Carnegie and Burreson 2008), Lynnhaven (Burke 2010), Elizabeth (Burke *unpublished data*), and lower Rappahannock (Burke 2010) Rivers. Carnegie and Burreson (2009) note:

> ". . .the divergent disease levels between long-exposed wild oyster populations and truly susceptible stocks provide evidence of developing resistance to disease, and thus a basis for optimism. Natural oyster populations in Virginia have a capacity for expansion if substrate can be managed effectively and if harvest pressure is not severe. Protection of larger adult oysters that have demonstrated an ability to survive repeated disease challenges should be central to strategies for oyster restoration as well as fishery management."

Broodstock Location: The location of oyster broodstock can change settlement timing, intensity, and distribution within an estuary (Carlsson et al. 2008). The settlement timing in the James River may be related to broodstock location and how it changed over the study period (Fig. 6c). It has been suggested that, historically, the majority of the settlement on the upper seed rive area originated from the oysters located in the lower, more saline, part of the river (Haven and Fritz 1985). Southworth and Mann (2004) suggest that, historically, the oysters in the upper seed area provided the first smaller settlement pulse, whereas the more downriver oysters provided the larvae for the major settlement events that typically occurred in late August and early September. Using cluster analysis, Austin et al. (1996) grouped James River oyster bars/reefs naturally by up- and downriver spatfall (Fig. 8a) and yearling (one-year old oysters; Fig. 8b) patterns (in spat per bushel) and detected similar trends. With the decline of these downriver populations, due to disease and overharvest (Hargis and Haven 1998), the present distribution of oysters in the James River is very different from what was observed several decades ago, with the majority of the settlement increasingly originating from the upper seed area, with an accompanying earlier settlement peak (Southworth and Mann 2004).

Overall there has been very little change in the timing of oyster settlement in the Piankatank River, especially compared with the changes observed in the James and Great Wicomico Rivers. Unlike the James River, there are very few anthropogenic influences in the Piankatank River (a fact further secured by The Nature Conservancy's acquisition of much of the upriver portion of the watershed called Dragon's Run), there has been no commercial harvesting in the system for decades and there are few watershed influences (Southworth and Mann 2004).

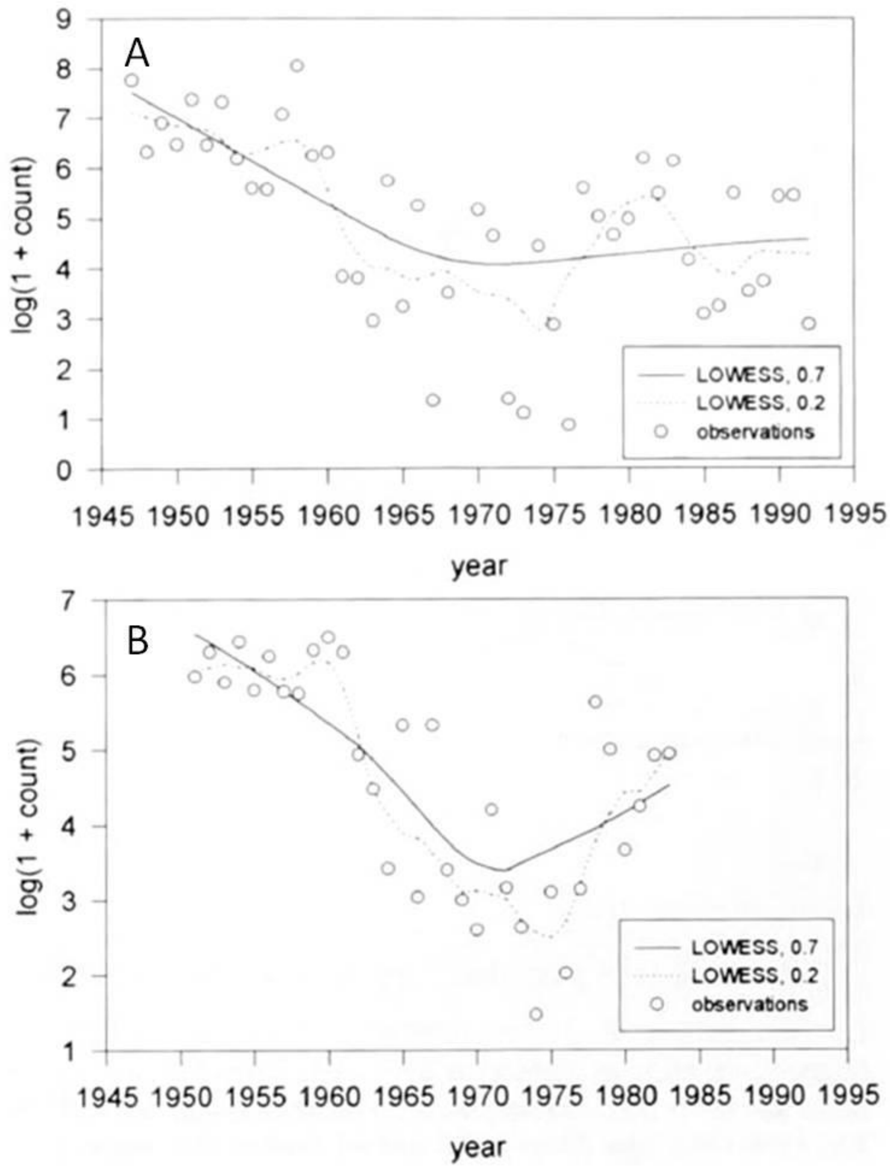


Figure 8. (A) Mean spatfall (number of spat-on-shell per bushel), James River, VA, 1946-1992; *loess* filters at the 0.2 and 0.7 degrees of smoothing. (B) Mean yearlings (number per bushel), James River, VA, 1948-1983; *loess* filters at the 0.2 and 0.7 degrees of smoothing (Austin et al. 1996).

Virginia's Tier 1 Tributaries

Great Wicomico River: Annual monitoring of oyster spatfall in the Great Wicomico River (Figs. 4, 9a) revealed a history of moderate-to-heavy recruitment (Figs. 6a, 9b). The Virginia Oyster Repletion Program shelled the public oyster grounds of this river quite intensively (Fig. 9c) to capture an abundant oyster larval source. The Great Wicomico River thus served as a major oyster seed-producing tributary for the public oyster fishery since seed transplanting began in the early twentieth century (Table 2). Note, seed from this system was rarely transplanted within the river system (Fig. 9d); more often, it was transplanted to the public oyster grounds of other Bay subestuaries for grow-out to market size.

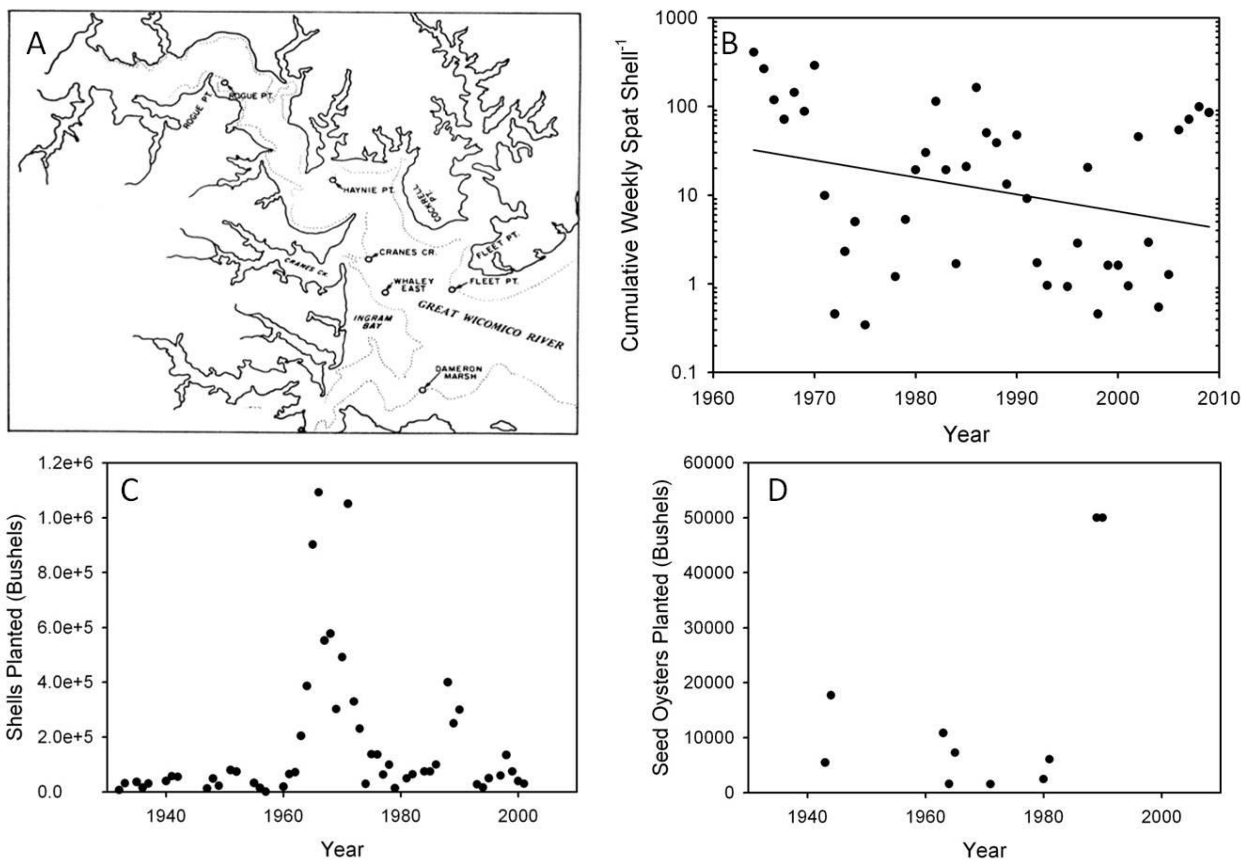


Figure 9. (A) Map of the Great Wicomico River (Commission of Fisheries Reports). (B) Annual spatfall trends across all sites in the Great Wicomico River (VIMS Annual Spatfall Summaries, 1969-2010). (C) Shells and (D) seed oysters (in Virginia bushels) planted on public oyster grounds in the Great Wicomico River (Commission of Fisheries/VMRC Reports, 1931-2009).

As noted earlier in the „Case Study' section, the Great Wicomico River is a relatively-shallow, trap-type estuary with spring-summer temperatures and salinities that have historically supported consistent recruitment and, subsequently, produced oysters of good condition. Despite a preponderance of MSX epizootics (Carnegie and Burreson 2009), some tolerance to Dermo has been measured in the Great Wicomico oyster population. In addition, large-scale ecological oyster restoration in this system has been conducted. This reestablished oyster metapopulation (Fig. 10a) is the most successful native oyster restoration project ever constructed (Schulte et al. 2009) and has maintained high oyster densities (Fig. 10b) in the presence of both diseases. Since its construction this reef network has produced numerous secondary benefits, including significant (1) system-wide oyster recruitment from 2006 through 2010, (2) water filtration (reduction of nutrients and suspended solids), and (3) opportunities for scientists to study functional subtidal oyster reefs. Further restoration in this Tier 1 Tributary would ensure the maintenance of the first sustainable restored oyster reef network in Chesapeake Bay.

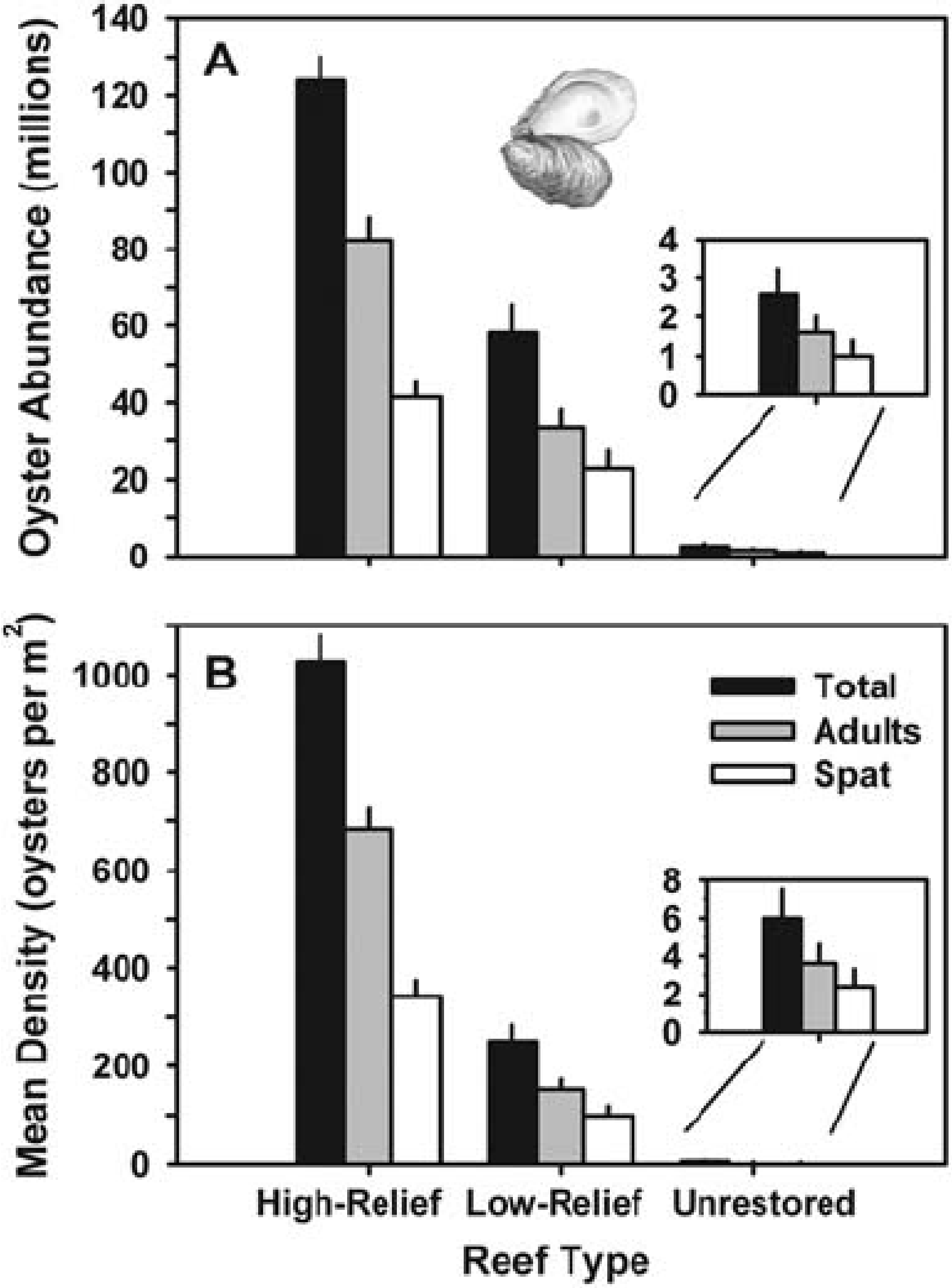


Figure 10. (A) Oyster abundance and (B) density on each of the reef types across the nine-reef system in the Great Wicomico River which consisted of a total of 184.5 million oysters (Schulte et al. 2009).

James River: Temporal patterns of spatfall in the Virginia Bay tributaries showed a decline in all rivers from 1946 through the early 1970s, with a subsequent leveling off. The decline was most severe in the James River (Fig. 11a). The shellstring survey of oyster spatfall in the James River (Fig. 11b) is the longest record of its kind in Virginia (historical survey: Andrews 1947, 1949-1952, 1954, Haven 1969-1973, Haven and Kendall 1974-1977). Hundreds of thousands of bushels of shells (Fig. 11c) were returned to the James River public oyster grounds from 1960 to 1990, as well as a few hundred thousand seed oysters (Fig. 11d). Given the dependence of the Marine Resource Commission on the James River as the largest seed oyster source, replenishing these beds was critical.

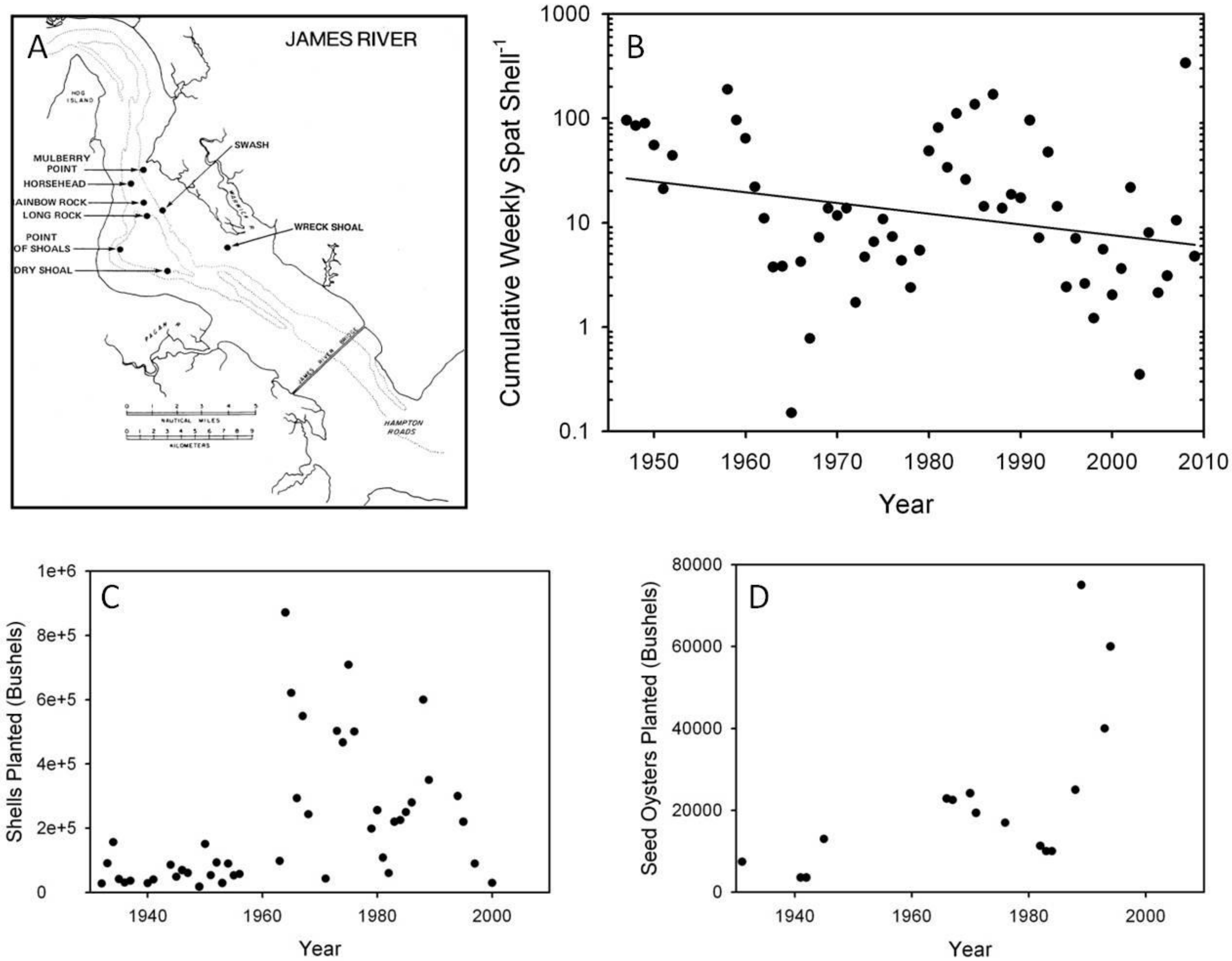
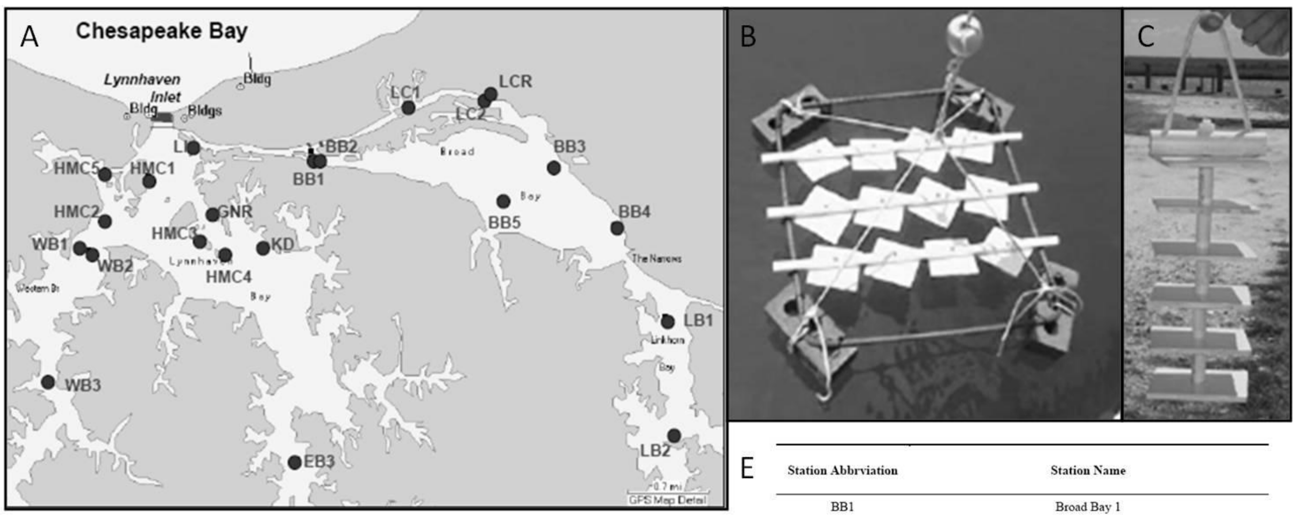


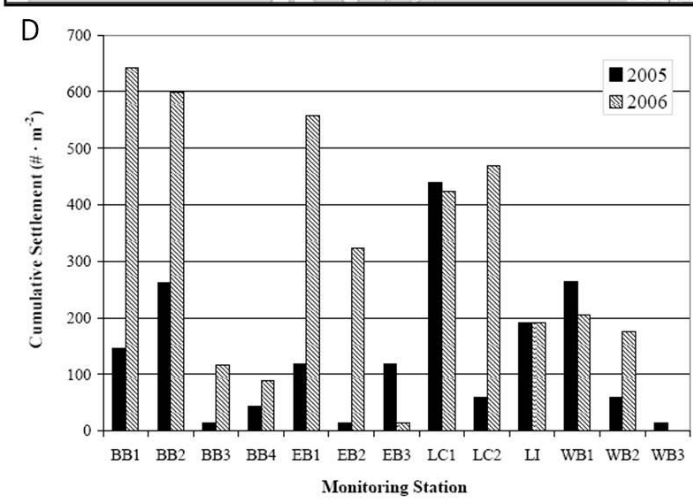
Figure 11. (A) Map of the James River (Commission of Fisheries Reports). (B) Annual spatfall trends across all sites in the James River (VIMS Annual Spatfall Summaries, 1947-2010). (C) Shells and (D) seed oysters (in Virginia bushels) planted on public oyster grounds in the James River (Commission of Fisheries/VMRC Reports, 1931-2009).

The James River still supports the largest oyster population in the lower Chesapeake Bay with adequate spatsets, including a modern-day high river-wide set in 2008 (Southworth et al. 2009). The hydrodynamic retentiveness of the James River, along with appropriate temperature, salinity, and depth ranges, make it a clear candidate for large-scale restoration. In addition, oyster condition is very good, partly as a result of developing resistance to MSX (Carnegie and

Burreson 2009). And dissolved oxygen is not a major problem in this river. The greatest challenge, however, will be the immense scale of the project and resources (cost, substrate, and time) necessary to exert a real influence on the James River oyster population.

Lynnhaven River: The Lynnhaven River Watershed (166 km^2) is shallow, highly urbanized, and contains a recovering oyster population. The Lynnhaven River was closed to direct shellfish harvest for over two decades from 1980 to 2006. Fecal coliform levels made shellfish consumption from these waters dangerous without prior depuration. A full-scale, multi-agency restoration effort has helped improve water quality conditions in the Lynnhaven River. In 2005, VIMS scientists from the Eastern Shore Laboratory were contracted to study the Lynnhaven River to establish baselines for oyster restoration. Oyster spatfall monitoring sites were selected (Fig. 12a), ceramic settlement tiles were deployed on two types of arrays (Fig. 12b-c), and weekly spatfall data were collected (Fig. 12d-e).





E

Station Abbrviation	Station Name
BB1	Broad Bay 1
BB2	Broad Bay 2
BB3	Broad Bay 3
BB4	Broad Bay 4
EB1	Eastern Branch 1
EB2 (KD FOR 2006)	Eastern Branch 2 (2005); Keeling Drain reef (2006)
EB3	Eastern Branch 3
LC1	Long Creek 1
LC2	Long Creek 2
LI	Lynnhaven Inlet
WB1	Western Branch 1
WB2	Western Branch 2
WB3	Western Branch 3
WB4	Western Branch 4
BB5	Broad Bay 5
HMC1	Humes Marsh Complex 1
HMC2	Humes Marsh Complex 2
HMC3	Humes Marsh Complex 3
HMC4	Humes Marsh Complex 4
HMC5	Humes Marsh Complex 5
LB1	Linkhorn Bay 1
LB2	Linkhorn Bay 2

Figure 12. (A) Map of the Lynnhaven River System containing settlement monitoring stations. (B, C) Two types of arrays of ceramic tiles used to assay oyster settlement on reefs. (D) Cumulative oyster settlement (# m^{-2}) at Lynnhaven monitoring stations deployed during 2005 and 2006 (Note some stations were added and some dropped during 2006 and are not included in this graph). (E) Abbreviations for the Lynnhaven monitoring stations (Luckenbach and Ross 2009).

Another critical pre-restoration activity undertaken in 2005 was the identification of shoreline types and their respective background oyster populations, throughout the entire Lynnhaven River System (Luckenbach and Ross 2009). Oyster populations were surveyed on four major intertidal habitats were studied: bulkhead, marsh, patch/fringing reefs, and riprap (Fig. 13). In addition, another group of VIMS scientists intensively studied the intertidal riprap oyster community (Burke 2010), the benthic community adjacent to the four intertidal shoreline types (Lawless 2008), and the hydrodynamic modeling of oyster reef connectivity via larval exchange (Lipcius et al. 2008) within the Lynnhaven River System.

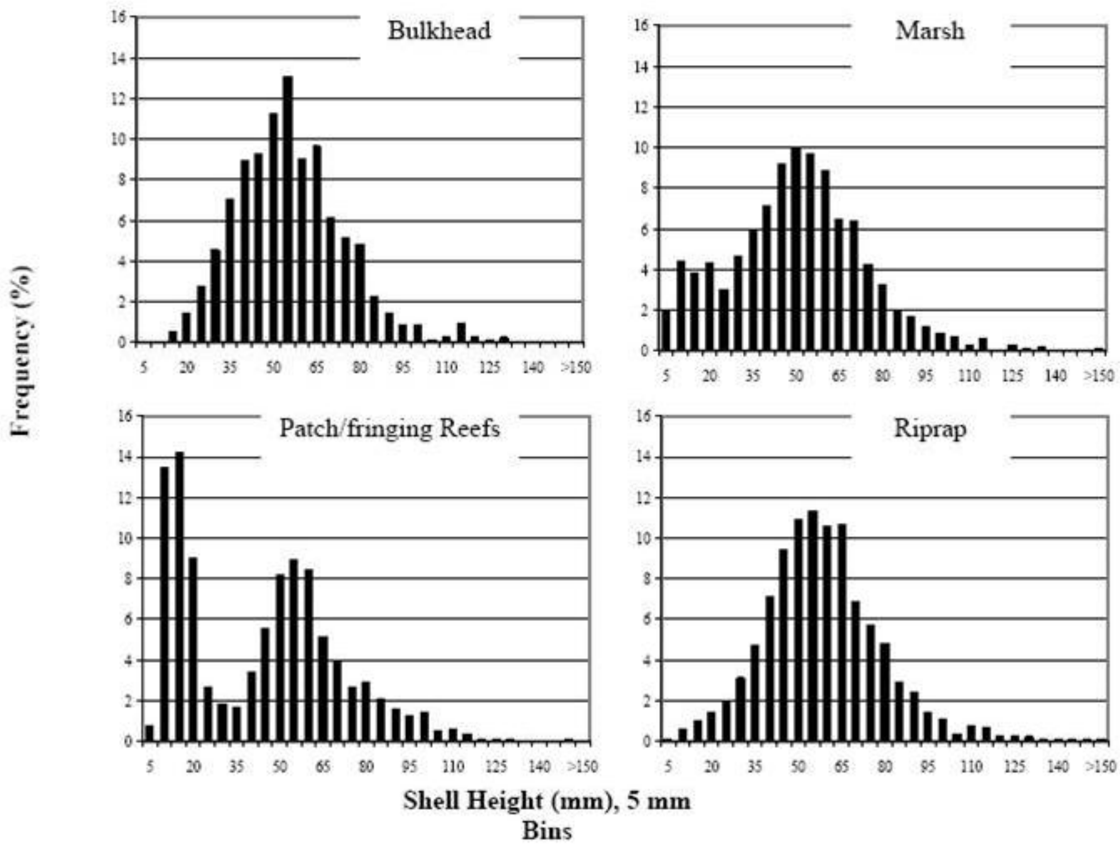


Figure 13. Lynnhaven River oyster shell height (mm) distribution (%) for bulkhead, marsh, patch/fringing reefs and riprap, with shell height plotted by 5 mm bins (Luckenbach and Ross 2009).

Since the initiation of this oyster restoration research, the US Army Corps of Engineers has constructed ~60 acres of sanctuary oyster reefs in Linkhorn and Broad Bays, as well as in the Eastern Branch of the Lynnhaven River. Informal surveys of the reefs in the summers of 2009 and 2010 (Burke and Schulte *unpublished data*) found that they have recruited spat each year since their construction. In addition, the spat-on-shell deployed on the Linkhorn Bay reefs has thrived over the last few years and has formed a cohesive oyster rock containing oysters > 6 inches, dispelling the belief that subtidal oyster reefs could not persist in this high-salinity system known for its high sedimentation and elevated predator pressure. Lastly, oyster recruitment was extremely heavy throughout the Lynnhaven River in 2010; wild oysters that were between 7 and 8 inches shell height, as well as DEBY oysters of similar size, were also documented (Burke and Schulte *unpublished data*). Clearly, the physical and biological characteristics of this Tier 1 Tributary make it a prime candidate for further restoration.

Mobjack Bay: Mobjack Bay (Fig. 14a) is relatively small compared to most Virginia Tier 1 Tributaries, though four small rivers flow into it: the East, North, Severn, and Ware Rivers. The record of spatfall measured in Mobjack Bay (Fig. 14b), as well as that for shell plants (Fig. 14c) and seed transplants (Fig. 14d) does not include its four tributaries (See Digital Appendices for these data). As described in the Introduction, seed oysters transplanted to soft, anoxic bottom sediments in Mobjack Bay in the 1930s resulted in mass mortality. Thus, despite the ability of some areas of Mobjack Bay to support oyster populations, site selection for restoration in this system will be crucial for success. Mobjack Bay does not appear to be hydrodynamically retentive. Oyster spatfall data for this body of water ceased to be collected in 1997, so the regularity of spatset is unknown; the trend leading up to 1997 was not encouraging, despite moderate recruitment in the 1980s (Fig. 14b). At the very least, consideration of Mobjack Bay for large-scale oyster restoration would benefit from further research, including a field survey.

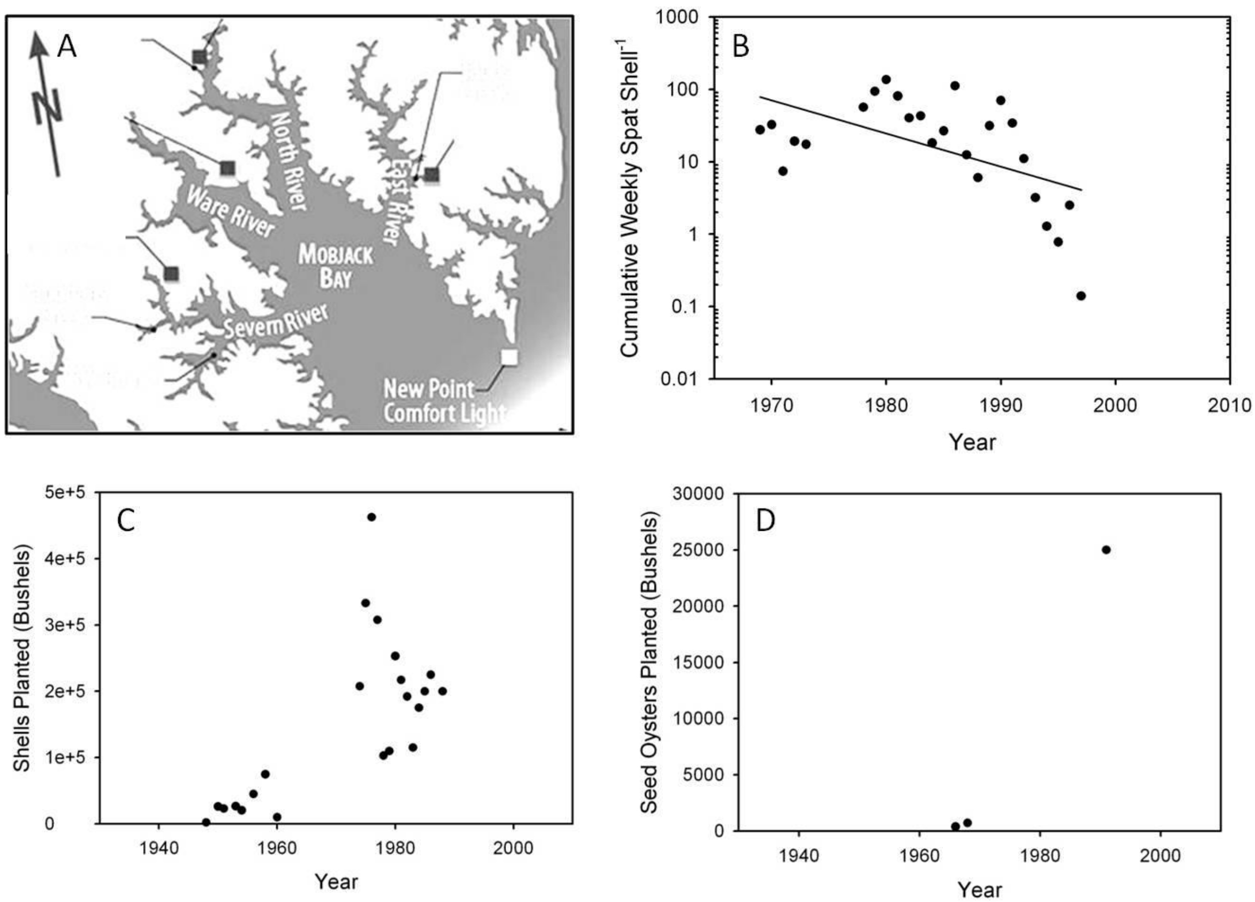


Figure 14. (A) Map of the Mobjack Bay (http://www.chesapeakeboating.net). (B) Annual spatfall trends across all sites in Mobjack Bay (VIMS Annual Spatfall Summaries, 1969-2010). (C) Shells and (D) seed oysters (in Virginia bushels) planted on public oyster grounds in Mobjack Bay (Commission of Fisheries/VMRC Reports, 1931-2009).

Piankatank River: The Piankatank River (Fig. 15a) oyster population has been monitored by the historical and modern VIMS Annual Spatfall Survey (Fig. 15b), due to its prolific historical seed production. To maintain seed-producing reefs, shells were planted in (Fig. 15c), and seed transplanted within (Fig. 15d), the Piankatank River, beginning in the early 1930s. As described in the „Case Study' section, the Piankatank River has been a location for considerable small-scale oyster restoration. This Tier 1 Tributary has been identified as the next site for large-scale oyster restoration in Virginia. After participating in pre-construction data collection in 2009 and 2010, it is clear that the Piankatank River is the right choice. By scale, it is nearly an order of magnitude larger than its sister tributary to the north – the Great Wicomico River – but is still smaller than most of the other candidate tributaries. The Piankatank River is hydrodynamically retentive, has a history of heavy oyster recruitment (despite lighter sets in the last 20 years), contains acceptable temperature, salinity, and dissolved oxygen ranges, is not a highly-developed watershed (especially upriver – Dragon Run), and produces oysters with good overall condition. Note, there are large (5+ inches) oysters located in the upper subtidal zone along riprap shorelines (near the Route 3 Bridge) that would be ideal for use as broodstock in spat-on-shell production.

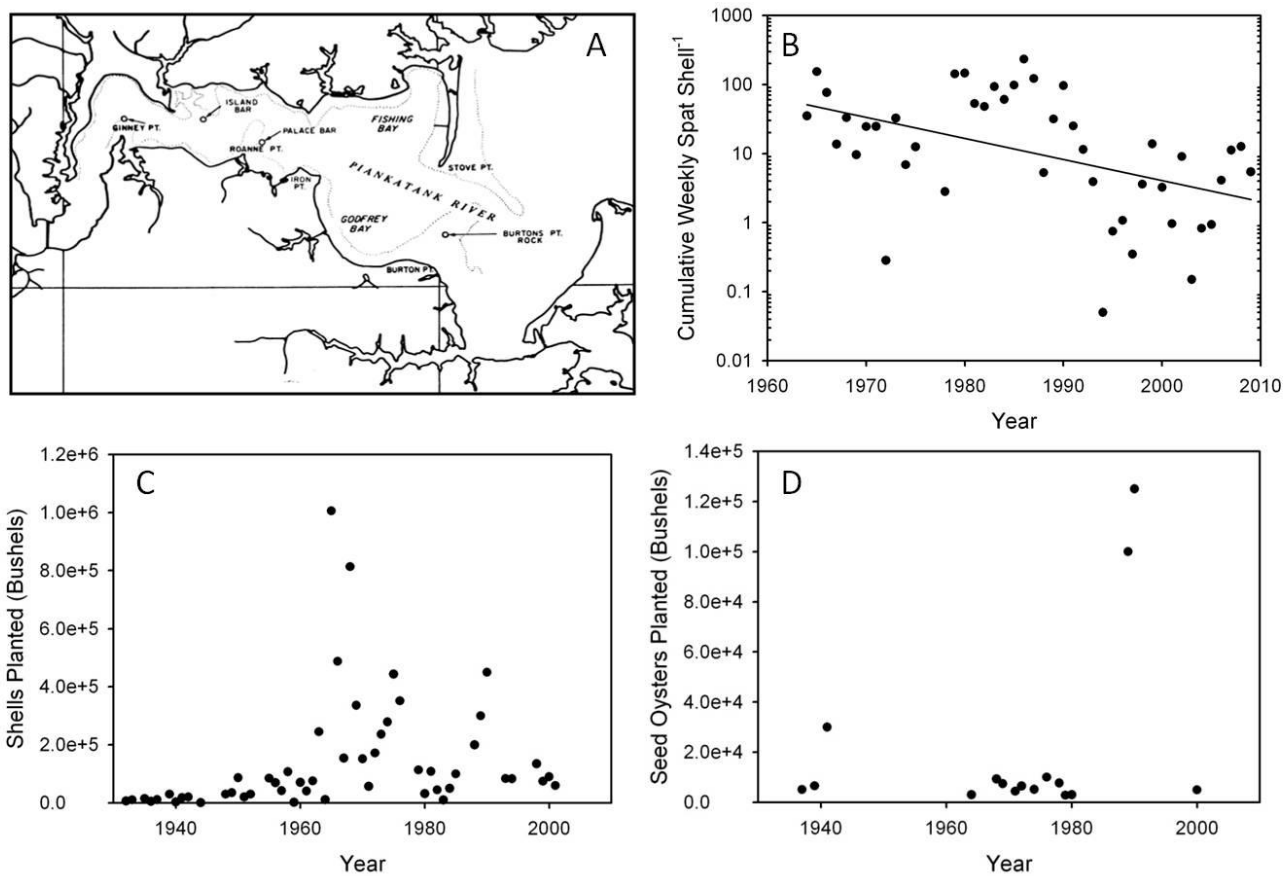


Figure 15. (A) Map of the Piankatank River (Haven and Kendall 1982). (B) Annual spatfall trends across all sites in the Piankatank River (VIMS Annual Spatfall Summaries, 1969-2010). (C) Shells and (D) seed oysters (in Virginia bushels) planted on public oyster grounds in the Piankatank River (Commission of Fisheries/VMRC Reports, 1931-2009).

Rappahannock River: The Rappahannock River (Fig. 16a) is not well-known for high recruitment (Fig. 16b, Fig. 17a); however, it has received considerable shell plants (Fig. 16c) and seed oyster transplants (Fig. 16d) in the lower portion of this river (Fig. 18a) over the last half century due to the consistently high quality of meat harvested from oysters grown there (Fig. 18b-c). The production of yearlings correlates with spat settlement and seed transplantation (Fig. 17b) and, thus, the Rappahannock River continues to be a focal tributary for the public and private fisheries, as well as for oyster restoration enthusiasts. Conducting large-scale oyster restoration in this Tier 1 Tributary is not ideal, however. Unlike many of the aforementioned tributaries, the Rappahannock River is not hydrodynamically retentive, experiences perennial oxygen depletion in deeper water (Fig. 18a), experiences light-to-moderate oyster recruitment, and is very large. Some other attractive characteristics, though, are its temperature, salinity, flushing, oyster condition (Austin et al. 1993, Burke 2010), and the development of some level of disease resistance to both Dermo and MSX (Burke 2010). Oysters larger than 6 inches, once common in Virginia (Fig. 19a), have been measured in this river over the last few years, evidence that some oysters are living past market size. The recent discovery by an oysterman of a wild, 9-inch oyster in the Rappahannock River (Fig. 19b), likely the largest documented wild oyster seen in the Chesapeake Bay since before the 1980s Dermo outbreak, makes the candidacy of this Tier 1 Tributary for future oyster restoration that much more viable.

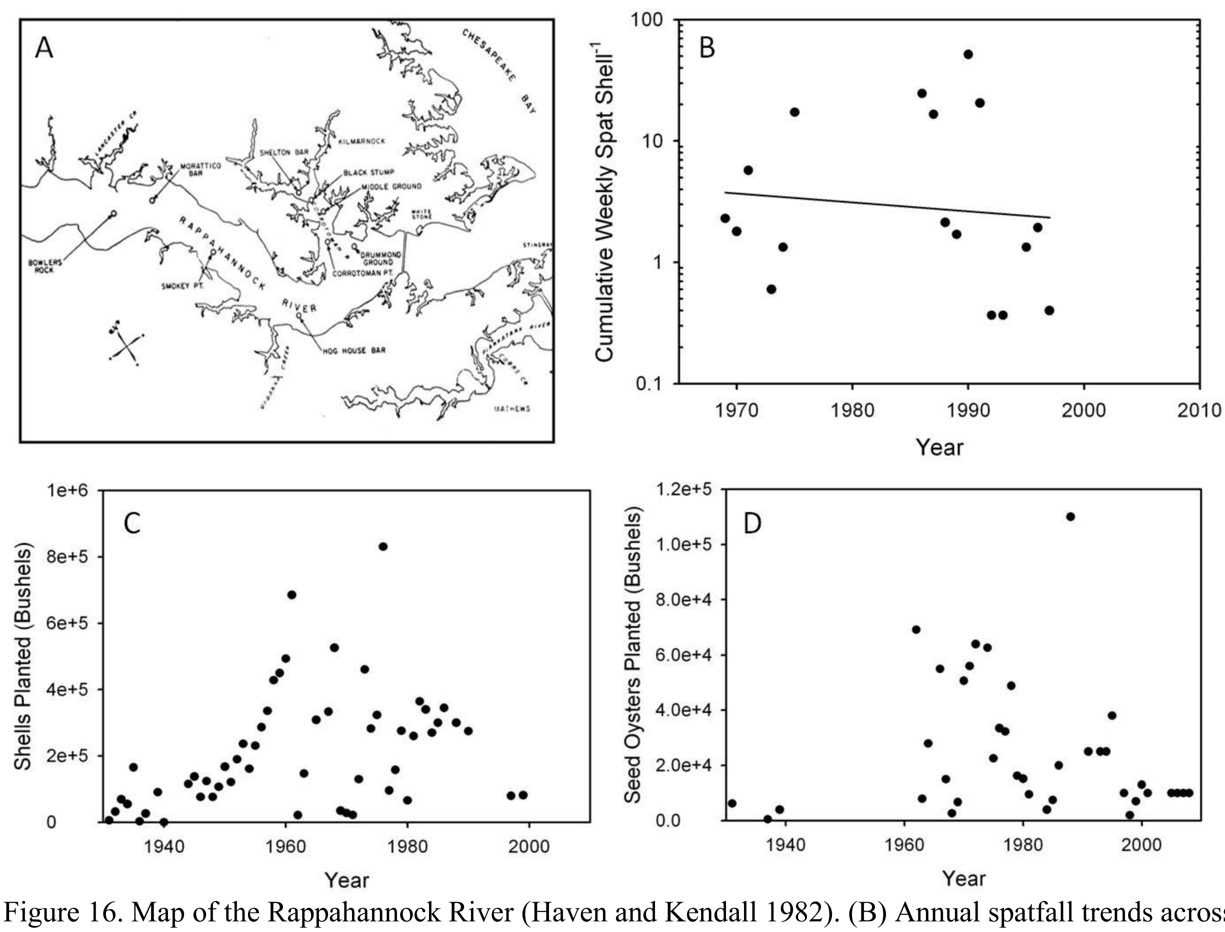


Figure 16. Map of the Rappahannock River (Haven and Kendall 1982). (B) Annual spatfall trends across all sites in the Rappahannock River (VIMS Annual Spatfall Summaries, 1969-2010). (C) Shells and (D) seed oysters (in Virginia bushels) planted on public oyster grounds in the Rappahannock River (Commission of Fisheries/VMRC Reports, 1931-2009).

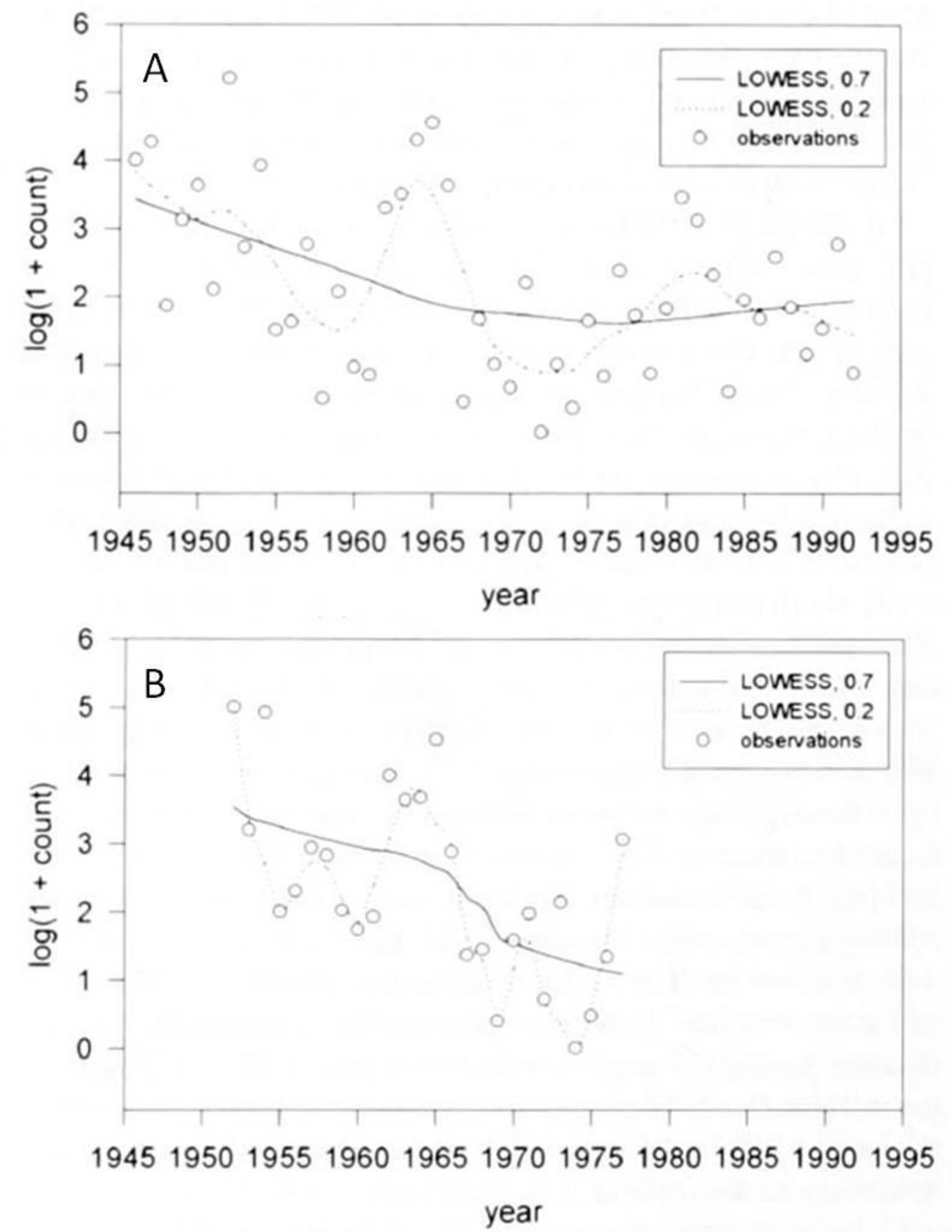


Figure 17. (A) Mean spatfall (number of spat-on-shell per bushel), Rappahannock River, VA, 1946-1992; *loess* filters at the 0.2 and 0.7 degrees of smoothing. (B) Mean yearlings (number per bushel), Rappahannock River, VA, 1946-1977; *loess* filters at the 0.2 and 0.7 degrees of smoothing (Austin et al. 1996).

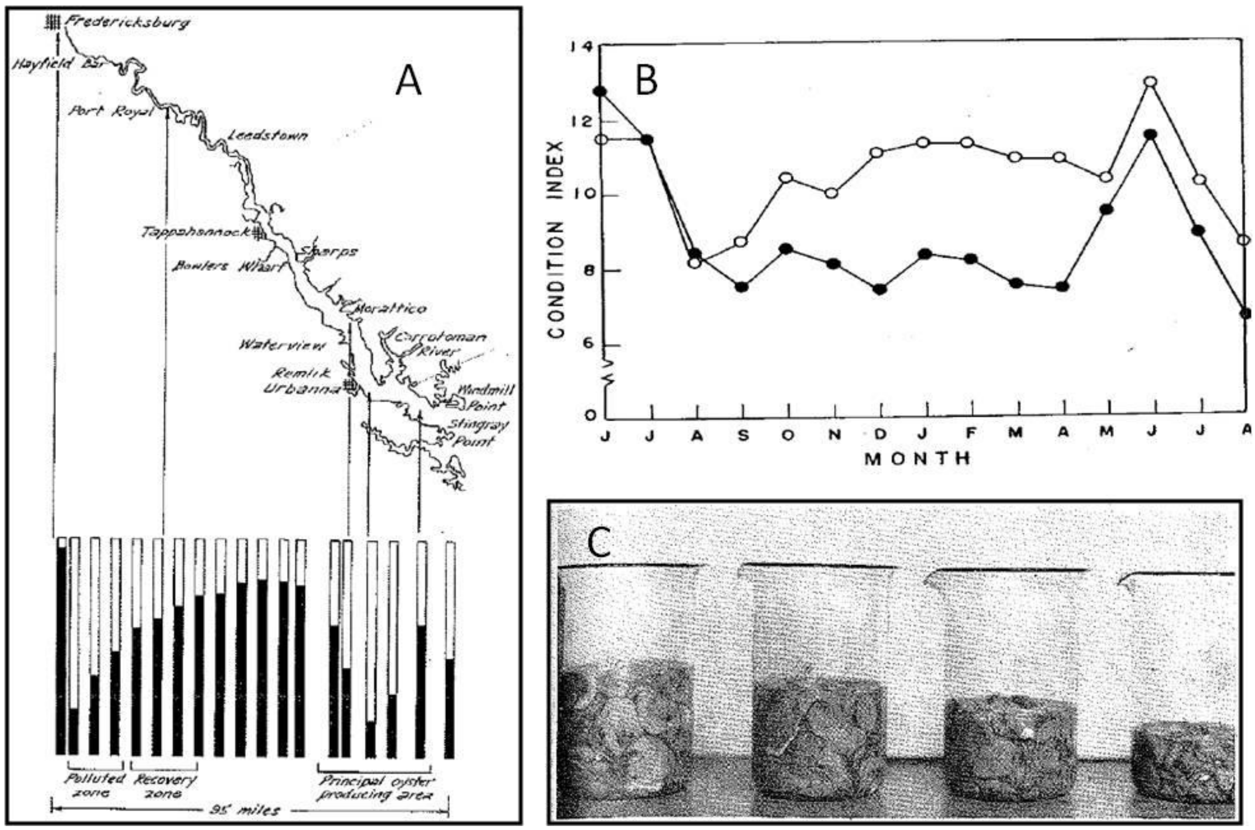
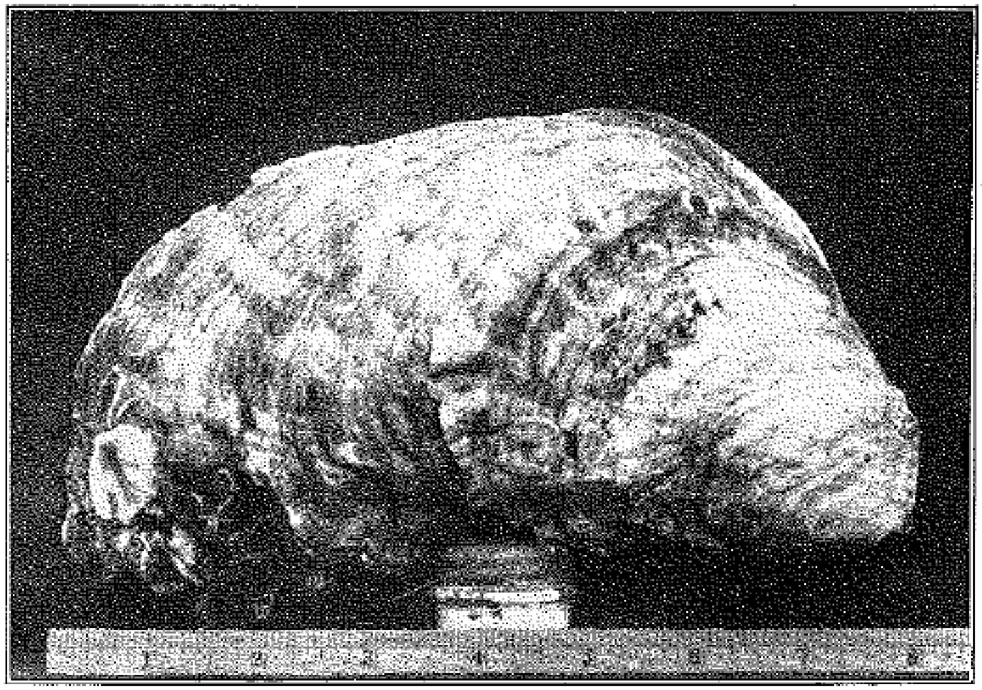


Figure 18. (A) Early detection of depleted oxygen zones in the principal oyster producing grounds of the Lower Rappahannock River (Commission of Fisheries 1957) . (B) Seasonal condition index curve for tray oysters cultured in the lower York River (closed circles) and those cultured in the lower Rappahannock River (open circles). Data represent mean values derived from three separate seasonal studies from 1956 through 1959 (Haven 1960). (C) Some area produce fatter oysters than others. Each container holds the same number of oysters of equivalent size and age. From left to right these oysters came from the lower Rappahannock River, Hampton Roads, the lower York and upper York River. The difference in consumer appeal and profit to oysterman is obvious. Seasonal variations equally as great may occur in one area, with best yields in late spring and poorest in late summer (Commission of Fisheries 1957). Fifty years later, these same trends have been documented when comparing oyster biomass on high- and low-quality oyster restoration reefs (Burke 2010).



A Large Oyster from Virginia Waters.

Oysters of this size should not all be taken but some left in the water for spawning to replenish the rocks.

A.

B.

Figure 19. (A) A large oyster (~8 inches shell height) from Virginia (Commission of Fisheries 1931). (B) A 9-inch native oyster harvested from the Rappahannock River (29 October 2010) next to a typical market oyster (3 inches); "Hannah" is likely the largest wild oyster found in the Chesapeake Bay since the outbreak of Dermo in the 1980s.

Tangier and Pocomoke Sounds: Tangier and Pocomoke Sounds (Fig. 20) were candidate Tier 1 Tributaries selected for oyster restoration ten years ago. A change in federal policy regarding harvest grounds made restoration in these waters untenable at the time. Historically, shells (Figs. 21a, c) and seed oysters (Figs. 21b, d) have been planted in Tangier and Pocomoke Sounds, respectively. During the mid 1860s, the entire Pocomoke Sound area (Maryland and Virginia) supported combined efforts of hundreds of dredge boats, but by 1879 intense harvest from both states had depleted the area to the point where dredging was not profitable (Ingersoll 1881). Whitcomb and Haven (1987) conducted an extensive survey of the Pocomoke Sound public oyster grounds. Spatfall rates in Pocomoke Sound were low during 1978 as shown by weekly spatfall data and by samples of bottom material. In addition, studies on spatfall made in Pocomoke Sound by the Maryland Department of Natural Resources between 1939 and 1975 documented that set failures (less than 25 spat/bushel of cultch) were recorded during 43% of the years (Krantz and Meritt 1977). Average spatfall during this entire period was rated as poor (25 to 100 spat/bushel). The total spat/shell counts for the years for Public Ground #9 were also low. These levels of spatset are regarded as too low for sustained commercial production (Krantz and Meritt 1977).

Temperature, salinity, and depth suggest these grounds might be productive, if oyster restoration was conducted, but the aforementioned spatset, as well as oyster densities ranging from 0 to 6.0 m^{-2}, suggest otherwise. At a minimum, these grounds would not only require significant substrate replenishment, but major broodstock enhancement. Also, monitoring of potential sanctuary grounds in these waters would be more difficult than traditional river-based restoration reefs due to their open nature; however, this may be accomplished, if federal and state (Virginia and Maryland) governments embraced vessel-positioning technology and required its use with strict penalties for failure to comply.

In 1978, dredging was declared legal during a short, designated late winter season each year. As a result, landings increased to 208,130 bushels for Pocomoke and Tangier Sounds combined during the 1978-79 season, but this level of production quickly decreased to only 23,800 bushels in Pocomoke Sound and 3570 bushels in Tangier Sound during 1983-84. Obviously, the accumulated stocks were quickly exhausted, which is the expected result of overharvest in a region where annual recruitment is marginal or low. Whitcomb and Haven (1987) concluded that while there were 2079 hectares in Pocomoke Sound classed as productive or potentially productive bottoms (Haven et al. 1981), these areas have not been capable of maintaining a sustained high level of natural production. Those conditions persist in Tangier and Pocomoke Sounds today and make these Tier 1 Tributaries poor candidates for large-scale oyster restoration.

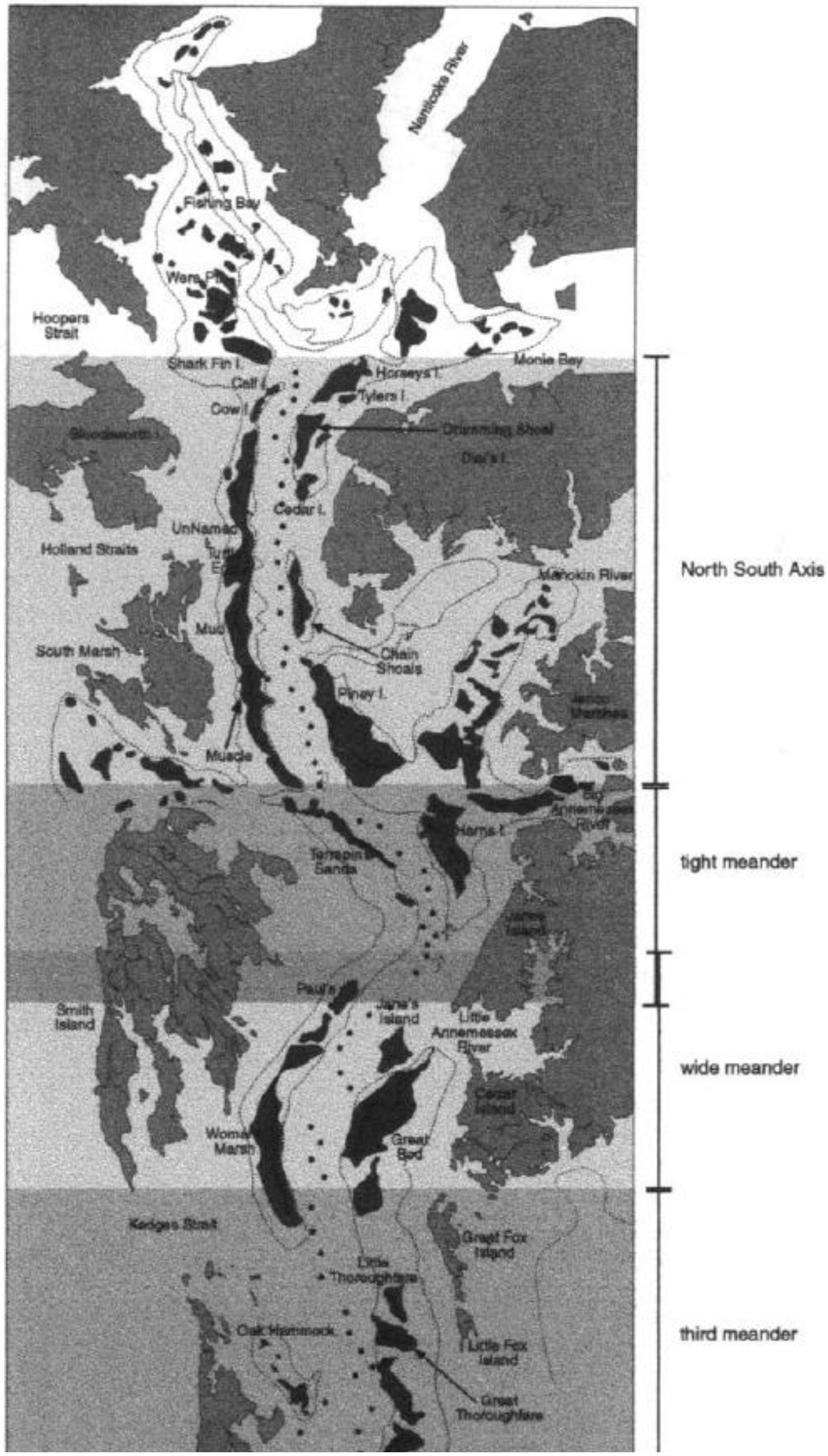


Figure 20. Lieutenant Francis Winslow's oyster bed chart of Tangier Sound. Oyster bed names are identified along the plan-form Tangier Channel. The dark shaded areas indicate hard bottom of normally concentrated oysters; the dashed lines enclose softer bottom occupied by scattered oysters; a solid black line on shaded beds indicates a dense ridge of oysters (McCormick-Ray 1998).

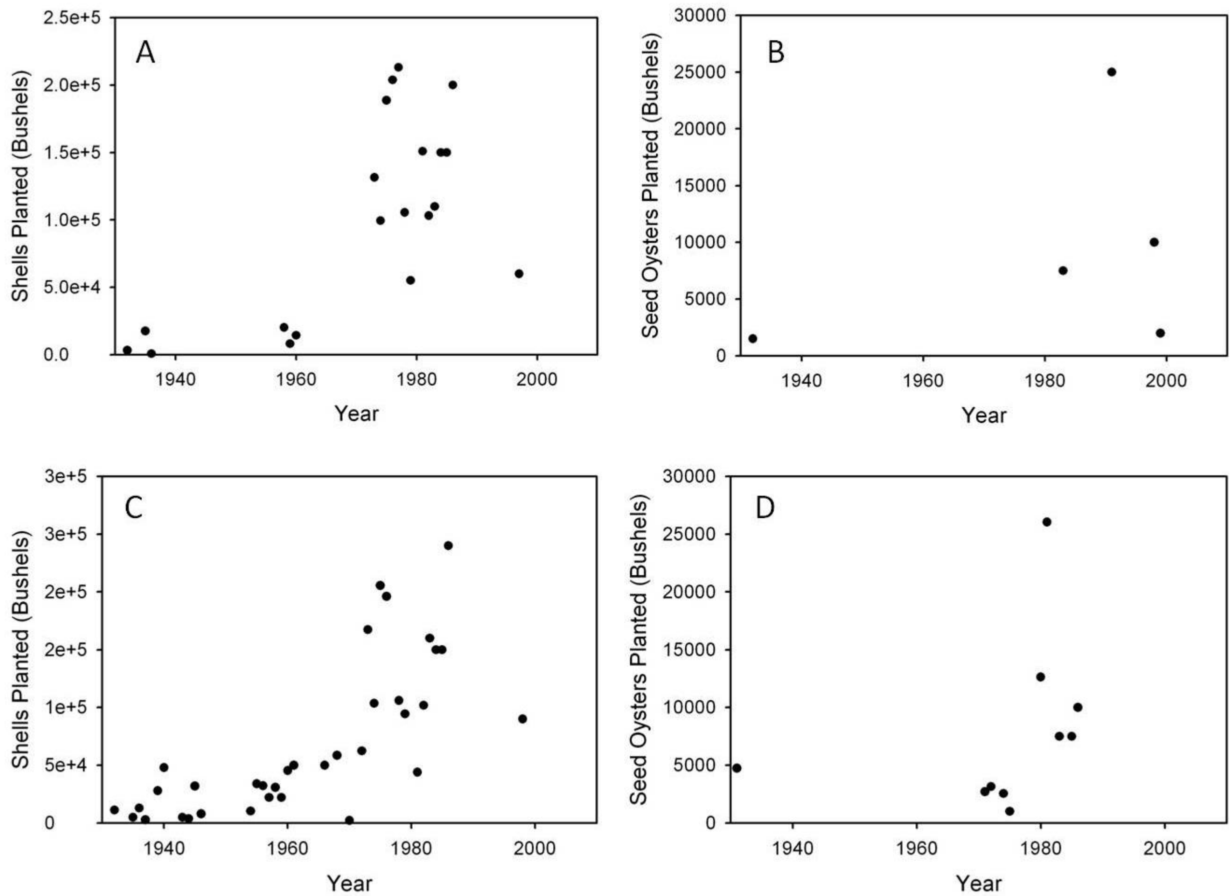


Figure 21. (A, C) Shells and (B, D) seed oysters (in Virginia bushels) planted on public oyster grounds in Tangier and Pocomoke Sounds, respectively (Commission of Fisheries/VMRC Reports, 1931-2009).

York River: The York River (Fig. 22a) is one of the best studied Tier 1 Tributaries due to its proximity to the Virginia Fisheries Laboratory (now VIMS). Oyster spatfall monitoring ranged from 1969 to 1997, with nearly all shellstring observations coming from off of a VIMS pier (Fig. 22b). In most years, recruitment was light-to-moderate. From 1930 through 1981, the York River received shell (Fig. 22c) and seed oysters (Fig. 22d) to support the public oyster fishery. Additional measurements of recruitment and survival to yearlings (Austin et al. 1996) were made in a survey of York River public oyster grounds (Fig. 23a-b), revealing a predictive relationship between spat and yearling abundance the following year (similar to the trend noted in the James and Rappahannock Rivers). The York River public oyster grounds laid fallow for a number of years after the Dermo outbreak of the 1980s and 1990s. In the last few years, however, leaseholders noticed that oysters had returned to their beds and those watermen, as well as public fishers, have begun to work the grounds again. This resurgence may be attributable to the development of disease resistance (Carnegie and Burreson 2009) or simply a natural response to a reduction in harvest pressure; either way, it is a good sign for oyster restoration speculators.

Recently, NOAA and VMRC initiated oyster restoration in the York River – a combination of sanctuary reefs and harvest grounds. The York River is not hydrodynamically retentive, but does contain a number of smaller tributaries that, with some focused attention, could become part of a functional oyster restoration network. And, although spatset has not been high historically and oyster condition varies (Haven 1960, Austin et al. 1993), the York River has appropriate ranges in depth, temperature, salinity, and adequate dissolved oxygen to warrant serious consideration as a candidate for large-scale oyster restoration among the other Virginia Tier 1 Tributaries.

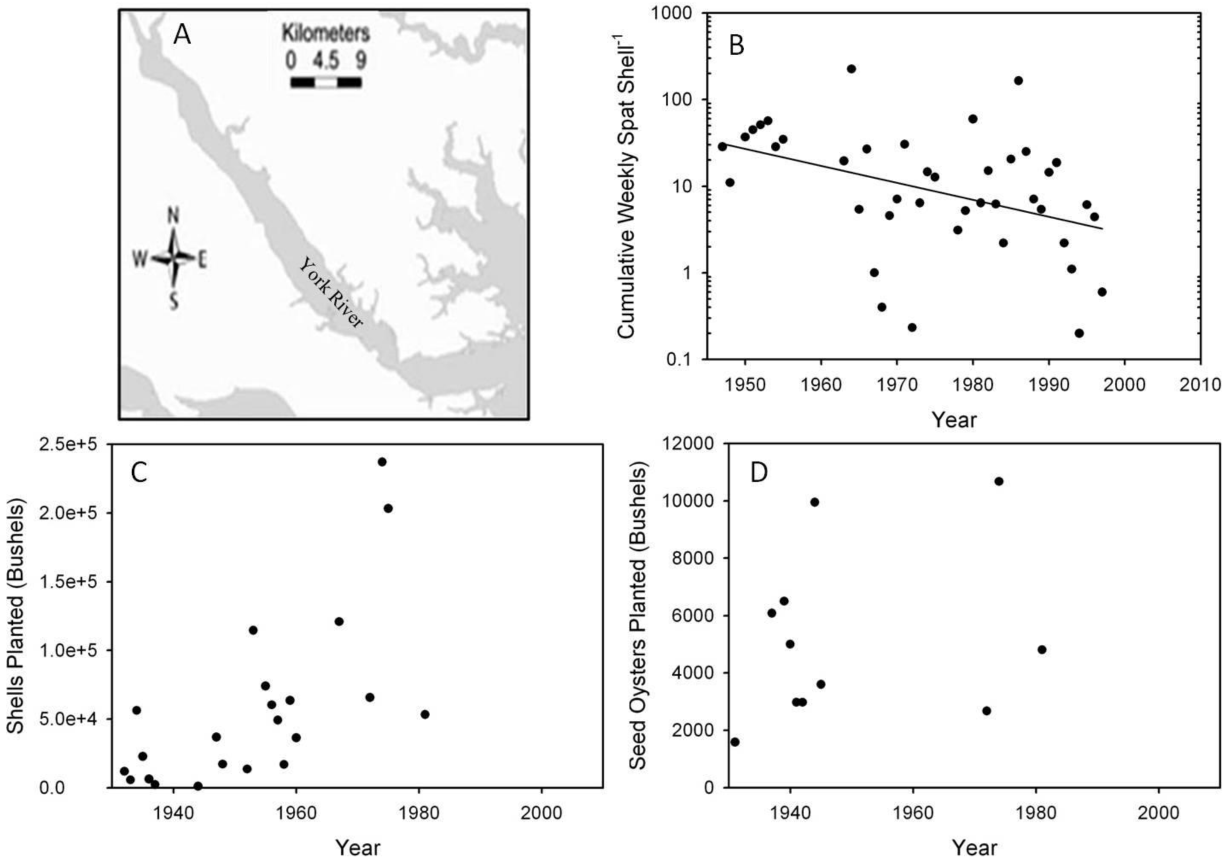


Figure 22. Map of shellstring survey stations in the York River (http://ian.umces.edu). (B) Annual spatfall trends across all sites in the York River (VIMS Annual Spatfall Summaries, 1969-2010). (C) Shells and (D) seed oysters (in Virginia bushels) planted on public oyster grounds in the York River (Commission of Fisheries/VMRC Reports, 1931-2009).

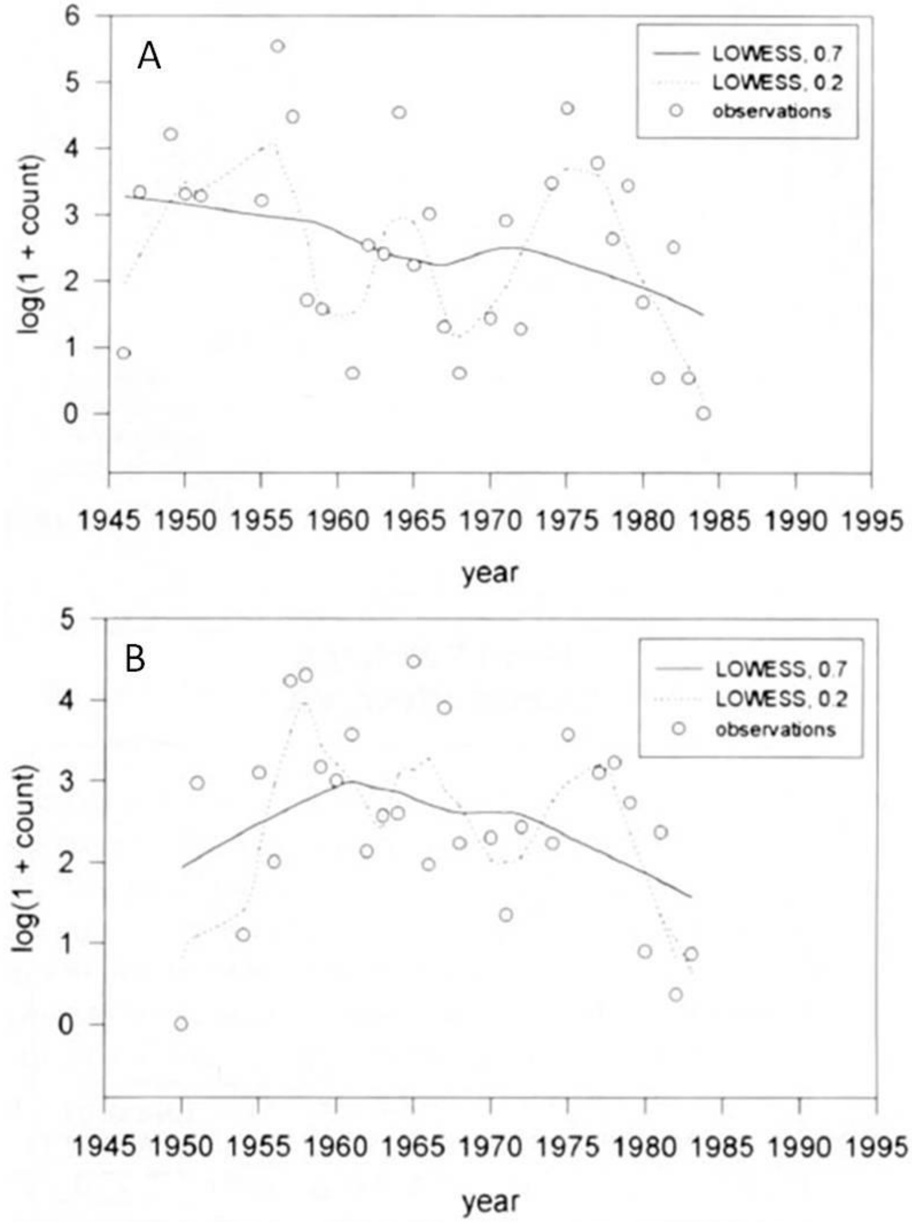


Figure 23. (A) Mean spatfall (number of spat-on-shell per bushel), York River, VA, 1946-1992; *loess* filters at the 0.2 and 0.7 degrees of smoothing. (B) Mean yearlings (number per bushel), York River, VA, 1950-1982; *loess* filters at the 0.2 and 0.7 degrees of smoothing (Austin et al. 1996).

RECOMMENDATIONS

- Major seed-producing tributaries should remain a priority for ecological oyster restoration, due to an enhanced probability of restoration success and the potential of restored oyster populations in these systems serving as sources of seed for future restoration of larger, less historically-productive tributaries.

- Consider the secondary ecological benefits of oyster restoration within the candidate Tier 1 Tributaries – selecting restoration sites based on these additional criteria, rather than those that may be more politically-motivated, will enhance the potential for project success (i.e. sustainability).

- Historically, seed was either transplanted within the source tributary or sent to other Bay subestuaries (Commission of Fisheries 1931-1982). Since 1994, nearly 77% of seed has been transplanted to areas in close proximity to the three remaining large Virginia oyster shucking houses in the Coan, Yeocomico/Nomini, and Rappahannock Rivers (VMRC 1994-2009). Since 2001, all (100%) available seed oysters purchased with Virginia's General Funds (118,000 bushels) have been transplanted to these locations; these seed were transplanted from either the James or Great Wicomico Rivers during these years (VMRC 2001-2009). Should this program of seed transplantation continue, we recommend transplanting seed within, or to, Tier 1 Tributaries actively being restored as part of the large-scale, federal program for ecological oyster restoration.

- Irrespective of the selected Tier 1 Tributaries, give serious consideration to using alternative substrates in tandem with more traditional shell reefs. Research to date shows that well-designed alternative substrate reefs are very durable, productive, attract fish and other mobile species, and provide de facto protection from poaching for the underlying and adjacent shell reefs.

Table 3. Recommendations and rankings for ecological oyster restoration in Virginia's Tier 1 Tributaries.

Tier 1 Tributary	Hydrodynamic Retentiveness	Water Depth	Salinity	Dissolved Oxygen	Adequate Spatset	Oyster Condition	Disease Resistance	Authors' Rank
Great Wicomico River	Yes	Yes	Yes	Yes	Yes	Good	Present (Dermo)	1
James River	Yes	Yes	Yes	Yes	Yes	Very Good	Developing (MSX)	4
Lynnhaven River	Yes	Yes	Yes	Yes	Yes	Good	Present (Dermo/MSX)	2
Mobjack Bay	Not Apparent	Yes	Yes	Yes; parts	Yes (historically)	Good	Likely to Develop	6
Piankatank River	Yes	Yes	Yes	Yes	Yes (historically)	Good	Likely to Develop	3
Rappahannock River	No	Yes	Yes	Yes; parts	Questionable	Very Good	Present (Dermo/MSX)	5
Tangier and Pocomoke Sounds	No	Yes	Yes	Yes	No	Good	Present (Dermo)	8
York River	No	Yes	Yes	Yes	Questionable	Fair to Good	Developing (MSX)	7

LITERATURE CITED

Airoldi L, Beck MW (2007) Loss, status and trends for coastal marine habitats of Europe. Oceanogr Mar Biol Ann Rev 45:345-405

Andrews JD (1947) Weekly oyster spatfall on shellbags, 1947 in the James River seed area. Virginia Institute of Marine Science. Gloucester Point, Virginia 23062

Andrews JD (1949) Weekly oyster spatfall on shellbags, 1948 & 1949 in the James River seed area. Virginia Institute of Marine Science. Gloucester Point, Virginia 23062

Andrews JD (1950) Weekly oyster spatfall on shellbags, 1950 in the James River seed area. Virginia Institute of Marine Science. Gloucester Point, Virginia 23062

Andrews JD (1951) Seasonal patterns of oyster setting in the James River and Chesapeake Bay. Ecology 32:752-758

Andrews JD (1952) Weekly oyster spatfall on shellbags, 1951 & 1952 in the James River seed area. Virginia Institute of Marine Science. Gloucester Point, Virginia 23062

Andrews JD (1954) Setting of oysters in Virginia. Proc Nat Shellfish Ass 45:38-46

Andrews JD (1979) Pelecypoda: Ostreidae. In: AC Giese and JS Pearse, editors. Reproduction of Marine invertebrates. New York, NY: Academic Press, 293-341

Andrews JD (1988) Epizootiology of the disease caused by the oyster pathogen *Perkinsus marinus* and its effects on the oyster industry. Amer Fish Soc Spec Pub 18:47-63

Austin HM, Haven DS, Moustafa MS (1993) The relationship between trends in a condition index of the American oyster, *Crassostrea virginica*, and environmental parameters in three Virginia estuaries. Estuaries 16(2):362-374

Austin HM, Evans DA, Haven DS (1996) A retrospective time series analysis of oyster, *Crassostrea virginica*, recruitment (1946-1993) J Shellfish Res 15(3):565-582

Baker S, Harris FH, Moody CE (1977) A benefit-cost analysis of the Virginia oyster industries: An historical appraisal and proposals for the future. A report to the Marine Resources Commission, Commonwealth of Virginia. Department of Economic. The College of William & Mary. Williamsburg, Virginia 23187

Beck MB, Brumbaugh RD, Airoldi L, Carranza A, Coen LD, Crawford C, Defeo O, Edgar GJ, Hancock B, Kay M, Lenihan H, Luckenbach MW, Toropova CL, Zhang G (2009) Shellfish reefs at risk: A global analysis of problems and solutions. The Nature Conservancy, Arlington VA. 52 pp

Burke RP (2010) Alternative substrates as a native oyster (*Crassostrea virginica*) reef restoration Strategy in Chesapeake Bay. Ph.D. Dissertation. Virginia Institute of Marine Science, The College of William & Mary. 286 pp

Burreson EM, Andrews JD (1988) Unusual intensification of Chesapeake Bay oyster diseases during recent drought conditions. Proc Oceans 88:799-802

Butler PA (1949) Gametogenesis in the oyster under conditions of depressed salinity. Biol Bull 96:263-269

Carlsson J, Carnegie RB, Cordes JF, Hare MP, Leggett AT, Reece KS (2008) Evaluating recruitment contribution of a selectively bred aquaculture line of the oyster, *Crassostrea virginica* used in restoration efforts. J Shellfish Res 27(5):1117-1124

Carnegie RB, Burreson EM (2008) Gametogenesis and spawning in *Crassostrea virginica* from disease-intense waters of Virginia, USA. 11th International Conference on Shellfish Restoration, Charleston, South Carolina 29401

Carnegie RB, Burreson EM (2009) Status of the major oyster diseases in Virginia 2006-2008: A summary of the annual oyster disease monitoring program. Virginia Institute of Marine Science. Gloucester Point, Virginia 23062

Choi KS, Wilson EA, Lewis DH, Powell EN, Ray SM (1989) The energetic cost of *Perkinsus marinus* parasitism in oysters: quantifications of the thioglycollate method. J Shellfish Res 8(1):125-131

Cleveland WS (1979) Robust locally weighted regression and smoothing scatterplots. J Amer Stat Assoc 74:829-836

Coen LD, Grizzle RE (2007) The importance of habitat created by molluscan shellfish to managed species along the Atlantic Coast of the United States. Atlantic States Marine Fisheries Commission Habitat Management Series #8

Commission of Fisheries of Virginia (1931) Thirty-third annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1931. Richmond, Virginia

Commission of Fisheries of Virginia (1932) Thirty-fourth annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1932. Richmond, Virginia

Commission of Fisheries of Virginia (1933) Thirty-fifth annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1933. Richmond, Virginia

Commission of Fisheries of Virginia (1934) Thirty-sixth annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1934. Richmond, Virginia

Commission of Fisheries of Virginia (1935) Thirty-seventh annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1935. Richmond, Virginia

Commission of Fisheries of Virginia (1936) Thirty-eighth annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1936. Richmond, Virginia

Commission of Fisheries of Virginia (1937) Thirty-ninth annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1937. Richmond, Virginia

Commission of Fisheries of Virginia (1939) Fortieth and forty-first annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1938 and June 30, 1939. Richmond, Virginia

Commission of Fisheries of Virginia (1941) Forty-second and forty-third annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1940 and June 30, 1941. Richmond, Virginia

Commission of Fisheries of Virginia (1943) Forty-fourth and forty-fifth annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1942 and June 30, 1943. Richmond, Virginia

Commission of Fisheries of Virginia (1945) Forty-sixth and forty-seventh annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1944 and June 30, 1945. Richmond, Virginia

Commission of Fisheries of Virginia (1947) Forty-eighth and forty-ninth annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1946 and June 30, 1947. Richmond, Virginia

Commission of Fisheries of Virginia (1949) Fiftieth and fifty-first annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1948 and June 30, 1949. Richmond, Virginia

Commission of Fisheries of Virginia (1951) Fifty-second and fifty-third annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1950 and June 30, 1951. Richmond, Virginia

Commission of Fisheries of Virginia (1953) Fifty-fourth and fifty-fifth annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1952 and June 30, 1953. Richmond, Virginia

Commission of Fisheries of Virginia (1955) Fifty-sixth and fifty-seventh annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1954 and June 30, 1955. Richmond, Virginia

Commission of Fisheries of Virginia (1957) Fifty-eighth and fifty-ninth annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1956 and June 30, 1957. Richmond, Virginia

Commission of Fisheries of Virginia (1959) Sixtieth and sixty-first annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1958 and June 30, 1959. Richmond, Virginia

Commission of Fisheries of Virginia (1961) Sixty-second and sixty-third annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1960 and June 30, 1961. Richmond, Virginia

Commission of Fisheries of Virginia (1963) Sixty-fourth and sixty-fifth annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1962 and June 30, 1963. Richmond, Virginia

Commission of Fisheries of Virginia (1965) Sixty-sixth and sixty-seventh annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1964 and June 30, 1965. Richmond, Virginia

Commission of Fisheries of Virginia (1967) Sixty-eighth and sixty-ninth annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1966 and June 30, 1967. Richmond, Virginia

Commission of Fisheries of Virginia (1969) Seventieth and seventy-first annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1968 and June 30, 1969. Richmond, Virginia

Commission of Fisheries of Virginia (1971) Seventy-second and seventy-third annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1970 and June 30, 1971. Richmond, Virginia

Commission of Fisheries of Virginia (1973) Seventy-fourth and seventy-fifth annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1972 and June 30, 1973. Richmond, Virginia

Commission of Fisheries of Virginia (1975) Seventy-sixth and seventy-seventh annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1974 and June 30, 1975. Richmond, Virginia

Commission of Fisheries of Virginia (1977) Seventy-eighth and seventy-ninth annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1976 and June 30, 1977. Richmond, Virginia

Commission of Fisheries of Virginia (1979) Eightieth and eighty-first annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1978 and June 30, 1979. Richmond, Virginia

Commission of Fisheries of Virginia (1980) Eighty-second annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1980. Richmond, Virginia

Commission of Fisheries of Virginia (1982) Eighty-third and eighty-fourth annual report of the Commission of Fisheries of Virginia for the fiscal year ending June 30, 1981 and June 30, 1982. Richmond, Virginia

Ford SE, Figueras AJ (1998) Effects of sublethal infection by the parasite *Haplosploridium nelsoni* (MSX) on gametogenesis, spawning, and sex ratios of oysters in Delaware Bay, USA. Dis Aquat Org 4:121-133

Hargis WH, Haven DS (1998) A reprint of the precarious state of the Chesapeake public oyster resource. Contribution No. 1965 of the Virginia Institute of Marine Science, Gloucester Point, VA 23062

Hargis WJ, Haven DS (1999) Chesapeake oyster reefs, their importance, destruction and guidelines for restoring them. p. 329-358. *In*: (eds) MW Luckenbach, R Mann, and JA Wesson. Virginia Institute of Marine Science Press, Gloucester Point, Virginia 23062

Haven D (1960) Seasonal cycle of condition index of oysters in the York and Rappahannock Rivers. Proceedings of the National Shellfisheries Association. 51:42-66

Haven D (1969) Annual summary for 1969: Oyster spatfall on shellstrings in Virginia rivers. Marine Resource Information Bulletin. Virginia Institute of Marine Science, Gloucester Point, Virginia 23062. 1(4):5-17

Haven D (1970) Annual summary for 1970: Oyster spatfall on shellstrings in Virginia rivers. Marine Resource Information Bulletin. Virginia Institute of Marine Science, Gloucester Point, Virginia 23062. 2(15):1-11

Haven D (1971a) Annual summary for 1970: Oyster spatfall on shellbags in Virginia rivers. Marine Resource Information Bulletin. Virginia Institute of Marine Science, Gloucester Point, Virginia 23062. 3(5):1-6

Haven D (1971b) Annual summary for 1971: Oyster spatfall on shellstrings in Virginia rivers. Marine Resource Information Bulletin. Virginia Institute of Marine Science, Gloucester Point, Virginia 23062. 3(18):1-12

Haven D, Kendall P (1973) 1972 Annual summary: Oyster spatfall on shellstrings in Virginia rivers. Marine Resource Information Bulletin. Special Report. Virginia Institute of Marine Science, Gloucester Point, Virginia 23062. 15 pp

Haven D, Kendall P (1974) 1973 Annual summary: Oyster spatfall on shellstrings in Virginia rivers. Marine Resource Information Bulletin. A Sea Grant Advisory Service Special Report. Virginia Institute of Marine Science, Gloucester Point, Virginia 23062. 15 pp

Haven DS, Hargis WJ, Loesch JG, Whitcomb JP (1974) The effect of tropical storm Agnes on oysters, hard clams, soft clams, and oyster drills. In: AM Andersen and ML Wass, editors. Reports on the effects of tropical storm Agnes on the Chesapeake Bay estuarine system. Ches Res Consortium Pub No. 34, D169-D208

Haven D, Kendall P (1977) 1977 Spatfall summary. Marine Resource Information Bulletin. Virginia Institute of Marine Science, Gloucester Point, Virginia 23062. p. 7

Haven DS, Hargis WJ, Kendall PC (1978) The oyster industry of Virginia: its status, problems and promise. VIMS special papers in marine science, Virginia Institute of Marine Science, Gloucester Point, VA 23062

Haven DS, Whitcomb JP, Kendall PC (1981) The present and potential productivity of the Baylor Grounds in Virginia. Special Report in Applied Marine Science and Ocean Engineering No. 243. Virginia Institute of Marine Science, Gloucester Point, VA 23062

Haven D, Kendall P (1982) 1981 Annual summary: Oyster spatfall in Virginia rivers. Marine Resource Special Report. Virginia Institute of Marine Science, Gloucester Point, Virginia 23062. 14 pp

Haven DS, Fritz LW (1985) Setting of the American oyster *Crassostrea virginica* in the James River, Virginia, USA: temporal and spatial distribution. Mar Biol 86:271-282

Herberich D (2006) Estimated return to harvest due to the Maryland Department of Natural Resources repletion activities 1990-2006. College Park, MD 20742

Ingersoll E (1881) 10th Census of the United States, the history and present condition of the fishery industries. The oyster industry. 251 pp

Kirby MX (2004) Fishing down the coast: historical expansion and collapse of oyster fisheries along continental margins. Proc Nat Acad Sci 101(35):13096-1309

Krantz GE, Meritt DW (1977) An analysis of trends in oyster spat set in the Maryland portion of the Chesapeake Bay. Proc Natl Shellfish Assoc 67:53-59

Lawless AS (2008) Effects of shoreline development and oyster reefs on benthic communities in Lynnhaven, Virginia. Master's Thesis. The College of William & Mary. Gloucester Point, Virginia 23062

Lipcius RN, Eggleston DB, Schreiber SJ, Seitz RD, Shen J, Sisson M, Stockhausen WT, Wang HV (2008) Importance of metapopulation connectivity to restocking and restoration of marine species. Rev Fish Sci 16(1-3):101-110

Lotze HK, Lenihan HS, Bourque BJ, Bradbury, RH, Cooke RG, Kay MC, Kidwell SM, Kirby MX, Peterson CH, Jackson JBC (2006) Depletion, degradation, and recovery potential of estuaries and coastal seas. Science 312:1806-1809

Luckenbach MW, Ross PG (2009) Recruitment, substrate quality and standing stock monitoring in support of NOAA-ACOE oyster restoration projects in the Great Wicomico, Rappahannock, Piankatank and Lynnhaven River Basins 2004-2006. VIMS ESL GIS-based Summary of Native Oyster Monitoring, Grant #NA06NMF4570303

McCormick-Ray MG (1998) Oyster reefs in 1878 seascape pattern: Winslow revisited. Estuaries 21(4B):784-800

Mann R, Morales-Alamo R (1994) The status of Virginia's public oyster resource 1993. Molluscan ecology program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 33 pp

Mann R, Evans DA (1998) Estimation of oyster, *Crassostrea virginica*, standing stock, larval production and advective loss in relation to observed recruitment in the James River, Virginia. J Shellfish Res 17(1):239-254

Mann R, Southworth M, Harding JM, Wesson JA (2009) Populations studies of the native eastern oyster, *Crassostrea virginica*, (Gmelin, 1791) in the James River, Virginia, USA J Shellfish Res 28(2):193-220

Medcof JC (1939) Larval life of the oyster (*Ostrea virginica*) in Bideford River. J Fish Res Bd Canada 4:287-301

Map of Mobjack Bay (2010) www.chesapeakeboating.net

Morales-Alamo R, Mann R (1995) The status of Virginia's public oyster resource 1994. Molluscan ecology program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 37 pp

Morales-Alamo R, Mann R (1996) The status of Virginia's public oyster resource 1995. Molluscan ecology program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 45 pp

Morales-Alamo R, Mann R (1997) The status of Virginia's public oyster resource 1996. Molluscan ecology program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 48 pp

Morales-Alamo R, Mann R (1998) The status of Virginia's public oyster resource 1997. Molluscan ecology program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 51 pp

Munch SB, Walsh MR, Conover DO (2005) Harvest selection, genetic correlations, and evolutionary changes in recruitment: one less thing to worry about? Can J Fish Aquat Sci 62:802-810

Newell RIE, Barber BJ (1990) Summary and recommendations of oyster recruitment and standing stock monitoring workshop held at Horn Point Environmental Laboratories, November 6 and 7, 1990. Funded by Maryland Department of Natural Resources

Oyster Advisory Commission (2008) http://www.dnr.state.md.us/fisheries/oysters/

Santopietro GD, Stephenson K, Satyal VA, Wesson J (2009) A bioeconomic analysis of management plans for the public oyster grounds of the Rappahannock River. J Shellfish Res 28(2):235-241

Schulte DM (2003) Final Decision Document Amendment, Section 704B as Amended, Chesapeake Bay Oyster Recovery Phase III, Great Wicomico River, Virginia. Norfolk District – United States Army Corps of Engineers. Norfolk, Virginia 23510-1096

Schulte DM, Cleland M, Groth K (2006) Final Decision Document Amendment, Section 704B as Amended, Chesapeake Bay Oyster Recovery Phase IV, Lynnhaven River, Virginia. Norfolk District – United States Army Corps of Engineers. Norfolk, Virginia 23510-1096

Schulte DM, Burke RP, Lipcius RN (2009) Unprecedented restoration of a native oyster metapopulation. Science 325:1124-1128

Smith GF, Bruce DG, Roach EB, Hansen A, Newell RIE, McManus AM (2005) Assessment of recent habitat conditions of eastern oyster *Crassostrea virginica* bars in mesohaline Chesapeake Bay. N Am J Fish Man 25:1569-1590

Southworth M, Mann R (1998) Oyster reef broodstock enhancement in the Great Wicomico River, Virginia. J Shellfish Res 17(4):1101-1114

Southworth M, Harding JM, Mann R (1999) The status of Virginia's public oyster resource 1998. Molluscan ecology program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 42 pp

Southworth M, Harding JM, Mann R (2000) The status of Virginia's public oyster resource 1999. Molluscan ecology program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 44 pp

Southworth M, Harding JM, Mann R (2001) The status of Virginia's public oyster resource 2000. Molluscan ecology program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 49 pp

Southworth M, Harding JM, Mann R (2002) The status of Virginia's public oyster resource 2001. Molluscan ecology program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 53 pp

Southworth M, Harding JM, Mann R (2003) The status of Virginia's public oyster resource 2002. Molluscan ecology program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 51 pp

Southworth M, Mann R (2004) Decadal scale changes in seasonal patterns of oyster recruitment in the Virginia sub estuaries of the Chesapeake Bay. J Shellfish Res 23(2):391-402

Southworth M, Harding JM, Mann R (2004) The status of Virginia's public oyster resource 2003. Molluscan ecology program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 55 pp

Southworth M, Harding JM, Mann R (2005) The status of Virginia's public oyster resource 2004. Molluscan ecology program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 51 pp

Southworth M, Harding JM, Mann R (2006) The status of Virginia's public oyster resource 2005. Molluscan ecology program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 49 pp

Southworth M, Harding JM, Mann R (2007) The status of Virginia's public oyster resource 2006. Molluscan ecology program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 49 pp

Southworth M, Harding JM, Mann R (2008) The status of Virginia's public oyster resource 2007. Molluscan ecology program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 49 pp

Southworth M, Harding JM, Mann R (2009) The status of Virginia's public oyster resource 2008. Molluscan ecology program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 53 pp

Southworth M, Harding JM, Mann R (2010) The status of Virginia's public oyster resource 2009. Molluscan ecology program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 52 pp

United States Army Corps of Engineers (2009) Final programmatic environmental impact statement for oyster restoration in Chesapeake Bay including the use of a native and/or nonnative oyster. Norfolk, Virginia 23510

Virginia Marine Resources Commission (1984) Official Minutes of the Virginia Marine Resources Commission, January-December 1983. Newport News, Virginia 23607

Virginia Marine Resources Commission (1985) Official Minutes of the Virginia Marine Resources Commission, January-December 1984. Newport News, Virginia 23607

Virginia Marine Resources Commission (1986) Official Minutes of the Virginia Marine Resources Commission, January-December 1985. Newport News, Virginia 23607

Virginia Marine Resources Commission (1987) Official Minutes of the Virginia Marine Resources Commission, January-December 1986. Newport News, Virginia 23607

Virginia Marine Resources Commission (1989) Official Minutes of the Virginia Marine Resources Commission, January-December 1988. Newport News, Virginia 23607

Virginia Marine Resources Commission (1990) Official Minutes of the Virginia Marine Resources Commission, January-December 1989. Newport News, Virginia 23607

Virginia Marine Resources Commission (1991) Official Minutes of the Virginia Marine Resources Commission, January-December 1990. Newport News, Virginia 23607

Virginia Marine Resources Commission (1992) Official Minutes of the Virginia Marine Resources Commission, January-December 1991. Newport News, Virginia 23607

Virginia Marine Resources Commission (1993) Official Minutes of the Virginia Marine Resources Commission, January-December 1992. Newport News, Virginia 23607

Virginia Marine Resources Commission (1994) Official Minutes of the Virginia Marine Resources Commission, January-December 1993. Newport News, Virginia 23607

Virginia Marine Resources Commission (1995) Official Minutes of the Virginia Marine Resources Commission, January-December 1994. Newport News, Virginia 23607

Virginia Marine Resources Commission (1996) Official Minutes of the Virginia Marine Resources Commission, January-December 1995. Newport News, Virginia 23607

Virginia Marine Resources Commission (1997) Official Minutes of the Virginia Marine Resources Commission, January-December 1996. Newport News, Virginia 23607

Virginia Marine Resources Commission (1998) Official Minutes of the Virginia Marine Resources Commission, January-December 1997. Newport News, Virginia 23607

Virginia Marine Resources Commission (1999) Official Minutes of the Virginia Marine Resources Commission, January-December 1998. Newport News, Virginia 23607

Virginia Marine Resources Commission (2000) Official Minutes of the Virginia Marine Resources Commission, January-December 1999. Newport News, Virginia 23607

Virginia Marine Resources Commission (2001) Official Minutes of the Virginia Marine Resources Commission, January-December 2000. Newport News, Virginia 23607

Virginia Marine Resources Commission (2002) Official Minutes of the Virginia Marine Resources Commission, January-December 2001. Newport News, Virginia 23607

Virginia Marine Resources Commission (2003) Official Minutes of the Virginia Marine Resources Commission, January-December 2002. Newport News, Virginia 23607

Virginia Marine Resources Commission (2004) Official Minutes of the Virginia Marine Resources Commission, January-December 2003. Newport News, Virginia 23607

Virginia Marine Resources Commission (2005) Official Minutes of the Virginia Marine Resources Commission, January-December 2004. Newport News, Virginia 23607

Virginia Marine Resources Commission (2006) Official Minutes of the Virginia Marine Resources Commission, January-December 2005. Newport News, Virginia 23607

Virginia Marine Resources Commission (2007) Official Minutes of the Virginia Marine Resources Commission, January-December 2006. Newport News, Virginia 23607

Virginia Marine Resources Commission (2008) Official Minutes of the Virginia Marine Resources Commission, January-December 2007. Newport News, Virginia 23607

Virginia Marine Resources Commission (2009) Official Minutes of the Virginia Marine Resources Commission, January-December 2008. Newport News, Virginia 23607

Virginia Marine Resources Commission (2010) Official Minutes of the Virginia Marine Resources Commission, January-December 2009. Newport News, Virginia 23607

Whitcomb J (1984) 1983 Annual summary: Oyster spatfall in Virginia rivers. Marine Resource Special Report. Virginia Institute of Marine Science, Gloucester Point, Virginia 23062 21 pp

Whitcomb J (1987) 1987 Annual summary: Oyster spatfall in Virginia rivers. Marine Resource Special Report. Virginia Institute of Marine Science, Gloucester Point, Virginia 23062 20 pp

Whitcomb JP and Haven DS (1987) The physiography and extent of public oyster grounds in Pocomoke Sound, Virginia. Jour Shellfish Res 6(2):55-65

Attachment 1-D: Small Tributary Flushing Time Analysis (Wazniak et al. 2009)

Residence Times of Small Chesapeake Bay Tributaries

Thomas Wazniak, William Boicourt, and Elizabeth North
University of Maryland Center for Environmental Science
Horn Point Laboratory

July 16, 2009

Table of Contents

Background and rationale

The retention of oyster larvae in a system depends upon the flushing time of the water in the system as well as the amount of suitable settlement habitat. Three dimensional numerical models are excellent tools to estimate the flushing time (e.g., Shen and Wang, 2007) because they can incorporate tidal, freshwater flow and wind forcing. But, these models are costly to implement in multiple systems, require high-resolution grids, and are not currently numerous enough to make comparisons of the flushing time among the many small tributaries in Chesapeake Bay that could serve as the site of oyster restoration projects. Another method of determining flushing time, the freshwater fraction method, is also valid and is relatively convenient to determine if salinity data are available. The chief advantage of the freshwater fraction method is that it integrates over many flushing mechanisms, including tide, estuarine gravitational flow, and wind circulation. However, most tributaries and embayments under consideration are not sufficiently large to have strong density-driven circulations. For this reason, the classic tidal-prism method is more appropriate for providing a comparative index among many tributaries.

Instead of using a three-dimensional model or the freshwater fraction technique, we use the adjusted intertidal volume method. This is a relatively simple yet robust approach to estimate the flushing time of many small tributaries that is a modification of the tidal-prism method. The method assumes that the intertidal volume, the volume of water that enters and leaves the estuary with the tidal currents, mixes completely with the existing water in the estuary at high tide. Calculation of intertidal volume takes into account the tributary shape (surface area, volume, and depth) as well as tidal forcing. This assumes that tidal currents provide the primary mechanism for moving larvae, contaminants, or other water-borne materials out of the water body of interest. While this assumption may overestimate flushing time for tributaries exposed to large fetches and hence, wind-driven flushing, it provides a straightforward and operationally defined method for the tidal component of flushing, which is steady and predictable. Traditionally, flushing time has been calculated by assuming all water-borne materials in the intertidal volume are eliminated on ebb tide. In reality, a portion of the intertidal volume and the water-borne materials flow back into the tributary or embayment on the following flood tide. To correct for this return flow, we calculate an adjusted intertidal volume using the Sanford, Boicourt, and Rives (1992) correction method. Testing of this method in an enclosed water body off Indian River Bay in Delaware indicated significant improvement in tidal flushing calculations.

Our objective was to create numerical indices that allow comparison of the ‘retentiveness’ of different basins in Chesapeake Bay. We calculated three indices for 36 tributaries of Chesapeake Bay: percent intertidal volume, tidal prism flushing time, and tidal prism flushing time adjusted by a return flow factor. We used readily available data to calculate these indices, including shoreline and bathymetric data as well as predicted tidal currents. Our methods and results are described here, and are placed in the context of previous estimates of residence time for Chesapeake Bay tributaries.

2. Tributaries of Interest

Thirty-six small tributaries were selected by Native Oyster Restoration Team members for inclusion in this analysis (Fig. 1, Table 1). Major tributaries of Chesapeake Bay (e.g. Potomac, James and Rappahannock Rivers) were not included in the analysis because their circulation patterns violate the assumptions of our methods. Significant freshwater flow into these tributary induces density-driven (gravitational) circulation. Our analysis assumes that tidally-driven circulation is the main component of the tributaries flow patterns. Hence, we limited our analysis to small tributaries that do not have significant freshwater input or a well-defined gravitational circulation.

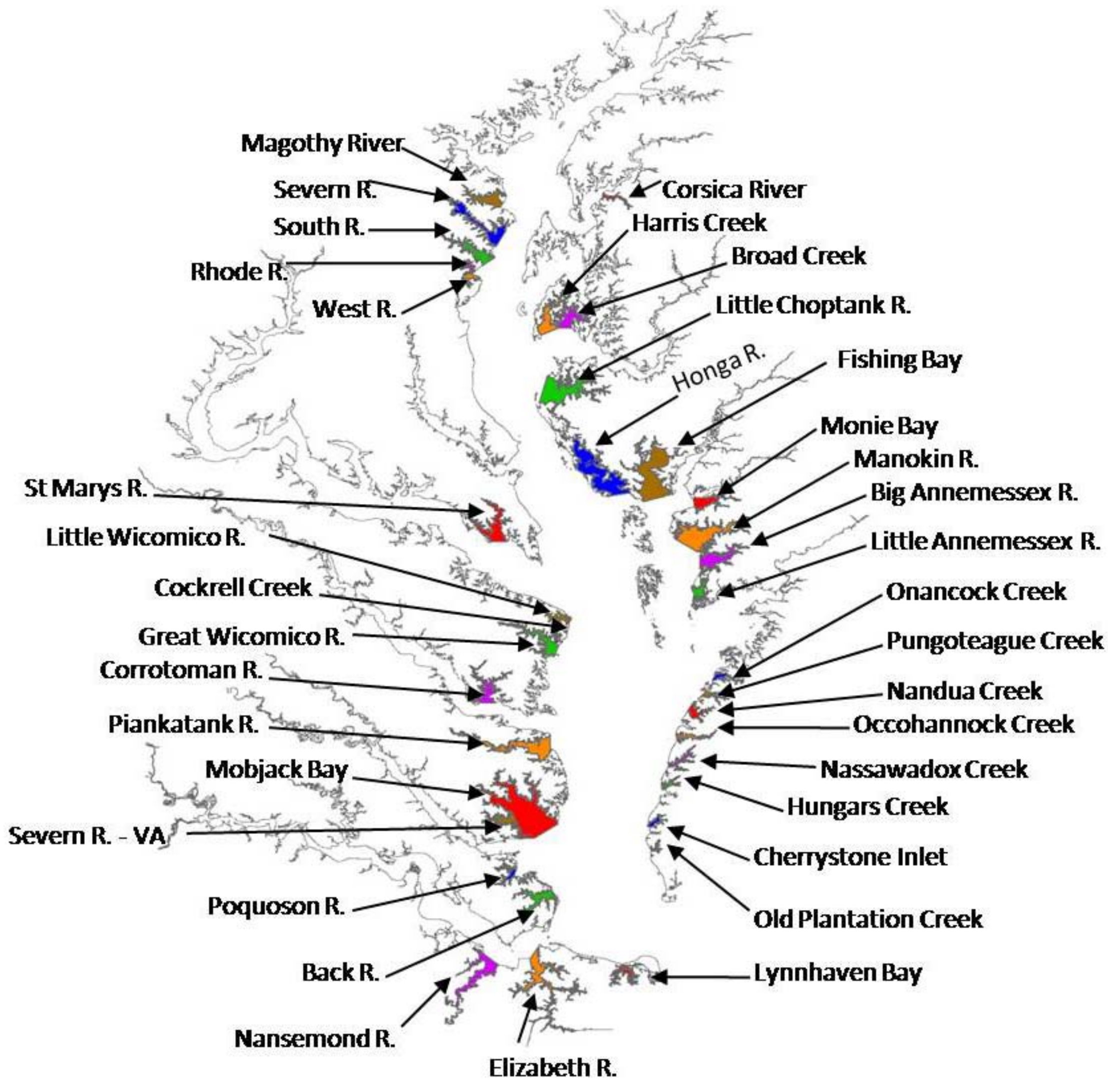


Fig. 1. Tributaries for which flushing times were calculated.

Table 1. List of tributaries included in this analysis.

No.	Tributary	State
1	Back River	VA
2	Big Annemessex River	MD
3	Broad Creek	MD
4	Cherrystone Inlet	VA
5	Cockrell Creek	VA
6	Corrotoman River	VA
7	Corsica River	MD
8	Elizabeth River	VA
9	Fishing Bay	MD
10	Great Wicomico River	VA
11	Harris Creek	MD
12	Honga River	MD
13	Hungars Creek	VA
14	Little Annemessex River	MD
15	Little Choptank River	MD
16	Little Wicomico River	VA
17	Lower Manokin River	MD
18	Lynnhaven Bay	VA
19	Magothy River	MD
20	Mobjack Bay	VA
21	Monie Bay	MD
22	Nandua Creek	VA
23	Nansemond River	VA
24	Nassawadox Creek	VA
25	Occohannock Creek	VA
26	Old Plantation Creek	VA
27	Onancock Creek	VA
28	Piankatank River	VA
29	Poquoson River	VA
30	Pungoteague River	VA
31	Rhode River	MD
32	Severn River	MD
33	Severn River	VA
34	South River	MD
35	St. Mary’s River	MD
36	West River	MD

3. Methods

Three indices of retentiveness were calculated: percent intertidal volume, tidal prism flushing time, and tidal prism flushing time adjusted by a return flow factor. The percent intertidal volume (*PIV*) is derived from the tidal prism (*P*, m^3) and mean basin volume (*V*, m^3):

$$PIV = 100 \times \frac{P}{V}$$

and $V = V_{MLW} + P/2$, where V_{MLW} is mean-low-water (MLW) volume. The tidal prism is:

$$P = A \times R$$

where *A* = surface area of the basin and *R* = the average tidal range (Sanford et al.1991). Data files and procedures for calculating surface area and volume of tributaries are described in sections 3.1 and 3.2 below. Tidal range data for each tributary was derived from the National Oceanic and Atmospheric Administration (NOAA) Technical Report NOS OMA 3 (Browne & Fisher 1988).

Tidal prism flushing time (T_f) was calculated with the following equation:

$$T_f = \frac{V}{P} T$$

where *T* = tidal period=12.42 hr. Flushing time is conventionally taken as the time for the concentration of a water-borne substance within a confined water body to fall to 1/e or 0.37 of its initial concentration. The assumptions of this technique are that the estuary is well mixed at high tide, there is low freshwater input, and there is no return flow on the subsequent flood tide. The latter two assumptions can be relaxed with minor changes in the formulations and with phases of tidal currents taken into account. A return flow factor takes into account the phases of the tidal currents. To calculate the tidal prism flushing time adjusted by a return flow factor, the following equation was applied:

$$T_f = \frac{V}{(1-b)P} T$$

where *b* is the return flow factor. The primary determinant of the return-flow factor is the relationship between the tidal height in the estuary and tidal current in the adjacent water body near the entrance to the tributary (Sanford et al., 1991). For small tributaries, the tide within the tributary is typically a standing wave, with slack water occurring at high and low tide. If the tide within the adjacent water body is also a standing wave, then a significant amount of water (and water-borne materials) that is discharged on ebb tide reenters the tributary on the subsequent flood tide (Fig. 2b).

If, however, the tide in the adjacent water body is a progressive wave, as it is for most of the main stem of Chesapeake Bay, then most of the water exiting the tributary gets swept away by tidal currents, and little reenters the tributary on flood tide (Fig. 2a). In other words, if the tides in the tributary and adjacent water body are in phase, then water that was transported out of the tributary on the previous tide would be in a position to be transported back into the tributary on the subsequent tide, thus reducing actual flushing time. To improve the estimate of the amount of water returned to the estuary, Sanford et al. (1991) explicitly modeled the behavior of the tributary plume in the adjacent water body between high tides. In addition to the relative tidal phasing between the tributary and the adjacent water body, the primary determinant of return flow was the degree of separation of the plume from the coastline. Sanford et al. also showed that the velocity of the exiting flow from the tributary must be greater than 60% of the velocity in the adjacent water body for the plume to separate. In the Chesapeake Bay, with the tide in the main stem of the estuary propagating as a nearly pure progressive wave (Fig. 3), the assumption of a non-separated plume will likely suffice for the purposes herein. In addition, given the progressive nature of this main-stem tidal wave, the return-flow factors are expected to be small for most tributaries of interest.

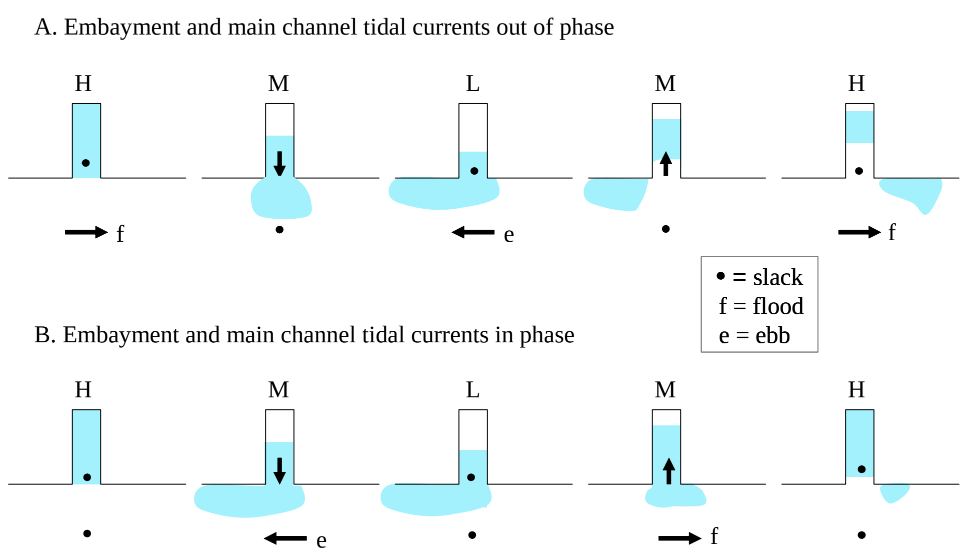


Fig. 2. Conceptual diagram of flushing water from an embayment when A) tidal currents in the embayment and main channel are out of phase (channel current is a progressive wave), and B) tidal currents are in phase (channel current is a standing wave). Letters above embayments indicate tidal heights (H = high, M = mean, L = low).

If detailed information were available on currents in tributary entrances and in the adjacent water body, then the return-flow factor could be determined directly by inserting these values into the Sanford et al. (1991) model. Without this information, the recommended strategy is to calculate flushing times for a range of return-flow factors and then provide a best estimate time based on actual phase differences and spatial relationships between tributaries and the main stem Bay (Fig. 3). If the problem at hand

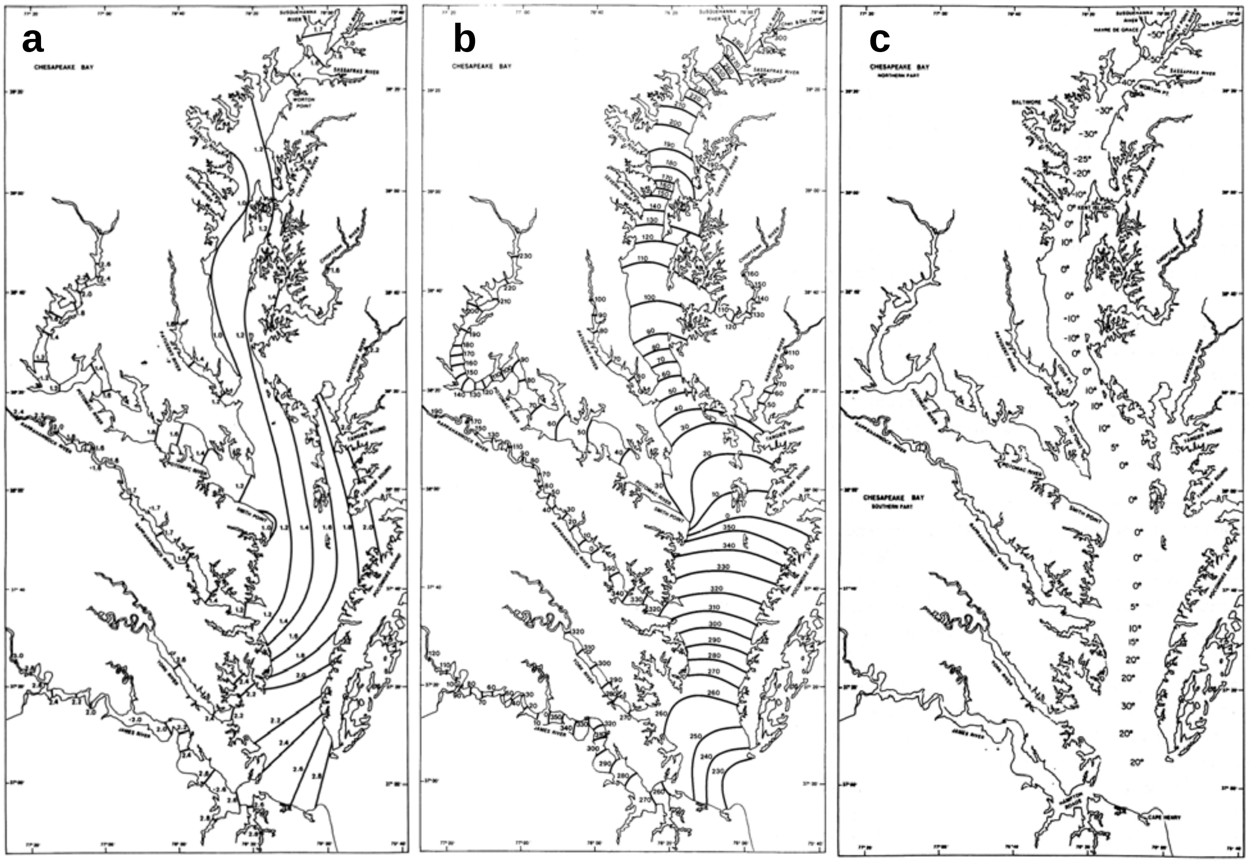


Fig. 3. Tidal characteristics of Chesapeake Bay, with a) co-range lines of total tide, b) co-phase lines of the M_2 tide, and c) phase difference between current and height of the M_2 tide. The semidiurnal tide propagates into the Bay as a progressive wave, altered slightly by the rotation of the earth. The earth's rotation effect can be seen best in the middle reaches of the Bay, where the range increases by a factor of 2 between Smith Point and Crisfield. The phase difference chart reveals the tidal character as nearly pure progressive (with tide and current in phase), rather than a standing wave, with tidal height and current 90^o out of phase. (Reprinted from Browne and Fisher, 1988)

were to provide a conservative estimate for flushing time for pollutants in a tributary, best-estimate return flow factors would typically be chosen on the higher end of the likely range. However, for the purposes herein, for estimating retentiveness of oyster larvae, a conservative estimate would be to select values in the lower portion of the range. Hence, with the progressive nature of the Chesapeake Bay tidal wave, most return flow factors were small, and represent only a relatively minor correction over the no return flow case. Higher values of return flow factors were chosen for tributaries such as the Elizabeth River, the Nansemond River, the Corrotoman River, and the West/Rhode Rivers, because their entrances are not located immediately adjacent to the main stem Bay channel. With the exception of Fishing Bay and the Corsica River, phase differences between tidal height and tidal current are sufficiently small enough that little correction is necessary for tidal phase (Fig. 3c). In these two counter examples, their entrances are separated at some distance from the main stem Bay, but more importantly, they communicate with a tributary to the Bay at a location where the character of the tidal wave begins to change from progressive to standing.

A literature search was conducted to collect other estimates of tributary retentiveness within the Chesapeake system. When possible, these values were directly compared with the indices calculated herein.

3.1. Data Files

Two master data files were used to calculate the surface area and volume for each small tributary. The first file, a high resolution-polyline-shapefile of the Chesapeake Bay shoreline, was used to define the extent of the data ("NGA_GlobalShoreline_cd17.shp"). The second file, a raster dataset, provided the bathymetric data to calculate the depth of the tributaries at MLW ("bathygrid_utm.adf"). By manipulating and combining the two files, then running multiple functions on each, we were able to calculate area and volume for each tributary. Kelly Greenhawk of Maryland Department of Natural Resources, provided the data files.

The Chesapeake Bay shoreline file, "ChesBay_Hull", was created from the GIS shapefile "NGA_GlobalShoreline_cd17.shp" with a geographic coordinate system of NAD 1983. The data was projected to the coordinate system NAD 1983 UTM Zone 18N. This projection was necessary because we performed calculations on data that reside in both Maryland and Virginia. The extent of the dataset incorporates the entirety of Chesapeake Bay and can be measured in linear units of meters and angular units of degrees.

The Chesapeake Bay bathymetric file, "bathygrid_utm", was created from a GIS raster file that was projected to the coordinate system NAD 1983 UTM Zone 18N. Again, the extent of the dataset includes the whole of Chesapeake Bay and can be measured in linear units of meters and angular units of degrees. The high resolution gridded water depth data has a cell size of 10m X 10m. The data were saved as integers and the depths were divided by ten (10) in order to reduce the file size for subsequent processing. In the final processing steps, the data were multiplied by 10 to yield the correct measurements.

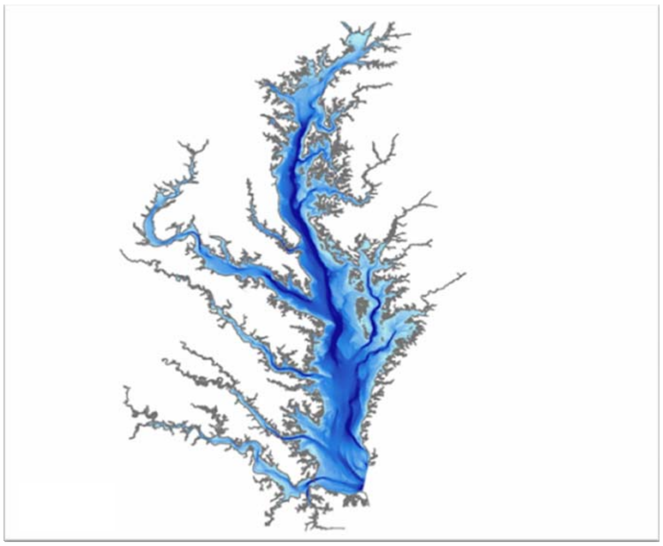


Fig. 4. Image of raw shoreline and bathymetry files.

3.2. Surface area and volume for small tributaries

To calculate surface area and volumes of each tributary, first the shoreline boundaries of the tributary were defined. From the Chesapeake Bay shoreline file (Fig. 4) we were able to clip out the smaller tributary shorelines.

A "dummy" shapefile was created to clip out the polyline data of each tributary's boundaries. This "hull" was not yet complete because it lacked the bounding lines of the tributary mouth. Specification of the mouth for most of the tributaries was accomplished by using river mouth coordinates established in CBI Special Report 20 (Cronin, 1971). For the tributaries for which there was no data in the CBI report, river mouths were delineated in a manner similar to Cronin (1971), with straight lines drawn across the entrances to the tributaries. In most cases, the determination was straightforward, connecting obvious geographic features forming the entrances. Even in less obvious cases, the exact definition is not of concern because residence time calculations are not sensitive to choices of entrance locations. Once the river mouth lines were determined, the tributary hull was complete (e.g., Fig. 5).

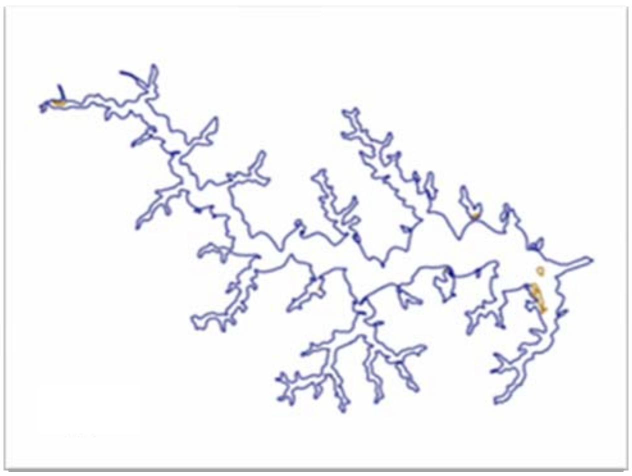


Fig. 5. Example of a tributary hull, an enclosed polygon comprised of the shoreline and a line across the mouth. Brown shapes are islands.

The next step was to convert the polylines of each tributary to polygons. However, in many cases there were problems with the polylines that were clipped out of the master shoreline file. We experienced "dangles" and "self-intersecting lines" when we tried to move to the next step (creating polygons) in the data processing. Dangles are extraneous lines that extend from the valid polyline data. Self-intersecting lines are sections of polylines that cross each other. In both cases, editing was necessary; deleting problem lines in the case of dangles, and removing duplicate nodes in the case of self-intersecting lines.

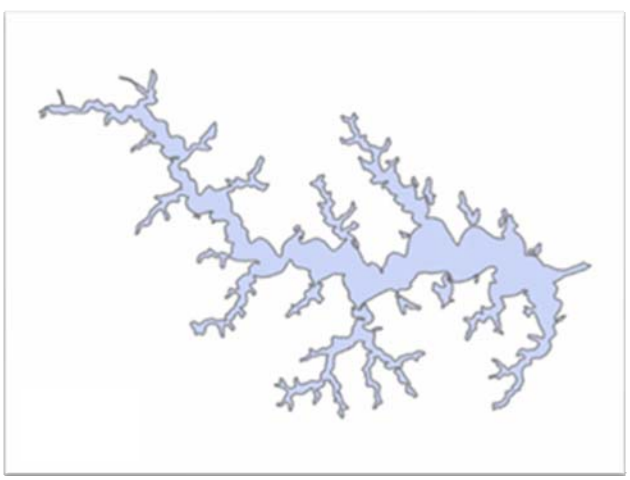


Fig. 6. Example of a tributary polygon without islands.

If islands were present in the tributaries, the islands were selected, exported as shapefiles, and removed from the shoreline file. After the islands were removed, the tributary polylines were converted to polygons (Fig. 6). This conversion was necessary for combining the shoreline and bathymetric data so that area and volume could be calculated. Polygons were also created from the island polylines. An erase function was used to remove the island polygons from the tributary polygons, ensuring that the area and volume calculations did not include the islands.

Once the boundaries of each tributary were defined within polygons we were able to use the master bathymetry file to extract the water depth data for each system. A raster clip tool was applied which used the tributary polygon to determine the bounding coordinates of the bathymetric data. Output of the bathymetric data for all tributaries can be seen in Fig. 7. Once the bathymetric data was selected, the ArcGIS 3D Analyst tool was used to calculate the surface area in square meters and the MLW water volume in cubic meters. GIS shape and grid files are provided for each tributary with the information used to generate Fig. 7. These files include the bounding coordinates of the tributary polygon (shape file) and water depth (grid file). Each file is named for the tributary as in Table 1.

The area and volume data were exported from GIS to an Excel spreadsheet where tributary volumes at MHW were calculated using the appropriate tidal range (Browne & Fisher 1988). These values were used to calculate flushing time estimates. An excel file (named "Tributary Calculation.xls") that contains results presented in Tables 2-4 is provided.

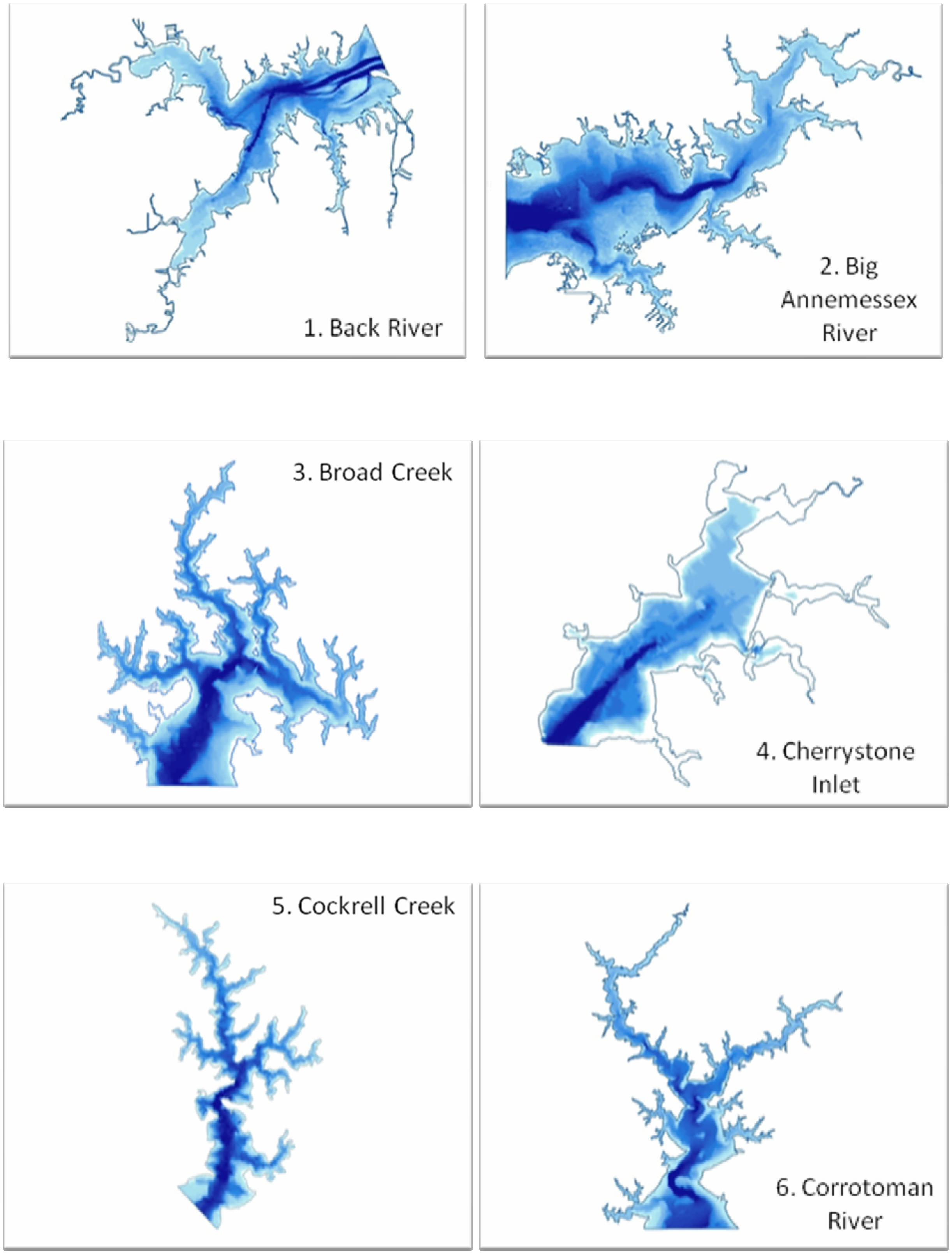


Fig. 7 Panels displaying bathymetric raster data for each tributary. Panel numbers correspond to numbering system in Table 1

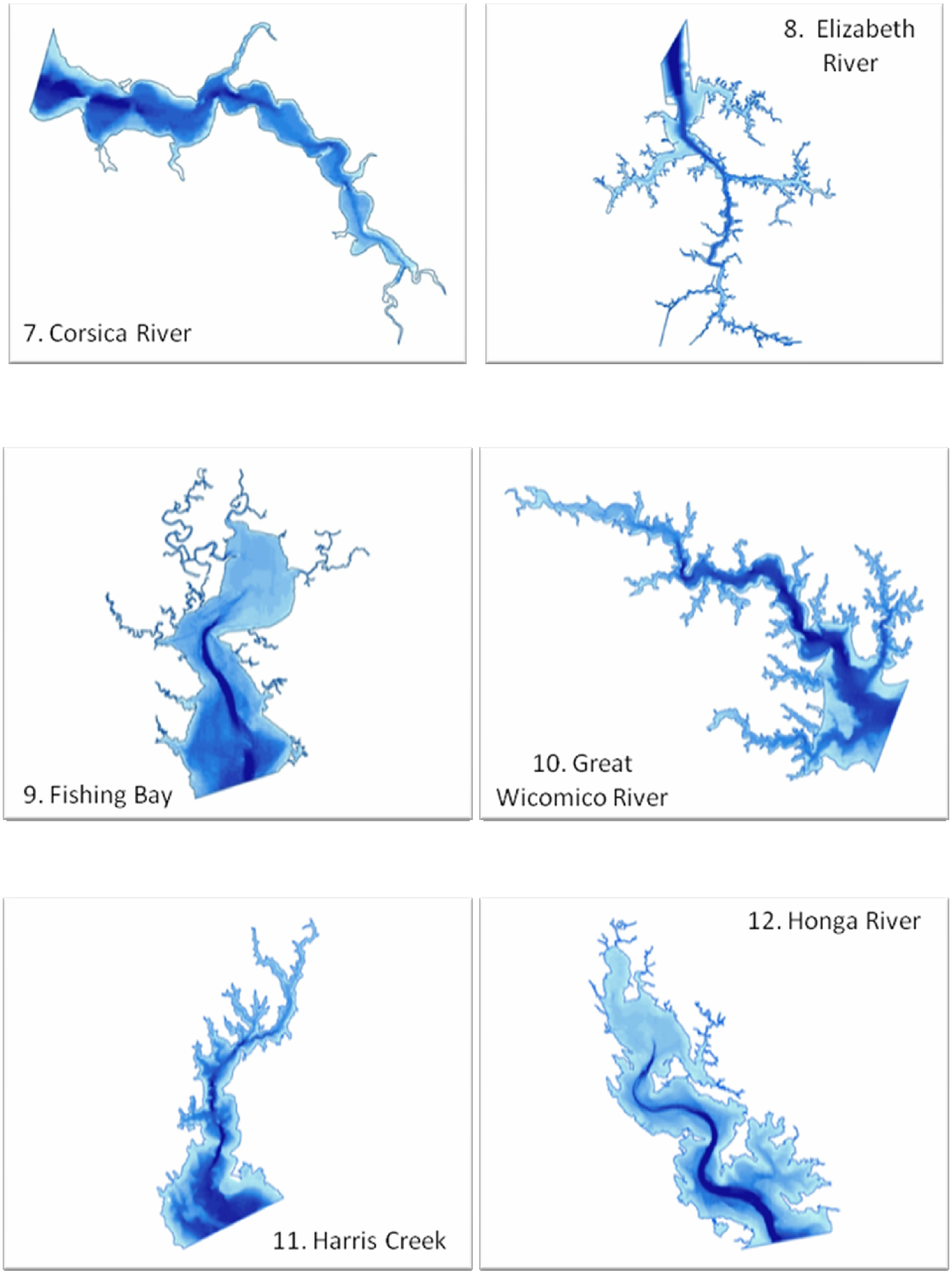

7. Corsica River
8. Elizabeth River
9. Fishing Bay
10. Great Wicomico River
11. Harris Creek
12. Honga River

Fig. 7. (cont.)

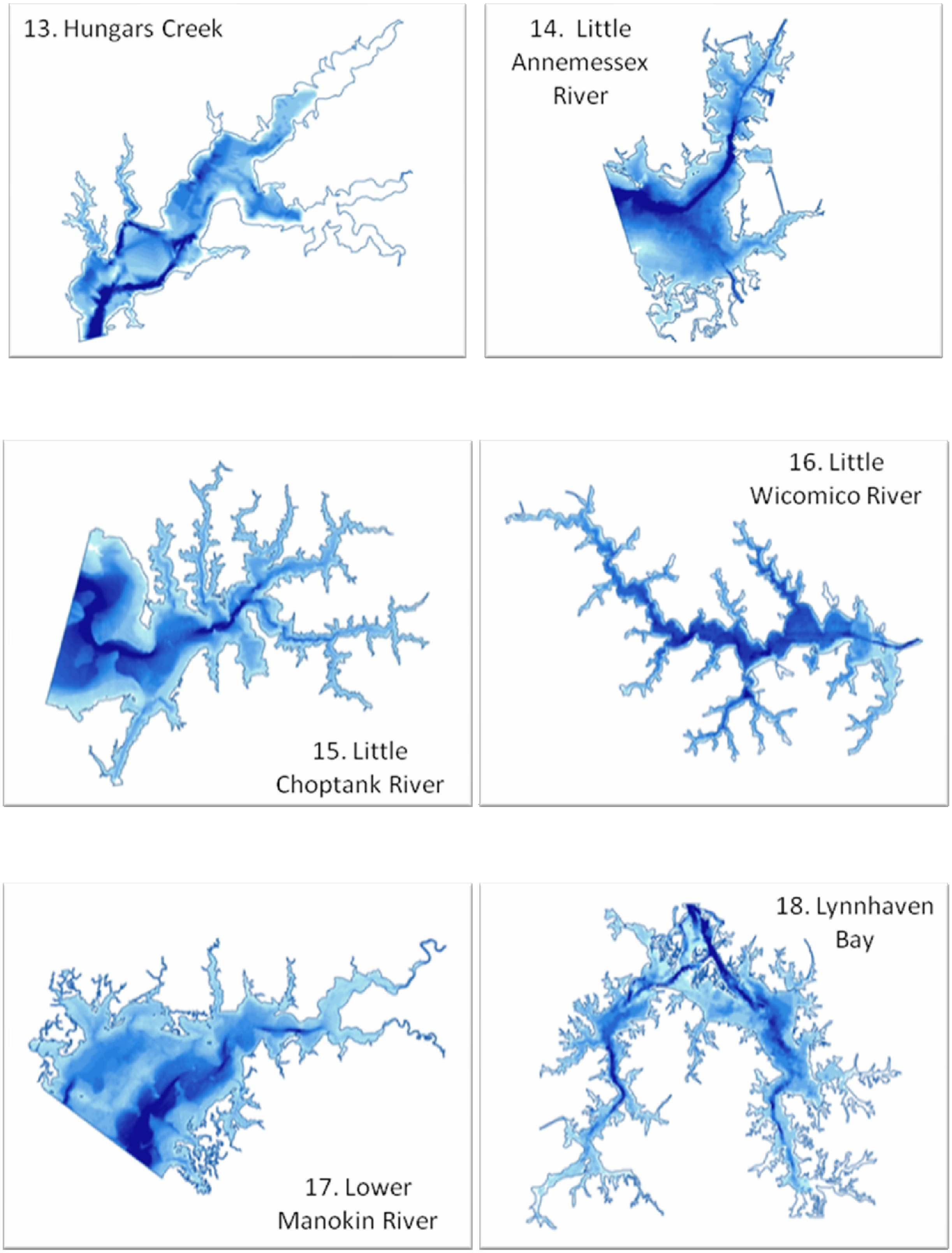

13. Hungars Creek
14. Little Annemessex River
15. Little Choptank River
16. Little Wicomico River
17. Lower Manokin River
18. Lynnhaven Bay

Fig. 7. (cont.)

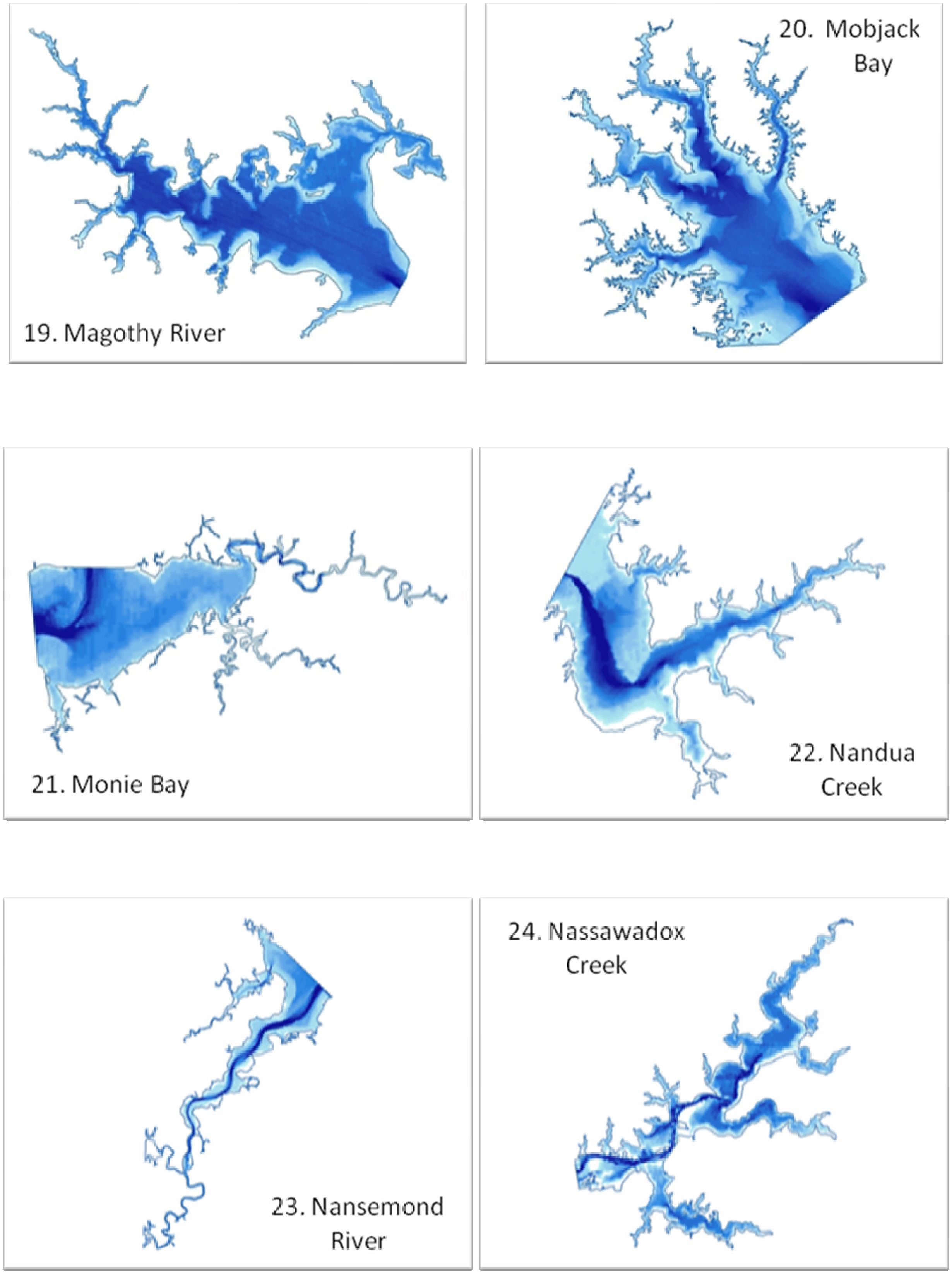

19. Magothy River
20. Mobjack Bay
21. Monie Bay
22. Nandua Creek
23. Nansemond River
24. Nassawadox Creek

Fig. 7. (cont).

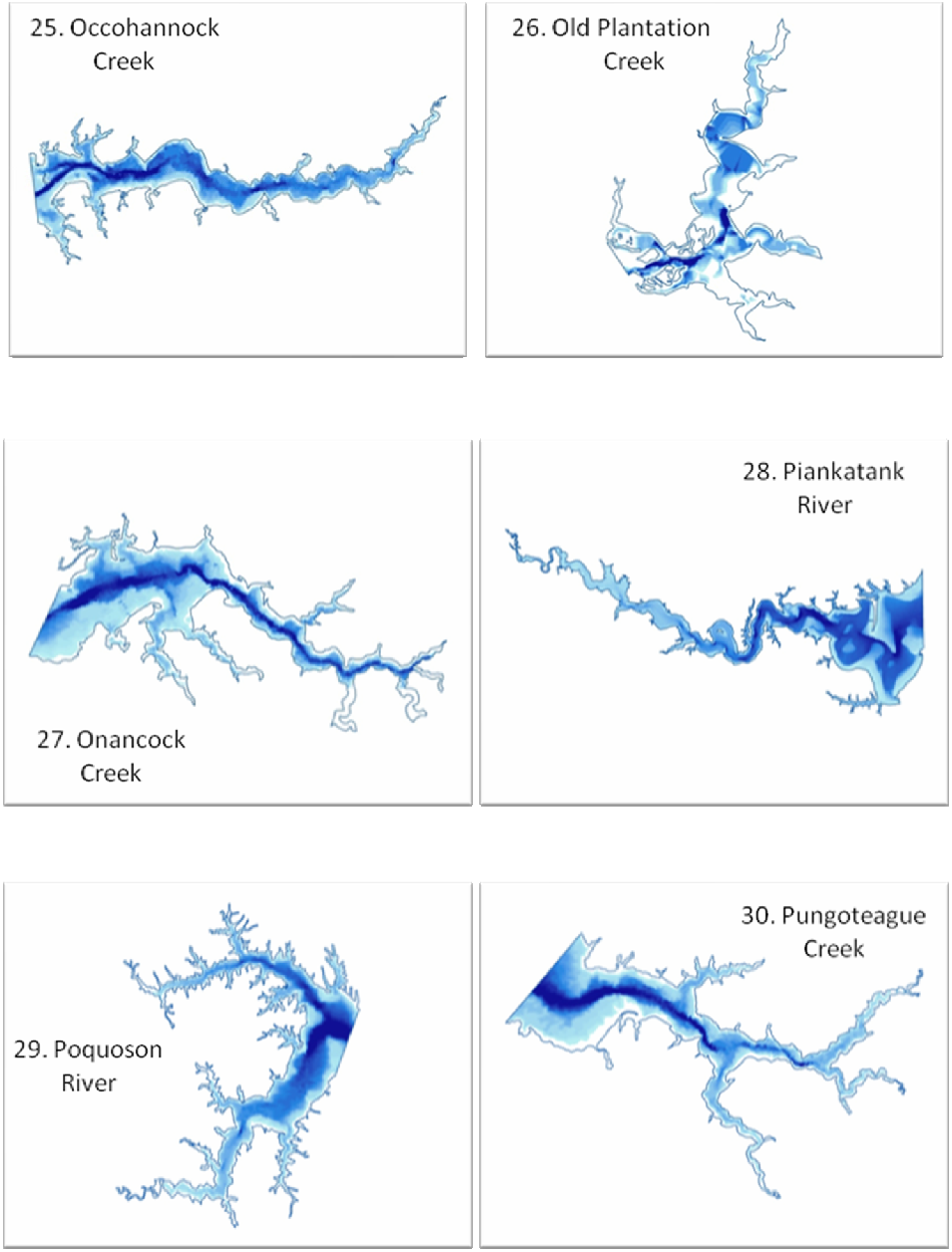

25. Occohannock Creek
26. Old Plantation Creek
27. Onancock Creek
28. Piankatank River
29. Poquoson River
30. Pungoteague Creek

Fig. 7 (cont.)

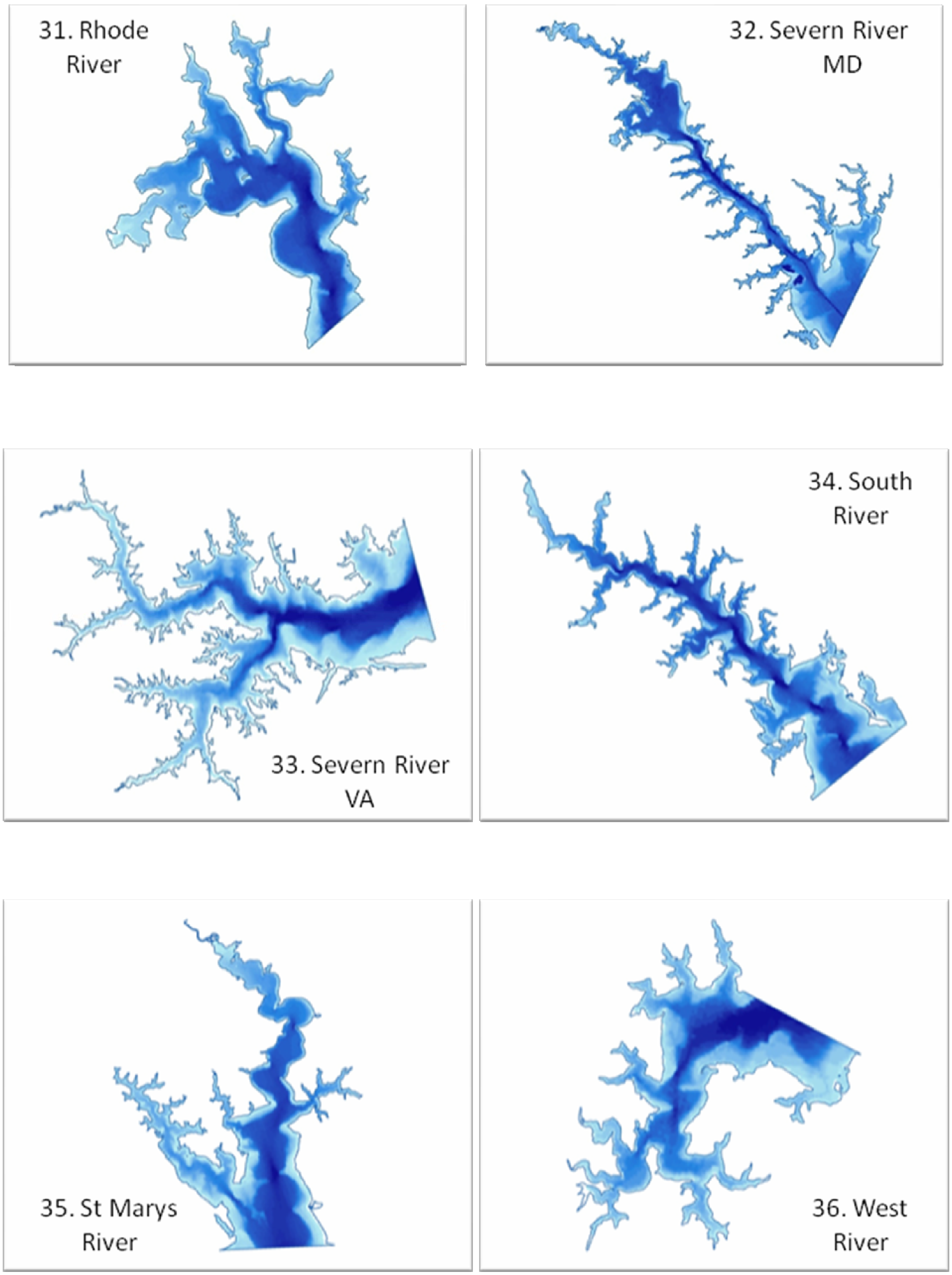

31. Rhode River
32. Severn River MD
33. Severn River VA
34. South River
35. St Marys River
36. West River

Fig. 7. (cont.)

4. Results

4.1. Retentiveness Indices

The GIS-calculated area (A), volume (V), Tidal Prism (P), and Percent Intertidal Volume (PIV) of each tributary are listed in Table 2. Tidal prism flushing times and adjusted tidal prism flushing times of the selected Chesapeake Bay tributaries are listed in Table 3. The best estimate of b, the return flow factor, also is listed. This factor was used to calculate the adjusted tidal prism flushing time by taking into account the phase difference between tidal height and current in the main stem estuary. For the most part, the additional residence time created by a return flow factor is small (see Appendix Table A.1), primarily because the tidal wave in Chesapeake Bay is nearly pure progressive so the return of water back into the embayment is minimal (Fig. 2A). The resulting residence times range from a half day, in Old Plantation Creek with a low return flow factor ($b = 0.05$), to 11 days in the Severn River with a return flow factor of 0.3. Old Plantation Creek is a shallow tributary with relatively high tidal range, where the tidal prism is twice as large as the mean-low-water volume.

Table 2. Area (A), Volume (V), Tidal Prism (P), and Percent Intertidal Volume (PIV). Tidal Range (R) was derived from CBI Special Report 20.

Tributary	A $10^6 m^2$	V (MLW) $10^6 m^3$	V (MHW) $10^6 m^3$	R (m)	P $10^6 m^3$	PIV %
Back River	16.41	20.23	31.73	0.70	11.51	36.3
Big Annemessex River	25.90	47.85	63.64	0.61	15.79	24.8
Broad Creek	25.65	59.32	69.49	0.40	10.16	14.6
Cherrystone Inlet	3.71	3.61	6.10	0.67	2.49	40.8
Cockrell Creek	2.63	5.55	6.36	0.30	0.80	12.6
Corrotoman River	22.30	73.17	82.69	0.43	9.52	11.5
Corsica River	4.79	10.35	12.54	0.46	2.19	17.5
Elizabeth River	34.48	196.88	224.21	0.79	27.32	12.2
Fishing Bay	76.75	137.79	179.90	0.55	42.11	23.4
Great Wicomico River	13.23	39.17	43.21	0.30	4.03	9.3
Harris Creek	24.42	54.33	63.26	0.37	8.93	14.1
Honga River	81.73	155.16	192.53	0.46	37.37	19.4
Hungars Creek	2.89	1.94	3.70	0.61	1.76	47.7
L. Annemessex River	9.56	12.97	18.21	0.55	5.24	28.8
L. Choptank River	64.50	165.44	191.00	0.40	25.56	13.4
L. Wicomico River	5.47	7.96	9.62	0.30	1.67	17.3
lower Manokin River	59.71	100.84	137.24	0.61	36.40	26.5
Lynnhaven Bay	7.60	5.03	11.28	0.82	6.26	55.4
Magothy River	20.92	66.42	72.80	0.30	6.38	8.8
Mobjack Bay	139.42	492.17	585.66	0.67	93.49	16.0
Monie Bay	14.71	23.95	32.92	0.61	8.96	27.2
Nandua Creek	7.85	8.92	13.23	0.55	4.31	32.6
Nansemond River	30.30	46.92	71.86	0.82	24.93	34.7
Nassawadox Creek	7.17	6.09	10.24	0.58	4.15	40.5
Occohannock Creek	6.42	7.53	11.05	0.55	3.52	31.9
Old Plantation Creek	1.23	0.49	1.39	0.73	0.90	64.7
Onancock Creek	5.62	7.68	10.93	0.58	3.25	29.8
Piankatank River	48.46	173.91	191.64	0.37	17.73	9.2
Poquoson River	6.24	9.64	13.82	0.67	4.18	30.3
Pungoteague Creek	3.93	4.18	6.33	0.55	2.15	34.0
Rhode River	4.37	8.14	9.47	0.30	1.33	14.1
Severn River - MD	38.60	151.42	162.01	0.27	10.59	6.5
Severn River - VA	11.96	26.18	34.56	0.70	8.38	24.3
South River	22.92	65.89	72.18	0.27	6.29	8.7
St Marys River	34.73	140.76	154.52	0.40	13.76	8.9
West River	7.32	11.30	13.54	0.30	2.23	16.5

Table 3. Tidal prism flushing time (T_f), the best estimate of the return flow factor (b) and adjusted tidal prism flushing time.

Tributary	T_f (days)	Best Estimate b	Adjusted T_f (days)
Back River	1.17	0.05	1.23
Big Annemessex River	1.83	0.10	2.03
Broad Creek	3.28	0.20	4.10
Cherrystone Inlet	1.01	0.05	1.06
Cockrell Creek	3.84	0.05	4.05
Corrotoman River	4.24	0.20	5.30
Corsica River	2.71	0.30	3.87
Elizabeth River	3.99	0.20	4.98
Fishing Bay	1.95	0.30	2.79
Great Wicomico River	5.29	0.05	5.56
Harris Creek	3.41	0.20	4.26
Honga River	2.41	0.20	3.01
Hungars Creek	0.83	0.05	0.87
L. Annemessex River	1.54	0.10	1.71
L. Choptank River	3.61	0.10	4.01
L. Wicomico River	2.73	0.05	2.87
lower Manokin River	1.69	0.10	1.88
Lynnhaven Bay	0.67	0.05	0.71
Magothy River	5.65	0.05	5.95
Mobjack Bay	2.98	0.20	3.73
Monie Bay	1.64	0.20	2.05
Nandua Creek	1.33	0.05	1.40
Nansemond River	1.23	0.20	1.54
Nassawadox Creek	1.02	0.05	1.07
Occohannock Creek	1.36	0.05	1.44
Old Plantation Creek	0.54	0.05	0.57
Onancock Creek	1.48	0.05	1.56
Piankatank River	5.34	0.05	5.62
Poquoson River	1.45	0.10	1.61
Pungoteague Creek	1.26	0.05	1.33
Rhode River	3.42	0.10	3.80
Severn River - MD	7.66	0.10	8.51
Severn River - VA	1.87	0.20	2.34
South River	5.68	0.05	5.98
St Marys River	5.55	0.10	6.17
West River	2.88	0.10	3.20

4.2. Comparison with literature

The tributary volumes (V) and Percent Intertidal Volumes (PIV) that were calculated with GIS can be compared with those determined by Cronin (1971) in a Chesapeake Bay Institute (CBI) report (Table 4, Figs. 8 and 9). A visual comparison (Fig. 8) reveals that there is first-order agreement between the volumes calculated with the two techniques, as does a linear regression of PIV values ($R^2 = 0.72$, Fig. 9). These comparisons also reveal that the modern GIS determinations tend to be slightly smaller than the earlier estimates and that there are substantial differences between the two approaches in the volumes of the Honga, Little Choptank and Great Wicomico Rivers. The Cronin estimates were constructed by hand: plotting cross sections at 1-5-mile intervals, measuring the area by planimeter, and then estimating the volumes by linearly interpolating between sections. The GIS technique is based on a geographic representation with far greater spatial resolution. In addition, GIS is an operational procedure conducted by entirely by machine, thereby minimizing manual errors. For this reason, we argue that these modern estimates represent a significant improvement in accuracy.

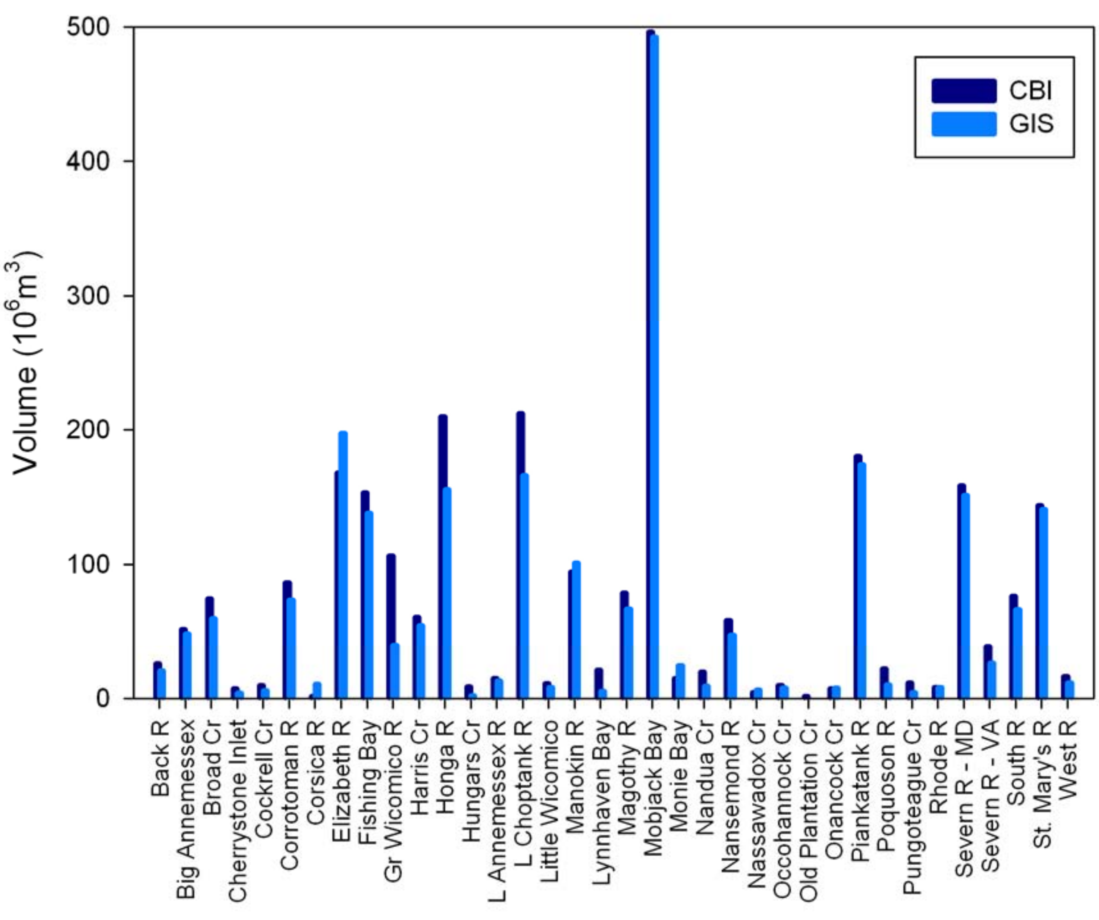


Fig. 8. Comparison of tributary volume estimates based on GIS and from the Chesapeake Bay Institute (CBI) report by Cronin (1971).

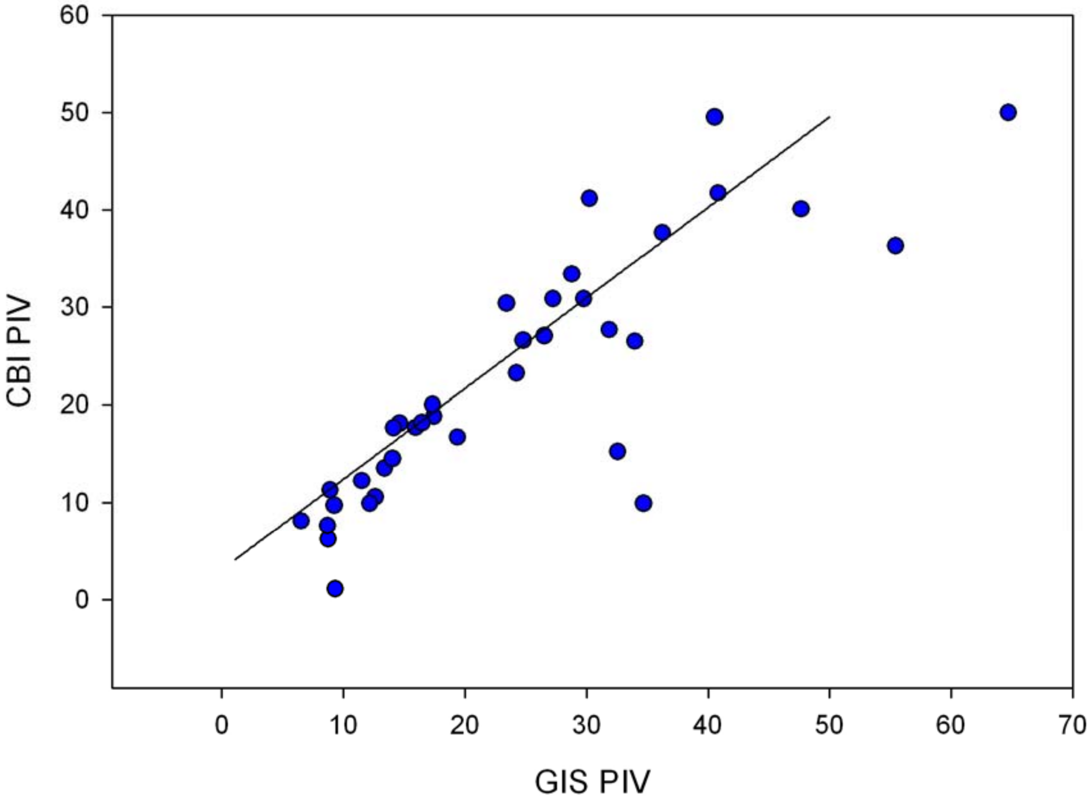


Fig. 9. Scatter plot of Percent Intertidal Volume (PIV) estimates based on GIS and from the Chesapeake Bay Institute (CBI) report by Cronin (1971). The black line is a linear regression line ($R^2 = 0.72$).

Table 4. Comparison of GIS Calculated and CBI Calculated Tidal Prism (P) and Percent Intertidal Volume (PIV). *Note: PIV value was assumed to be 9.9 for the Elizabeth and Nansemond Rivers.

Tributary	P (GIS) (10^6 m^3)	P (CBI) (10^6 m^3)	P Difference (10^6 m^3)	PIV (GIS) %	PIV (CBI) %	PIV Difference %
Back River	11.5	15.5	4.0	36.3	37.7	1.4
Big Annemessex River	15.8	18.8	3.0	24.8	26.6	1.8
Broad Creek	10.2	16.4	6.2	14.6	18.1	3.5
Cherrystone Inlet	2.5	4.8	2.3	40.8	41.7	0.9
Cockrell Creek	0.8	1.1	0.3	12.6	10.6	-2.0
Corrotoman River	9.5	12.0	2.5	11.5	12.2	0.7
Corsica River	2.2	2.4	0.2	17.5	18.8	1.4
Elizabeth River	27.3	36.3	9.0	12.2	<10	-2.3 *
Fishing Bay	42.1	67.7	25.5	23.4	30.4	7.0
Great Wicomico River	4.0	11.5	7.4	9.3	1.1	-8.2
Harris Creek	8.9	12.9	3.9	14.1	17.6	3.5
Honga River	37.4	42.1	4.7	19.4	16.7	-2.7
Hungars Creek	1.8	5.6	3.9	47.7	40.1	-7.6
L. Annemessex River	5.2	7.3	2.1	28.8	33.4	4.6
L. Choptank River	25.6	33.1	7.5	13.4	13.5	0.1
L. Wicomico River	1.7	2.7	1.0	17.3	20.0	2.7
lower Manokin River	36.4	34.9	-1.5	26.5	27.0	0.5
Lynnhaven Bay	6.3	12.0	5.7	55.4	36.3	-19.1
Magothy River	6.4	5.2	-1.2	8.8	6.2	-2.6
Mobjack Bay	93.5	106.7	13.2	16.0	17.7	1.7
Monie Bay	9.0	6.5	-2.4	27.2	30.8	3.6
Nandua Creek	4.3	3.5	-0.8	32.6	15.2	-17.3
Nansemond River	24.9	25.9	1.0	34.7	<10	-24.8 *
Nassawadox Creek	4.2	4.3	0.1	40.5	49.5	9.0
Occohannock Creek	3.5	3.7	0.1	31.9	27.7	-4.2
Old Plantation Creek	0.9	1.2	0.3	64.7	50.0	-14.7
Onancock Creek	3.3	3.2	-0.1	29.8	30.9	1.1
Piankatank River	17.7	19.2	1.5	9.2	9.7	0.5
Poquoson River	4.2	15.2	11.0	30.3	41.2	10.9
Pungoteague Creek	2.2	4.0	1.8	34.0	26.5	-7.5
Rhode River	1.3	1.4	0.0	14.1	14.5	0.4
Severn River - MD	10.6	13.9	3.3	6.5	8.1	1.6
Severn River - VA	8.4	11.6	3.3	24.3	23.2	-1.0
South River	6.3	6.5	0.2	8.7	7.6	-1.1
St Marys River	13.8	18.3	4.5	8.9	11.3	2.4
West River	2.2	2.6	0.4	16.5	18.2	1.7

Chesapeake Bay and its large tributaries were not included in this analysis because they would have violated the analysis assumptions. For comparison with the flushing times calculated for small tributaries, a brief literature review was conducted to assemble estimates of residence times of large tributaries in Chesapeake Bay. Table 5 contains these estimates. The highest GIS-calculated flushing rate for small tributaries was for the Severn River in Maryland (8.5 days) which was four times smaller than the smallest residence time estimate for the larger tributaries.

Table 5. Residence time (days) for Chesapeake Bay and major tributaries derived from for different years of model simulation (Shen and Wang, 2007; Shen and Haas, 2004; Shen and Lin, 2006) or salinity data (Gay and O'Donnell, 2009). Model simulations used variable forcing from either low (1995) and high (1996) freshwater flow years or constant forcing that were based on means and high freshwater flow values in the system.

	Shen & Wang (2007)		Shen & Haas (2004)		Gay & O'Donnell (2009)	Shen & Lin (2006)	
	1995	1996	mean	high	1984-2008	mean	high
Whole Bay	230	168			122		
Choptank							
James	108	50				95	35
Patuxent							
Potomac	214	106					
York	136	62	100	55			

4.3 Rankings and Ratings

Tributaries were sorted and ranked by their adjusted tidal prism flushing time, with the best ranks assigned to the highest flushing times (Table 6). The highest flushing times correspond to the systems that are likely to have the longest residence times and the greatest potential to retain oyster larvae.

Table 6. Tributaries ranked by highest adjusted tidal prism flushing time (T_f).

Rank	Tributary	Adjusted T_f (days)
1	Severn River - MD	8.51
2	St Marys River	6.17
3	South River	5.98
4	Magothy River	5.95
5	Piankatank River	5.62
6	Great Wicomico River	5.56
7	Corrotoman River	5.3
8	Elizabeth River	4.98
9	Harris Creek	4.26
10	Broad Creek	4.1
11	Cockrell Creek	4.05
12	L. Choptank River	4.01
13	Corsica River	3.87
14	Rhode River	3.8
15	Mobjack Bay	3.73
16	West River	3.2
17	Honga River	3.01
18	L. Wicomico River	2.87
19	Fishing Bay	2.79
20	Severn River - VA	2.34
21	Monie Bay	2.05
22	Big Annemessex River	2.03
23	lower Manokin River	1.88
24	L. Annemessex River	1.71
25	Poquoson River	1.61
26	Onancock Creek	1.56
27	Nansemond River	1.54
28	Occohannock Creek	1.44
29	Nandua Creek	1.4
30	Pungoteague Creek	1.33
31	Back River	1.23
32	Nassawadox Creek	1.07
33	Cherrystone Inlet	1.06
34	Hungars Creek	0.87
35	Lynnhaven Bay	0.71
36	Old Plantation Creek	0.57

5. Discussion

As stated earlier, the tidal prism flushing calculation relies on a few assumptions (e.g. low freshwater flow, lack of density-driven circulation, tides control flushing, and complete mixing occurs on flood tide), which for the most part, are valid for the tributaries of interest. However, this method does not take into account the classical two-layer estuarine circulation or wind-driven circulation. In most of the tributaries discussed herein, only weak estuarine circulation is expected because the freshwater inflow is negligibly small. Wind-driven flow can be very effective in driving exchanges between tributaries and the main-stem estuary, but is pulsed, episodic, and difficult to accurately predict. If the first-order flushing estimates are to be refined for selected tributaries of interest, then the recommended procedure is to obtain field observations on currents and salinity. With this information in hand, the tidal prism method can be assessed and alternative methods, such as freshwater fraction, can be implemented, along with simple parameterizations of the wind-driven exchange.

It should be noted that flushing time based on water flow (this report) and larval retentiveness based on particle tracking (North and Wazniak 2009) are two very different indices. Comparing them is like comparing apples to oranges. Flushing time is simply a measure of how fast circulation processes exchange water and water borne materials between a confined water body and the adjacent water body with which it communicates. Larval transport calculations include how fast water turns over in a system as well as where larvae are spawned, how much habitat is available, and how larval swimming behavior influences their trajectories. In order to compare 'large' and 'small' tributaries, we recommend using flushing time indices because they describe the same thing (apples to apples).

6. Acknowledgements

We are especially grateful for the assistance and data sets provided by Kelly Greenhawk of Maryland Department of Natural Resources.

7. Literature Cited

Browne, D.R., and C.W. Fisher. 1988. Tide and tidal currents in the Chesapeake Bay. NOAA Technical Report NOS OMA 3.

Cronin, W.B. 1971. Volumetric, Areal, and Tidal Statistics of The Chesapeake Bay Estuary and its Tributaries. Special Report 20, The Johns Hopkins University, Chesapeake Bay Institute.

Gay, P., and J. O'Donnell, 2009. Comparison of the salinity structure of the Chesapeake Bay, the Delaware Bay and Long Island Sound using a Linearly Tapered Advection-Dispersion Model. Estuaries and Coasts 32: 68-87.

North, E.W., and T.M. Wazniak. 2009. Larval Transport Maps. Final report to US Army Corps of Engineers, July 15, 2009, 26 p.

Sanford, L.P., W.C. Boicourt, and S.R. Rives. 1992. Model for estimating tidal flushing of small embayments. Journal of Waterway, Port, Coastal, and Ocean Engineering, American Society of Civil Engineers 118:635-654.

Shen, J. and L. Haas. 2004. Calculating age and residence time in the tidal York River using three-dimensional model experiments. Estuarine, Coastal and Shelf Science 61: 449-461.

Shen, J., and J. Lin, 2006. Modeling study of the influences of tide and stratification on age of water in the tidal James River. Estuarine, Coastal and Shelf Science 68: 102-112.

Shen, J., and H. V. Wang. 2007. Determining the age of water and long-term transport timescale of the Chesapeake Bay. Estuarine Coastal and Shelf Science 74:585–598.

8. Appendix

List of Terms

A – Average surface area of embayment basin.

b – Return flow factor

Flushing time (Residence time) – Amount of time it takes to effectively flush a body of water.

GIS – Geographic Information System

P – Tidal prism, or intertidal volume, of embayment.

PIV – Percent Intertidal Volume.

R - Average tidal range.

Retentiveness – The ability of a tributary or other water body to retain larvae, contaminants, or other water-borne particles.

T – Period of tide, 12.42 hours for Chesapeake Bay.

T_f - Tidal prism flushing time.

V – Average volume of embayment basin (MLW)

Table 7. Adjusted tidal prism flushing times calculated for each tributary with different return flow factor (b) values. This analysis was conducted to determine how sensitive flushing time estimates were to return flow factor values.

Tributary	b=0 (days)	b=0.05 (days)	b=0.1 (days)	b=0.2 (days)	b=0.3 (days)
Back River	1.17	1.23	1.30	1.46	1.67
Big Annemessex R.	1.83	1.92	2.03	2.28	2.61
Broad Creek	3.28	3.45	3.64	4.10	4.68
Cherrystone Inlet	1.01	1.06	1.12	1.26	1.44
Cockrell Creek	3.84	4.05	4.27	4.80	5.49
Corrotoman River	4.24	4.46	4.71	5.30	6.05
Corsica River	2.71	2.85	3.01	3.38	3.87
Elizabeth River	3.99	4.20	4.43	4.98	5.70
Fishing Bay	1.95	2.05	2.17	2.44	2.79
Great Wicomico R.	5.29	5.56	5.87	6.61	7.55
Harris Creek	3.41	3.59	3.78	4.26	4.87
Honga River	2.41	2.53	2.68	3.01	3.44
Hungars Creek	0.83	0.87	0.92	1.03	1.18

Tributary	b=0 (days)	b=0.05 (days)	b=0.1 (days)	b=0.2 (days)	b=0.3 (days)
Little Annemessex R.	1.54	1.62	1.71	1.92	2.20
Little Choptank R.	3.61	3.80	4.01	4.51	5.16
Little Wicomico R.	2.73	2.87	3.03	3.41	3.90
lower Manokin R.	1.69	1.78	1.88	2.12	2.42
Lynnhaven Bay	0.67	0.71	0.75	0.84	0.96
Magothy River	5.65	5.95	6.28	7.06	8.07
Mobjack Bay	2.98	3.14	3.31	3.73	4.26
Monie Bay	1.64	1.73	1.82	2.05	2.35
Nandua Creek	1.33	1.40	1.48	1.66	1.90
Nansemond River	1.23	1.30	1.37	1.54	1.76
Nassawadox Creek	1.02	1.07	1.13	1.27	1.45
Occohannock Creek	1.36	1.44	1.52	1.71	1.95
Old Plantation Creek	0.54	0.57	0.60	0.68	0.77
Onancock Creek	1.48	1.56	1.64	1.85	2.11
Piankatank River	5.34	5.62	5.93	6.67	7.62
Poquoson River	1.45	1.53	1.61	1.81	2.07
Pungoteague Creek	1.26	1.33	1.40	1.58	1.80
Rhode River	3.42	3.60	3.80	4.28	4.89
Severn River - MD	7.66	8.06	8.51	9.57	10.94
Severn River - VA	1.87	1.97	2.08	2.34	2.68
South River	5.68	5.98	6.31	7.10	8.12
St Marys River	5.55	5.84	6.17	6.94	7.93
West River	2.88	3.03	3.20	3.60	4.12

Attachment 1-E: Larval Transport Modeling – self-recruitment of sub-basins (North and Wazniak 2009)

FINAL REPORT
Larval Transport Maps

Elizabeth North and Thomas Wazniak
University of Maryland Center for Environmental Science
Horn Point Laboratory

July 16, 2009

Table of Contents

1. Background and rationale

The Larval TRANSport Lagrangian (LTRANS) model has been used to provide predictions of oyster larvae transport as part of an effort to assess the potential for *Crassostrea virginica* and *Crassostrea ariakensis* oyster populations to spread throughout Chesapeake Bay. LTRANS is a state-of-the-art off-line particle-tracking model that runs with the stored predictions of a 3D hydrodynamic model, specifically the Regional Ocean Modeling System (ROMS). LTRANS is written in Fortran 90 and is designed to track the trajectories of particles in three dimensions. It includes a 4th order Runge-Kutta scheme for particle advection and a random displacement model for vertical turbulent particle motion. Reflective boundary conditions, larval behavior, and settlement routines are also included. LTRANS was built by Elizabeth North and Zachary Schlag of University of Maryland Center for Environmental Science Horn Point Laboratory. Funding was provided by the Maryland Department of Natural Resources (MD DNR), National Science Foundation Biological Oceanography Program, National Oceanic and Atmospheric Administration (NOAA) Chesapeake Bay Office, and the NOAA-funded UMCP Advanced Study Institute for the Environment. Components of LTRANS have been in development since 2002 and are described in the following publications: North et al. 2005, North et al. 2006a, North et al. 2006b, and North et al. 2008. LTRANS has an open-source license and the code is freely available on the internet (http://northweb.hpl.umces.edu/LTRANS.htm) along with a detailed User's Guide (Schlag et al. 2008), test case and visualization routines. The additional larval transport model analyses presented in this report build upon these past efforts and are funded by U.S. Army Corps of Engineers (USACE).

A suite of LTRANS model simulations were conducted as part of the Environmental Impact Statement (EIS) to assess the potential introduction of the non-native oyster, *C. ariakensis* in the Chesapeake Bay and restoration activities related to the native oyster, *C. virginica*. Model formulation and results have been described in a detailed report (North et al. 2006b) as well as a peer reviewed publication (North et al. 2008). The following brief description of the model simulations and assumptions provide background for the analyses presented in this report.

LTRANS was designed to predict the movement of oyster larvae based on advection (water currents), turbulence and larval behavior. It incorporated predictions from a hydrodynamic model that was run with forcing conditions from 5 years (measured wind and freshwater flow) in order to capture a range of physical conditions that likely influence larval dispersal. Spawning dates, larval swimming speeds and behavior, and larval stage durations were parameterized with results from recent laboratory studies and published literature. In the model, simulated gametes were released from the centroids of oyster habitat polygons and their trajectories were calculated over the course of their development to the pediveliger stage. A settlement sub-model was used to predict if pediveliger-stage particles were inside or outside suitable habitat. In Maryland waters, suitable habitat was based on the "cultch" (i.e., oyster shell) GIS-layer polygons from the Maryland Bay Bottom Survey (MBBS) which were reduced to 29.17% of their original area (Greenhawk 2005). In Virginia waters, oyster habitat included polygons for both public and lease bottom that were based on bottom surveys in the 1990s.

Particles were released at the beginning of each scenario from the center location of each cultch polygon in numbers that were proportional to the area of each polygon. For polygons > 10 acres, one particle per acre was released. For polygons < 10 acres, 10 particles were released to ensure that enough particles were released during each year to adequately capture the distribution of possible trajectories. Five scenarios (i.e., five releases of particles) were conducted for each year to simulate observed pulses in spawning and settlement. Bay-wide, this resulted in five releases of 62,773 particles for each year (313,865 particles per year or 1,569,330 particles total for all simulations). Because the number of particles that were released was determined by the size of the habitat polygons, the number of particles that were released in each tributary or sub-tributary was directly related to the number and size of oyster habitat polygons in each tributary.

The larval transport model predicts the dispersal of oyster larvae based solely on physical conditions and larval behavior. It was designed to calculate movement of larvae-like particles from starting locations to settlement locations, thereby creating trajectories of larval dispersal in the context of realistic physical conditions. Although the larval transport model is state-of-the-art and based on the best available information, there are several major assumptions that should be kept in mind while interpreting the results of the analyses presented here. They include:

- **Hydrodynamic model resolution**. As described in North et al. (2008), the hydrodynamic model has been validated against a wide variety of observational data and accurately predicts tidal elevation, tidal and subtidal currents, and temperature and salinity distributions from annual time scales to the episodic event time scale of hurricanes. Although simulation of Bay-wide physical dynamics is robust, computational constraints limited the grid resolution such that small embayments were not included in the model and some of the bathymetry that could influence circulation patterns may not be well resolved in tributaries.

- **Larval behavior and settlement**. Although larval swimming behavior was parameterized with the best available information from recent laboratory studies and the peer-reviewed literature (North et al. 2006, 2008), model predictions of the vertical distribution of oyster larvae have not been validated in the field. (PI North currently has an NSF-funded project underway designed to validate model predictions). In addition, the settlement sub-model had the following assumptions: pediveligers were assumed to be able to settle if they were within a habitat polygon, and cultch was the only substrate on which oyster larvae could settle. These simplifications were necessary because information to simulate more complex settlement processes was not available.

- **Oyster habitat distribution**. There are assumptions regarding the location of oyster habitat in the model. Some oyster bars in both states were outside the domain of the hydrodynamic models so could not be included in the larval transport model. Although much of the Virginia lease bottom was outside the hydrodynamic model (61%), and therefore not included in the larval transport model, 82% and 93% of the public oyster bars in Maryland and Virginia, respectively, were within the model boundaries. In Maryland waters, suitable habitat was based on the “cultch” (i.e., oyster shell) GIS-layer polygons from the Maryland Bay Bottom Survey (MBBS). This survey was conducted in the late-1970s and 1980. Since the 1980s, the area of oyster habitat in Maryland’s Choptank River has been greatly reduced (Smith et al 2005). For the larval transport model, the cultch-layer polygon in Maryland waters were reduced to 29.17% of their original area, but their shape and centriods (center locations) was retained (Greenhawk 2005).

- **Larval biological and adult demography**. The larval transport model does not include important biological processes like predation and salinity-dependent mortality of larvae and the abundance and size of spawning adults. This was a conscious decision for the purposes of the EIS because the demographic model used in the EIS predicted adult population sizes and incorporated a stock-recruitment relationship to determine the number of surviving juveniles per female spawning oyster. The many biological processes that influence larval survival are implicit in the stock-recruitment relationship. For the analyses presented here, it is important to keep in mind that the larval dispersal patterns are due solely to circulation patterns, larval behavior and available habitat, and that the other factors like salinity-dependent mortality and the abundance of spawning individuals should be considered when choosing areas for restoration.

Despite the simplifications in model structure, the larval transport model provides valuable insights on the potential for oyster reefs to produce larvae that successfully encounter suitable habitat (North et al. 2008). Most of the analysis of the larval transport model output for the EIS was conducted on the whole tributary scale and was limited to successfully settling particles. Additional information can be extracted from the larval transport model output that can be useful for designating optimal areas for restoration of native oyster populations in Chesapeake Bay.

The purpose of this study is to provide in-depth analysis of the larval transport model output for the native oyster, *C. virginica*, specifically to summarize information about transport success, self-recruitment, and export success within sub-basins of Chesapeake Bay (i.e., at scales smaller than whole tributaries) and to identify regions where particles accumulated in the absence of suitable substrate. This information will be used for the Chesapeake Bay Native Oyster Restoration Master Plan (NORMP) which seeks to develop a bay-wide strategy to restore an abundant, self-sustaining oyster population throughout the Chesapeake Bay. The NORMP is being developed by the USACE, MD DNR, and the Virginia Marine Resources Commission (VMRC).

The methods and results for these analyses are described in the following sections of this report: 3. Transport success, 4. Self-recruitment and export success, and 5. Accumulation zones. Data files that are products of this report are given identification numbers (ID), described in each section, and listed in tabular format in Appendix A.

2. Sub-basin classification

The oyster larval transport model included 2,776 polygons that were based on the best available information on the location and size of present-day oyster habitat (see North et al. 2006b, 2008 for details). For the analyses presented in this report, these oyster habitat polygons are referred to as ‘bars’. The simulated oyster bars were grouped into thirty-one sub-basins (Figs. 1 and 2) in order to summarize information on transport source, self-recruitment, and export of oyster larvae from smaller regions than those presented in the prior analyses of larval transport model output. The sub-basin classifications were made based on channel morphology and bar spacing so that natural groupings of oyster habitat polygons resulted. Oyster habitat polygons in large tributaries (e.g., Potomac and Rappahannock Rivers) were divided into three groups. Polygons were divided into two groups in the medium size tributaries (e.g., Choptank and York Rivers). Small systems like the Little Choptank River were not sub-divided because the larval transport model was not designed to be accurate at smaller scales than these basins. When classifying oyster bars in the mainstem, lines were simply drawn from point to point across tributary mouths and those bars outside the tributaries were designated as being in the mainstem. A combination of SAS v.9.2 and Surfer 8.05 was used to make the sub-basin classifications.

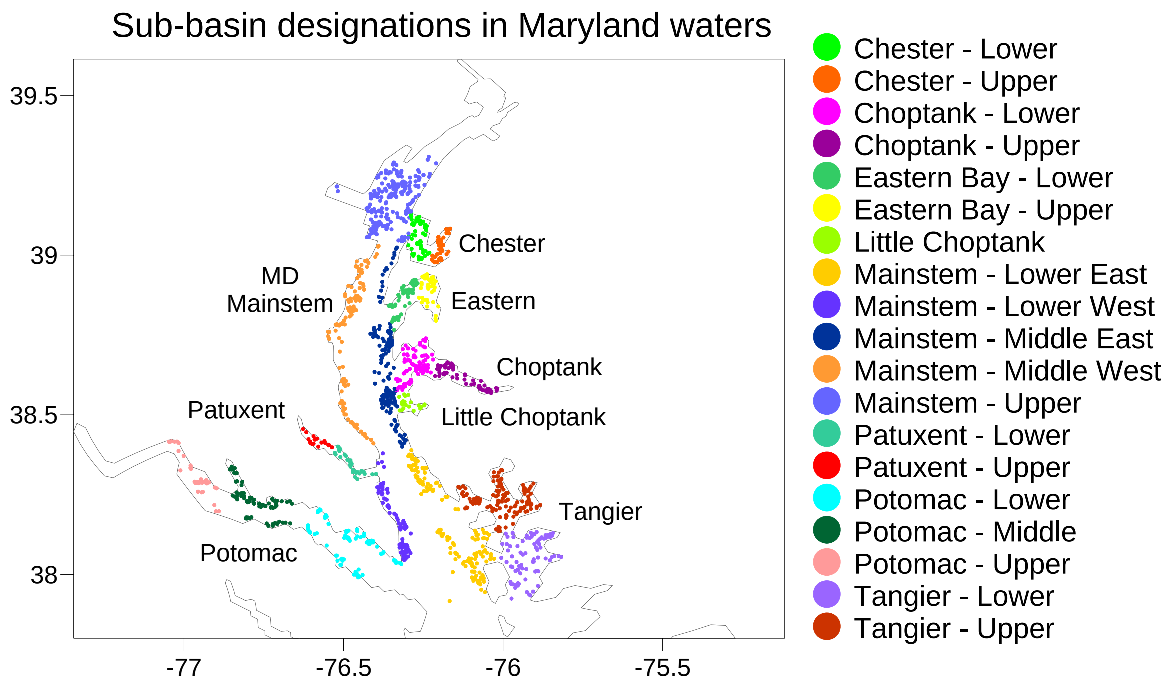


Fig. 1. Oyster habitat polygons in Maryland waters color coded by sub-basin classification.

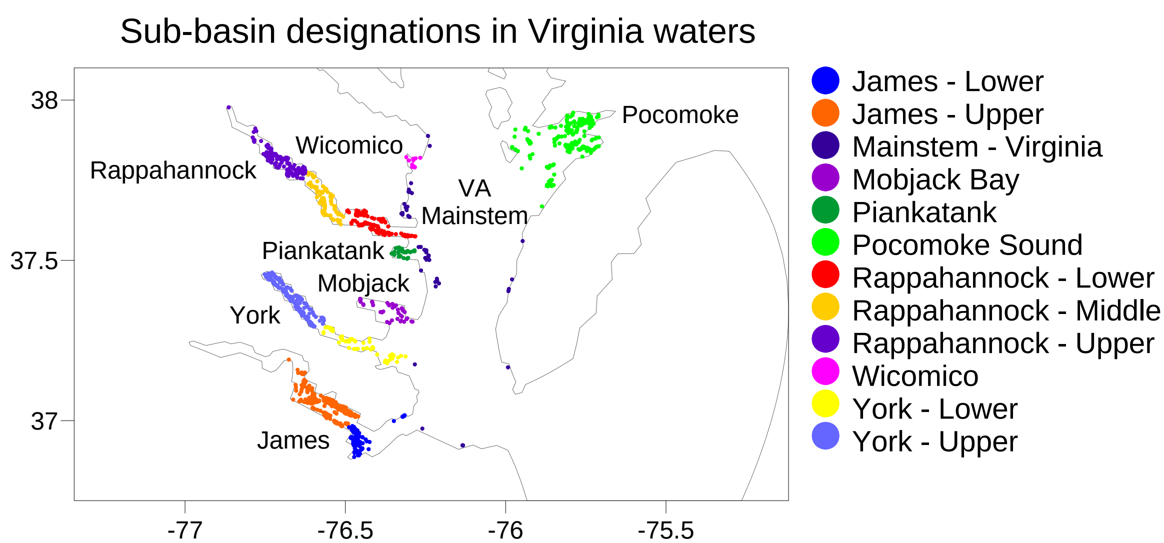


Fig. 2. Oyster habitat polygons in Virginia waters color coded by sub-basin classification.

3. Transport success by sub-basin

The transport success is defined as the percentage of particles released from a region or bar that successfully settled anywhere. This metric provides information about the potential for a bar or region to produce larvae that are successfully transported to suitable habitat. It quantifies the potential for a bar or region to be a source of larvae based on its location in relation to circulation patterns and other oyster bars. The report by North et al. (2006b) includes information on bar-specific transport success (Fig. 3) that incorporates the output of all larval transport model runs which simulated physical conditions in 1995-1999. This information was interpolated to a fixed grid and contoured (Fig. 4) in Surfer 8.05 using the “inverse distance to a power” interpolation method with fault lines. Fault lines were created to ensure that information from one tributary did not influence interpolation results in another tributary. Where fault lines failed, spurious results were corrected with a grid node editor. The file which contains the original bar-specific results (Fig. 3) is listed in Appendix A (file ID 3.1), as is the interpolated data used to create the contour plot (Fig. 4) (file ID 3.2).

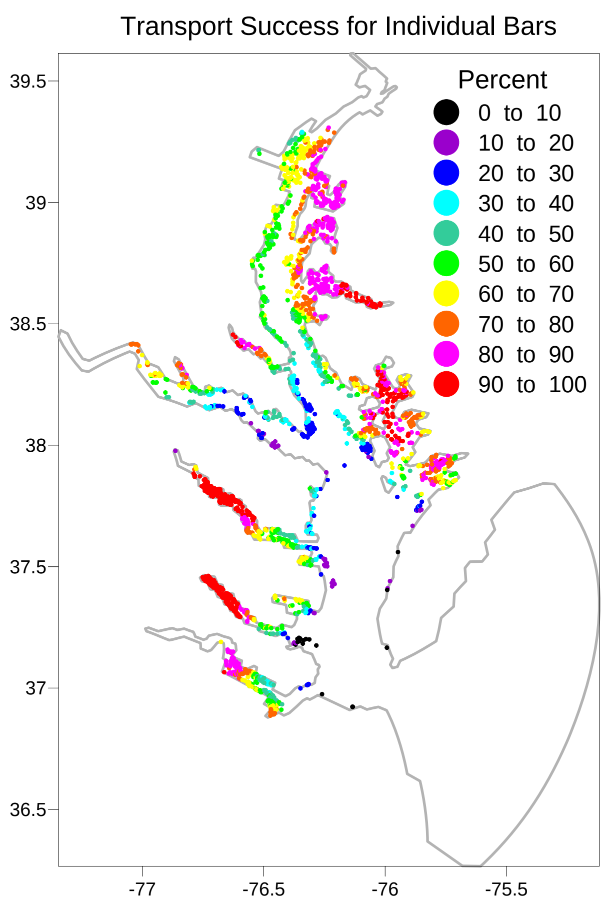


Fig. 3. Bar-specific results for all simulations (1995-1999). Each bar is color-coded according to the percentages of particles that were released from the bar and were successfully transported to another bar or back to the bar from which it was released. Figure reproduced from North et al. 2006b (Fig. 26).

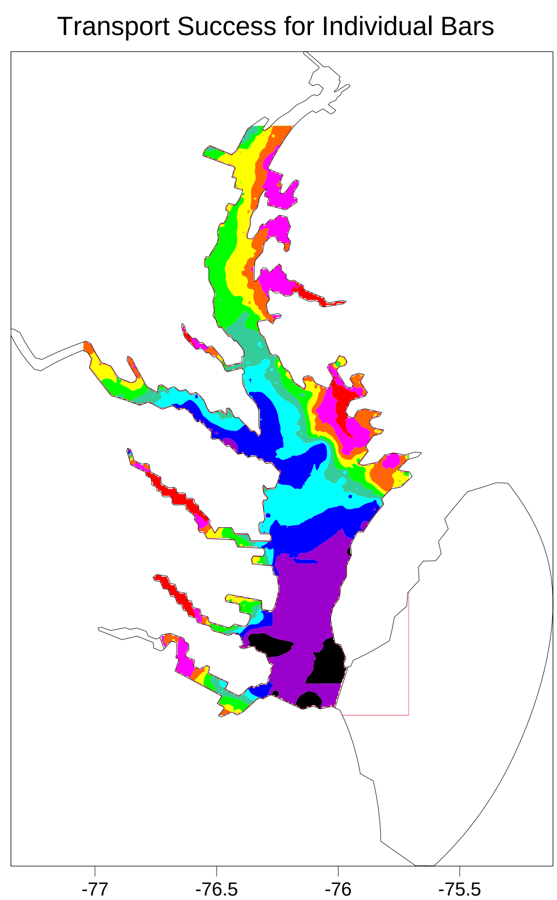


Fig. 4. Contour plot of data presented in Fig. 3.

Transport success was calculated for the sub-basins described in section 2 of this report (Figs. 1 and 2). SAS (v.9.2) was used to assign each of the 1.5 million *C. virginica* particles to a sub-basin based on their starting location and then calculate 1) the total number of particles that were released from each sub-basin (*R*) and 2) the total number of particles that were released and settled anywhere within the model domain (*S*). Transport success (*T*) for each sub-basin was simply calculated as:

$$T = 100 \times \frac{S}{R}$$

Transport success for each basin ranged from a high of 96.6% for the upper York to a low of 9.3% for the Virginia mainstem (Table 1, Fig. 5). Generally, transport success was highest in the upper tributaries and decreased from upstream to downstream. The information in Table 1 is provided in excel format (see Appendix A, ID 3.3 for file name).

Summary and discussion. Based on larval transport model results, the majority of larvae produced by oysters in the Virginia mainstem, lower Maryland mainstem, and lower Potomac River will not encounter suitable habitat on which to settle. Therefore, these regions would not be recommended for sites to enhance native oyster populations because most larvae that they produce are not predicted to survive.

Although sites at the heads of tributaries had very high transport success scores (e.g., Choptank, Rappahannock, and York Rivers), the salinity in these regions should be taken into account when selecting sites for restoration. Even though larvae that are produced in these regions have a high probability of encountering suitable settlement habitat, if salinities are too low then the larvae may not survive to reach that habitat. We recommend selecting sites with relatively high transport success scores (>60%) and favorable salinities rather than sites with the highest transport success scores and unfavorable salinities.

It is important to note that the sub-basin transport success scores represent the accumulated success of all bars in the sub-basin and can smooth over spatial variability within the sub-basin. For example, the upper James River sub-basin (Fig. 2) includes bars with high (80-90%) and relatively low (30-40%) transport success scores. When combined for the whole upper James sub-basin, the transport success score occurred between these values (60-70%).

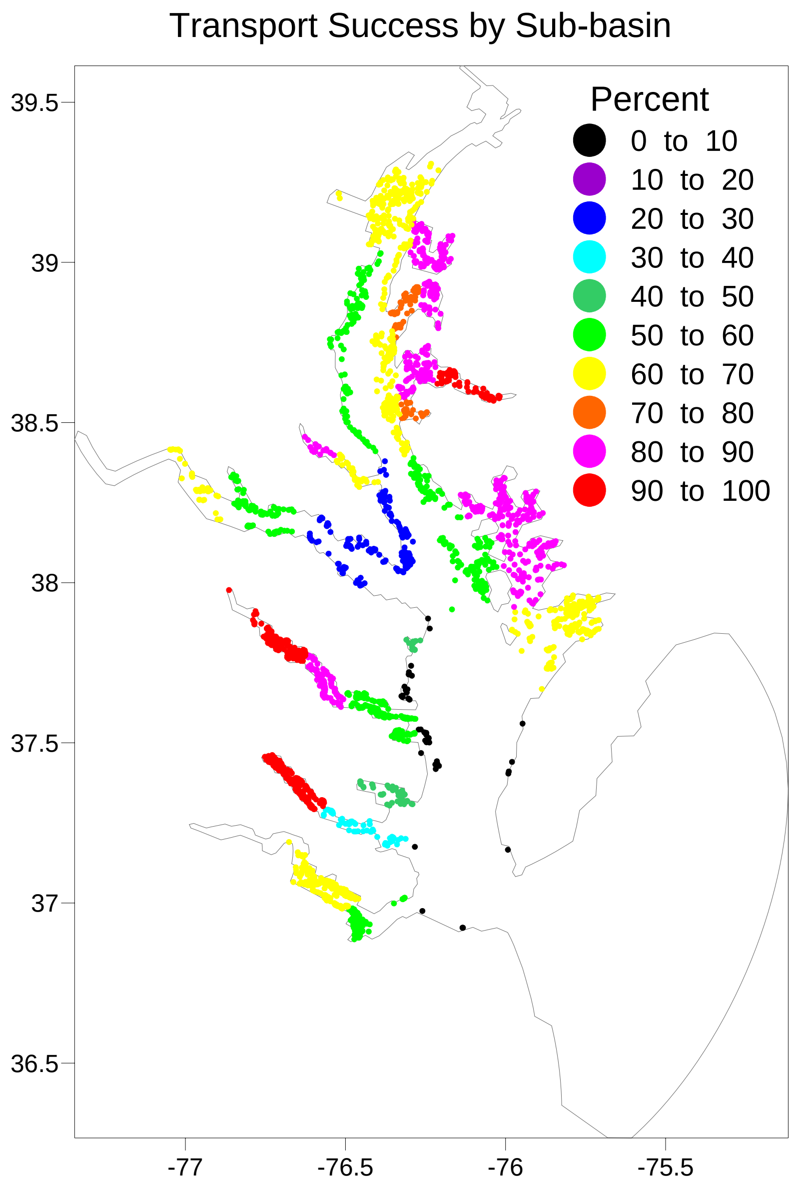


Fig. 5. Sub-basin-specific transport success (percent). Each oyster bar is color coded by the percent transport success of the sub-basin in which it is located (based on Table 1). Transport success is defined as the percentage of particles that were released within the sub-basin and were successfully transported to an oyster bar anywhere within the model domain. Sub-basin names are in Figs. 1 and 2.

Table 1. Transport success (percent) for each sub-basin. Transport success is defined as the percentage of particles that were released within the sub-basin and successfully transported to an oyster bar anywhere within the model domain. Sub-basin locations are indicated in Figs. 1 and 2.

Basin Name	**Settled particles released from basin**	**All particles released from basin**	**Percent Transport Success**
1. York - Upper	76,069	78,750	96.6
2. Rappahannock - Upper	63,310	66,025	95.9
3. Choptank - Upper	39,980	43,625	91.6
4. Patuxent - Upper	15,071	17,175	87.8
5. Rappahannock - Middle	45,656	53,125	85.9
6. Choptank - Lower	54,150	64,100	84.5
7. Chester - Upper	18,873	22,400	84.3
8. Eastern Bay - Upper	20,522	24,425	84.0
9. Tangier - Upper	54,499	65,225	83.6
10. Tangier - Lower	57,174	68,700	83.2
11. Chester - Lower	19,566	23,575	83.0
12. Eastern Bay - Lower	16,287	20,825	78.2
13. Little Choptank	14,523	18,725	77.6
14. Pocomoke Sound	63,407	90,850	69.8
15. James - Upper	88,995	129,125	68.9
16. Mainstem - Upper	123,502	185,300	66.7
17. Mainstem - Middle East	53,082	83,150	63.8
18. Patuxent - Lower	8,535	13,375	63.8
19. Potomac - Upper	9,822	15,825	62.1
20. Piankatank	5,704	9,750	58.5
21. Potomac - Middle	33,539	60,825	55.1
22. James - Lower	25,705	47,225	54.4
23. Mainstem - Middle West	38,415	70,600	54.4
24. Mainstem - Lower East	39,151	72,875	53.7
25. Rappahannock - Lower	23,765	45,400	52.3
26. Mobjack Bay	12,968	26,350	49.2
27. Wicomico	2,646	6,500	40.7
28. York - Lower	13,596	34,150	39.8
29. Mainstem - Lower West	13,581	45,325	30.0
30. Potomac - Lower	9,232	32,825	28.1
31. Mainstem - Virginia	3,087	33,200	9.3

4. Self-recruitment and export success

Self-recruitment is defined as the percentage of particles that returned to the same bar or region in which they started. Export success is the percentage of particles that successfully encountered habitat outside the region in which they were released. The sum of self recruitment and export success scores equals transport success. These metrics can be used to identify locations where bars/regions have the greatest potential for self-sustaining populations and the potential to provide larvae to other regions based on circulation patterns and available habitat.

Self-recruitment was calculated for individual oyster bars using all larval transport model predictions (simulations from 1995-99). SAS (v.9.2) was used to calculate the self-recruitment for each bar. Minimum self recruitment was zero, median was 0.4% and maximum was 37.5%. Self recruitment on 85% of bars was 2.0% or less. Many of the bars that had high self-recruitment were located in the upper reaches of tributaries and in Tangier and Pocomoke Sounds (Fig. 6). The information in Fig. 6 is provided in excel and GIS formats (see Appendix A, ID 4.1).

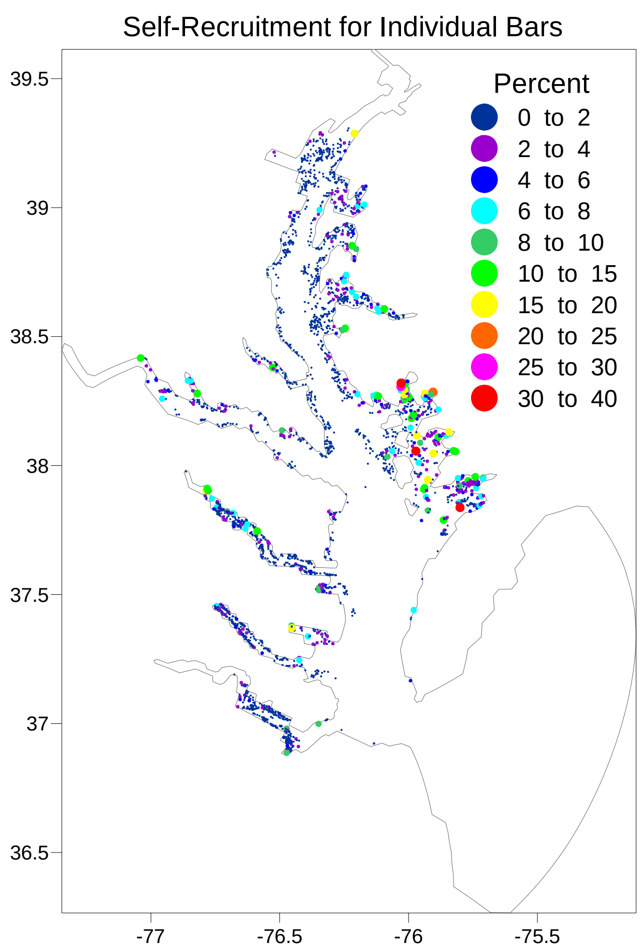


Fig. 6. Self recruitment for individual bars. Self-recruitment is defined as the percentage of particles that returned to the same bar on which they started.

Export success (Fig. 7) and self recruitment was calculated for each sub-basin based on the classifications in Figs. 1 and 2. SAS (v.9.2) was used to identify in which sub-basin each particle started and ended. All particles from 1995-99 model runs were included in the analysis. Results are presented in a matrix with rows that represent starting basins and columns that represent ending basins. Because of the many sub-basins, the names of the sub-basins were abbreviated. A key to the abbreviations is provided in Table 2.

The matrix of results for each sub-basin (Table 3) includes self-recruitment scores (green shaded elements) as well as export scores (all other elements). Elements with no values indicate no particles were exported from one sub-basin to another. The information in Table 2 and 3 is provided in excel format (see Appendix A, ID 4.2 for file name).

Sub-basins were ranked according to their transport success, self-recruitment, and export success metrics (Table 4). The sub-basins with the highest self-recruitment were the upper York, upper Tangier, and upper Rappahannock. The basins with the highest export success were the upper Patuxent, lower Eastern Bay, and Little

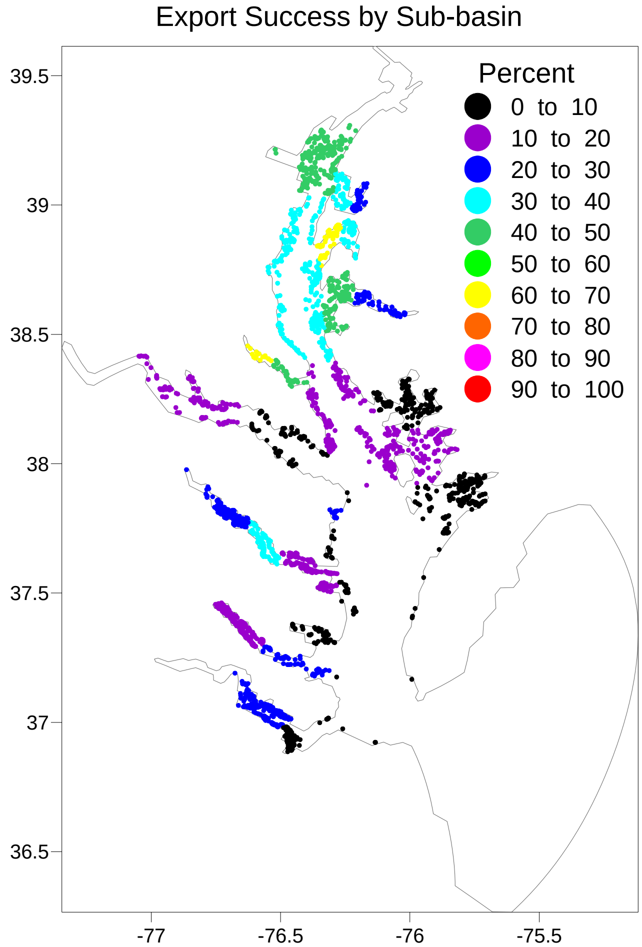


Fig. 7. Sub-basin export success (percent). Each oyster bar is color coded by the percent export success of the sub-basin in which it is located (based on Table 1). Export success is defined as the percentage of particles that were released within the sub-basin and successfully transported to an oyster bar outside that sub-basin. Sub-basin names are in Figs. 1 and 2.

Choptank. The basins that were best overall for both self-recruitment and export success were the Rappahannock (upper and middle), Chester (lower and upper), upper Eastern Bay, and Choptank River (lower and upper). The information in Table 4 is provided in excel format (see Appendix A, ID 4.3 for file name).

Summary and discussion. Sub-basins with high self-recruitment scores have the potential to retain a significant fraction of larvae within the sub-basin. In sub-basins with high self-recruitment scores, circulation patterns and the location of habitat are such that most pediveliger larvae are predicted to encounter suitable substrate. It is important to note that self-recruitment scores simply quantifies the percent of larvae that may be transported back to the bar from which they were spawned or may settle within the sub-basin in which they were spawned. It does not indicate whether a bar would be self-sustaining. Population demographics (e.g., abundance, growth and mortality) would need to be taken into account in order to determine if a bar could be self-sustaining.

Basins that have high transport success but low self-recruitment (e.g., lower Eastern Bay) may not be the best place to focus initial restoration efforts because larvae would not have a high probability of remaining in the sub-basin and thereby promoting a sustained population. It may be beneficial to choose restoration sites that have relatively high self-recruitment and export success scores because the populations in these regions may have 1) a better chance of creating a self-sustaining population in the sub-basin, and 2) the potential to export larvae that will successfully encounter habitat in other regions.

The larval transport model predictions of transport success, self-recruitment and export success depend on the location of present day habitat within and downstream of each sub-basin. North et al (2008) conducted a statistical analysis to determine if wind, freshwater flow or area of suitable habitat described a significant amount of the variability in transport success for basins. They found that "most of the variability in transport success was accounted for by habitat coverage in each basin (Table 3 of North et al (2008)), indicating that the proportion of suitable oyster habitat in a basin positively influenced transport success." Sub-basins that have a large proportion of suitable habitat may have a higher chance of successful larval settlement and, therefore, a higher chance of establishing a self-sustaining population.

Table 2. Abbreviation of sub-basin names which are found in Table 3.

Basin Name	Abbreviation
Chester - Lower	Ches-L
Chester - Upper	Ches-U
Choptank - Lower	Chop-L
Choptank - Upper	Chop-U
Eastern Bay - Lower	East-L
Eastern Bay - Upper	East-U
James - Lower	Jam-L
James - Upper	Jam-U
Little Choptank	LilChop
Mainstem - Lower East	Main-LE
Mainstem - Lower West	Main-LW
Mainstem - Middle East	Main-ME
Mainstem - Middle West	Main-MW
Mainstem - Upper	Main-U
Mainstem - Virginia	Main-VA
Mobjack Bay	Mobj
Patuxent - Lower	Pax-L
Patuxent - Upper	Pax-U
Piankatank	Piank
Pocomoke Sound	Poco
Potomac - Lower	Poto-L
Potomac - Middle	Poto-M
Potomac - Upper	Poto-U
Rappahannock - Lower	Rapp-L
Rappahannock - Middle	Rapp-M
Rappahannock - Upper	Rapp-U
Tangier - Lower	Tang-L
Tangier - Upper	Tang-U
Wicomico	Wico
York - Lower	York-L
York - Upper	York-U

Table 3. Export success and self-recruitment by sub-basin. The first column of the table lists the sub-basin from which particles were released. The subsequent columns contain the percent of particles that were successful transported to an oyster bar in the sub-basin listed at the top of the column. Full sub-basin names associated with the abbreviations in this table can be found in Table 3. Blank elements indicate zero particles were released from one basin and were transported successfully to oyster bar habitat in another. An element with ‘0.0’ indicates a negligible percentage of particles were successfully transported. The elements with green shading contain self recruitment scores (i.e., the percent of particles that were released and successfully transported to oyster habitat within the same basin).

	Ches-L	Ches-U	Chop-L	Chop-U	East-L	East-U	Jam-L	Jam-U	LilChop	Main-LE	Main-LW	Main-ME
Ches-L	50.9	9.2	0.0		0.0				0.0	0.0	0.1	3.1
Ches-U	26.3	54.5										0.2
Chop-L	0.0		42.8	9.5	0.4	0.0			1.0	0.3	0.4	23.6
Chop-U			19.6	68.3	0.0				0.1	0.0	0.0	3.0
East-L	0.9	0.0	0.4		15.4	11.4			0.1	0.3	0.7	23.8
East-U	0.2		0.0		20.1	48.1			0.0	0.0	0.0	8.7
Jam-L							49.7	3.1				
Jam-U							20.4	47.8				
LilChop			10.4	0.3	0.0				29.2	3.0	2.2	30.0
Main-LE			0.0						0.0	35.1	1.8	2.6
Main-LW										3.7	11.4	0.2
Main-ME	0.9	0.0	4.3	0.2	1.2	0.2			2.0	4.4	3.5	29.4
Main-MW	0.2		0.5	0.0	0.2	0.0			0.3	3.2	16.3	8.3
Main-U	7.8	0.2	0.4	0.0	0.2	0.0			0.1	0.8	2.9	11.2
Main-VA							0.3			0.1	0.0	
Mobj							0.0					
Pax-L										2.2	32.7	0.3
Pax-U										0.3	14.4	0.1
Piank												
Poco										0.1	0.0	
Poto-L										1.4	0.0	0.0
Poto-M										0.5	0.0	
Poto-U										0.0		
Rapp-L												
Rapp-M												
Rapp-U												
Tang-L										4.0	0.0	
Tang-U										4.2	0.1	0.0
Wico										0.1		
York-L							0.1					
York-U												

Table 3. (continued)

	Main-MW	Main-U	Main-VA	Mobj	Pax-L	Pax-U	Piank	Poco	Poto-L	Poto-M	Poto-U	Rapp-L
Ches-L	3.0	16.5			0.0				0.0			
Ches-U	0.1	3.2										
Chop-L	6.1	0.3	0.0		0.0				0.0			0.0
Chop-U	0.6	0.0										
East-L	19.2	5.8			0.0				0.0			
East-U	5.1	1.7			0.0							
Jam-L			1.6									
Jam-U			0.8									
LilChop	1.9	0.0	0.1		0.0				0.3			0.0
Main-LE	0.2	0.0	1.1	0.0	0.0		0.0		0.5	0.0		0.3
Main-LW	0.0		4.7	0.1	0.0		0.2		7.7	0.2		1.2
Main-ME	13.8	2.7	0.4	0.0	0.1		0.0		0.7	0.0		0.1
Main-MW	21.4	0.4	0.3	0.0	1.3		0.0		1.9	0.0		0.1
Main-U	18.4	24.3	0.0		0.2				0.2			0.0
Main-VA			5.4	1.1			0.6	0.0				0.8
Mobj			0.9	45.4								
Pax-L	0.1		0.6		22.1	1.5			4.1	0.0		0.2
Pax-U	0.0				53.5	19.0			0.5			
Piank			15.4	0.2			40.6					2.0
Poco			0.2	0.0			0.0	68.7				0.0
Poto-L	0.0		4.0	0.0			0.1		19.8	1.4		0.9
Poto-M			0.9				0.0		10.8	40.1	2.6	0.2
Poto-U			0.1						5.0	13.5	43.4	
Rapp-L			10.7	0.6			4.1	0.0				34.3
Rapp-M			3.7	0.1			1.3					29.7
Rapp-U			0.4	0.0			0.1					2.2
Tang-L			0.0									0.0
Tang-U	0.0		0.0		0.0				0.0			0.0
Wico			24.3	0.1			0.3	0.0				3.6
York-L			1.6	12.6								
York-U			0.2	0.8								

Table 3. (continued)

	Rapp-M	Rapp-U	Tang-L	Tang-U	Wico	York-L	York-U
Ches-L							
Ches-U							
Chop-L				0.0			
Chop-U							
East-L							
East-U							
Jam-L							
Jam-U							
LilChop				0.0	0.0		
Main-LE			9.9	2.0	0.0	0.0	
Main-LW			0.0	0.2	0.3	0.1	
Main-ME			0.0	0.1	0.0	0.0	
Main-MW			0.0	0.1	0.0		
Main-U				0.0			
Main-VA					0.0	1.0	
Mobj						2.9	
Pax-L			0.0	0.0	0.0		
Pax-U				0.0			
Piank						0.3	
Poco			0.9		0.0	0.0	
Poto-L			0.0	0.1	0.4	0.0	
Poto-M				0.0	0.1		
Poto-U							
Rapp-L	1.7					0.9	
Rapp-M	49.2	1.7				0.2	
Rapp-U	24.4	68.7					
Tang-L			68.6	10.6			
Tang-U			4.5	74.8			
Wico					12.1	0.2	
York-L						18.0	7.5
York-U						14.3	81.3

Table 4. Percent transport success, self-recruitment, and export success for sub-basins as well as the rank of the sub-basin for each of these metrics (1 = best; 31 = worst).

	Percent			Rank		
	Transport Success	**Self-Recruitment**	**Export Success**	**Transport Success**	**Self-Recruitment**	**Export Success**
Chester - Lower	83.0	50.9	32.1	11	8	11
Chester - Upper	84.3	54.5	29.8	7	7	12
Choptank - Lower	84.5	42.8	41.7	6	15	6
Choptank - Upper	91.6	68.3	23.3	3	6	15
Eastern Bay - Lower	78.2	15.4	62.8	12	28	2
Eastern Bay - Upper	84.0	48.1	35.9	8	11	8
James - Lower	54.4	49.7	4.7	22	9	28
James - Upper	68.9	47.8	21.2	15	12	17
Little Choptank	77.6	29.2	48.4	13	21	3
Mainstem - Lower East	53.7	35.1	18.6	24	18	19
Mainstem - Lower West	30.0	11.4	18.6	29	30	20
Mainstem - Middle East	63.8	29.4	34.4	17	20	9
Mainstem - Middle West	54.4	21.4	33.0	23	24	10
Mainstem - Upper	66.6	24.3	42.3	16	22	4
Mainstem - Virginia	9.3	5.4	3.9	31	31	29
Mobjack Bay	49.2	45.4	3.8	26	13	30
Patuxent - Lower	63.8	22.1	41.8	18	23	5
Patuxent - Upper	87.7	19.0	68.8	4	26	1
Piankatank	58.5	40.6	17.9	20	16	22
Pocomoke Sound	69.8	68.7	1.1	14	4	31
Potomac - Lower	28.1	19.8	8.3	30	25	27
Potomac - Middle	55.1	40.1	15.1	21	17	24
Potomac - Upper	62.1	43.4	18.7	19	14	18
Rappahannock - Lower	52.3	34.3	18.0	25	19	21
Rappahannock - Middle	85.9	49.2	36.7	5	10	7
Rappahannock - Upper	95.9	68.7	27.2	2	3	14
Tangier - Lower	83.2	68.6	14.6	10	5	25
Tangier - Upper	83.6	74.8	8.8	9	2	26
Wicomico	40.7	12.1	28.6	27	29	13
York - Lower	39.8	18.0	21.8	28	27	16
York - Upper	96.6	81.3	15.3	1	1	23

5. Accumulation zones

Larval transport model output for each simulation reveals regions where 'dead' particles accumulate (see Fig. 8 which was reproduced from North et al. (2006)). A particle was considered 'dead' when it failed to encounter suitable habitat before its assigned energy reserves were spent. Analysis of accumulation zones of dead particles was undertaken to determine if there could be regions where habitat could be constructed that could catch larvae before they were no longer competent to settle (i.e., before they died). The particle distribution pattern in Fig. 8 is based on 62,733 particles instead of the 1.5 million particles that were released in all model scenarios for *C. virginica* larvae. We created better estimates of accumulation zones by plotting the locations of all (1995-99) 'dead' particles and 'dead' particles released during each year of model simulation (Fig. 9). There was some variation in particle distributions between years, indicating that differences in river flow and wind conditions did affect accumulation of particles. But, overall, repeated patterns in regions with what appeared to be high concentrations of particles were evident (e.g., eastern Maryland mainstem, south of the Patuxent and Rappahannock Rivers).

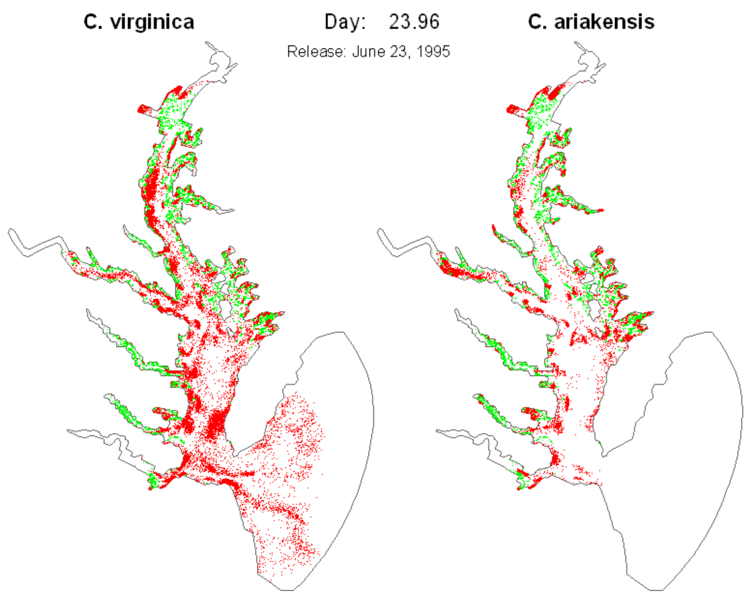


Fig. 8. End particle locations for *C. virginica* (left) and *C. ariakensis* (right) simulations with release date of June 23, 1995. Colors indicate whether particles are settled (green) or dead (red). Reproduced from North et al. 2006b, Fig 17.

To create a better estimate of possible accumulations zones, contour maps of the accumulation zones were produced for all particles in all years, and 'dead' particles in all years. To accomplish this, a 500 m x 500 m grid was generated in GIS, intersected with a shape file of the model boundaries, the grid cells near the boundaries were clipped, and the area of each grid cell was calculated. A spatial join between the grid and the particle locations was performed to yield a count of particles for each cell ("join_count"). Particle counts, cell areas, and grid cell centriod latitude/longitude values were exported from GIS. Particle concentrations were calculated in SAS and contoured in Surfer using the Kriging interpolation algorithm. Accumulation zones were defined as particle concentrations greater than the 75th percentile of all particle concentration values. The 75th and 95th percentiles were determined for each data set using SAS (v.9.2). For all particles (1995-1999), the 75th and 95th percentile values were 36 and 156 particles m^{-2}, respectively. For all 'dead' particles (1995-1999), the 75th and 95th percentile values were 20 and 76 particles m^{-2}, respectively. For 'dead' particles during individual years, the 75th and 95th percentile values were 4 and 16 particles m^{-2}, respectively. Contour maps of settled particles for each year were created but not included in this report because they did not contribute additional information. The data sets used to derive the accumulation zone figures are provided in comma delimited and GIS format (see Appendix A, ID 5.1 – 5.7 for file names).

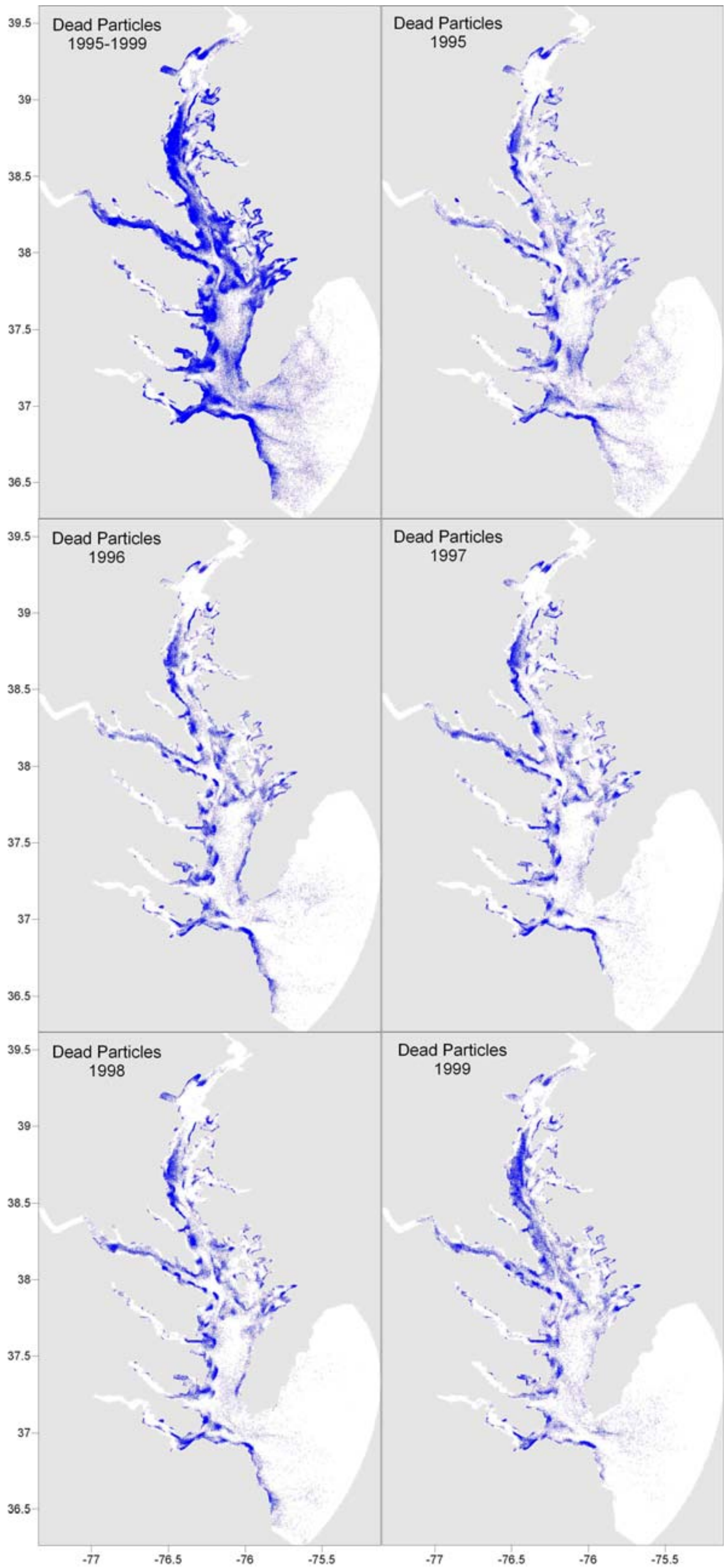


Fig. 9. Location of dead particles in all years combined (upper left) and in each year of larval transport model simulations.

Distinct accumulation zones were evident when the accumulation zones were constructed with particles from all years (Figs. 10 and 11). Accumulation zones of all particles (Fig. 10) appear to be controlled in a large part by the distribution of settled particles (note the similarity in patterns between the accumulation zones in Fig. 10 and the distribution of oyster habitat in Figs. 1 and 2). When the settled particles are excluded, there are clear accumulation zones of 'dead' particles, many of which occur along the western shore (Fig. 11). The pattern of accumulation along the western shore makes sense because water flowing out of Chesapeake Bay tends to travel along the western shore. Hence, larvae transported in down-estuary flowing water could be concentrated along the western shore. There are also notable particle accumulations in the deep waters of the Maryland mainstem and the Potomac River, although these regions are adversely affected by seasonal hypoxia and anoxia so they would not likely be prime regions for restoration.

Although the location of accumulation zones of 'dead' particles shows some variation between years (Fig. 12), the major patterns in each year are consistent with those discerned in the plot of all 'dead' particles for all years (Fig. 11).

Summary and discussion. Accumulation zones indicate regions that would be expected to 'catch' larvae if 1) habitat were constructed in the region and 2) abundant spawning adults are located on the bars that provide larvae to these regions. When developing a plan to create a network of self-sustaining bars, the accumulations zones provide additional information that could be used to select possible restoration sites.

Although the model predicts that larvae could accumulate in these zones, it does not indicate whether a restoration site would be successful. For example, although particle accumulations may be high in the western Maryland mainstem, the muddy bottom and prevalence of anoxia would make much of this region unsuitable. Still, using the accumulation zones in conjunction with additional information, such as maps of historic oyster bottom (or better yet, recent maps of hard bottom derived from acoustics), would be valuable for identifying additional restoration areas.

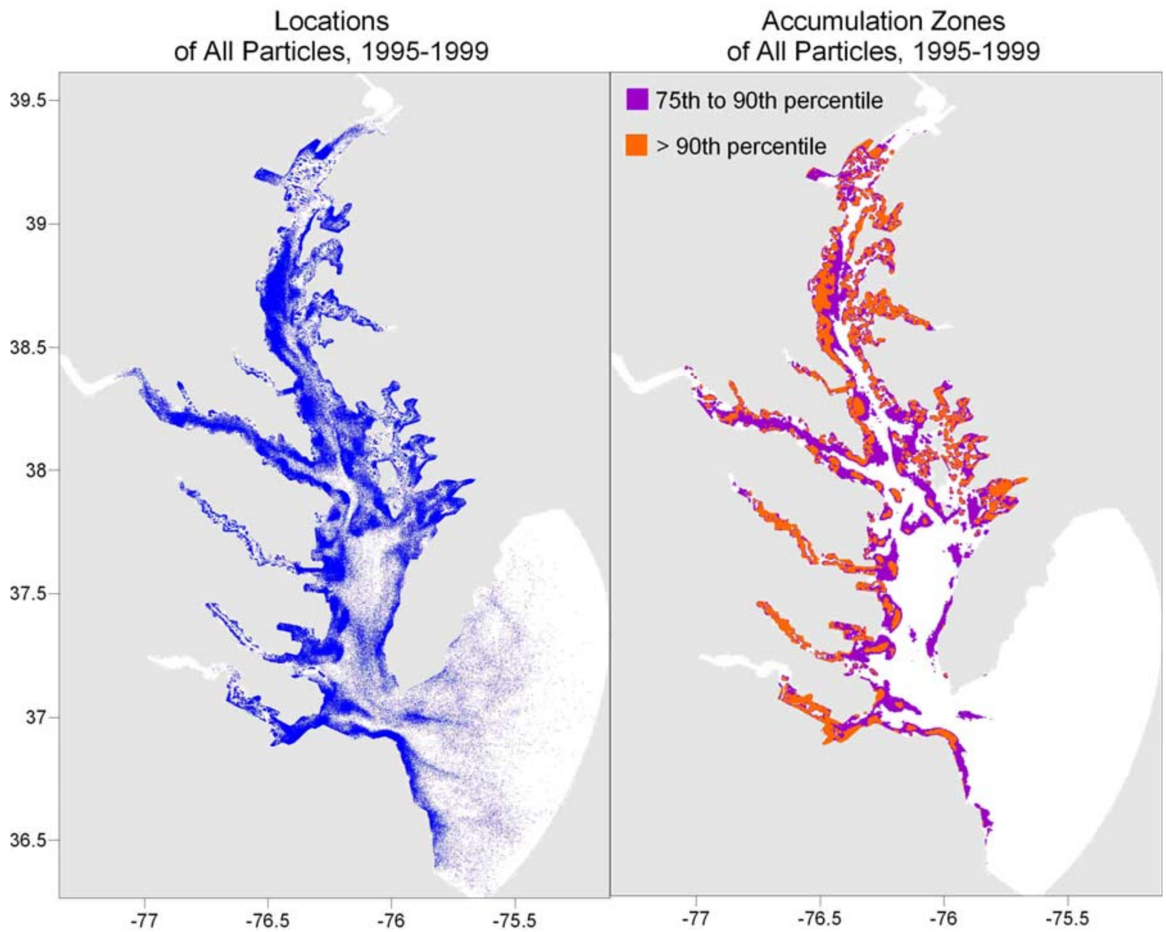


Fig. 10. Location of all *C. virginica* particles (both 'settled' and 'dead') for all model simulations for years 1995-1999 (left panel) and accumulation zones which indicate the locations of highest particle concentrations (right panel).

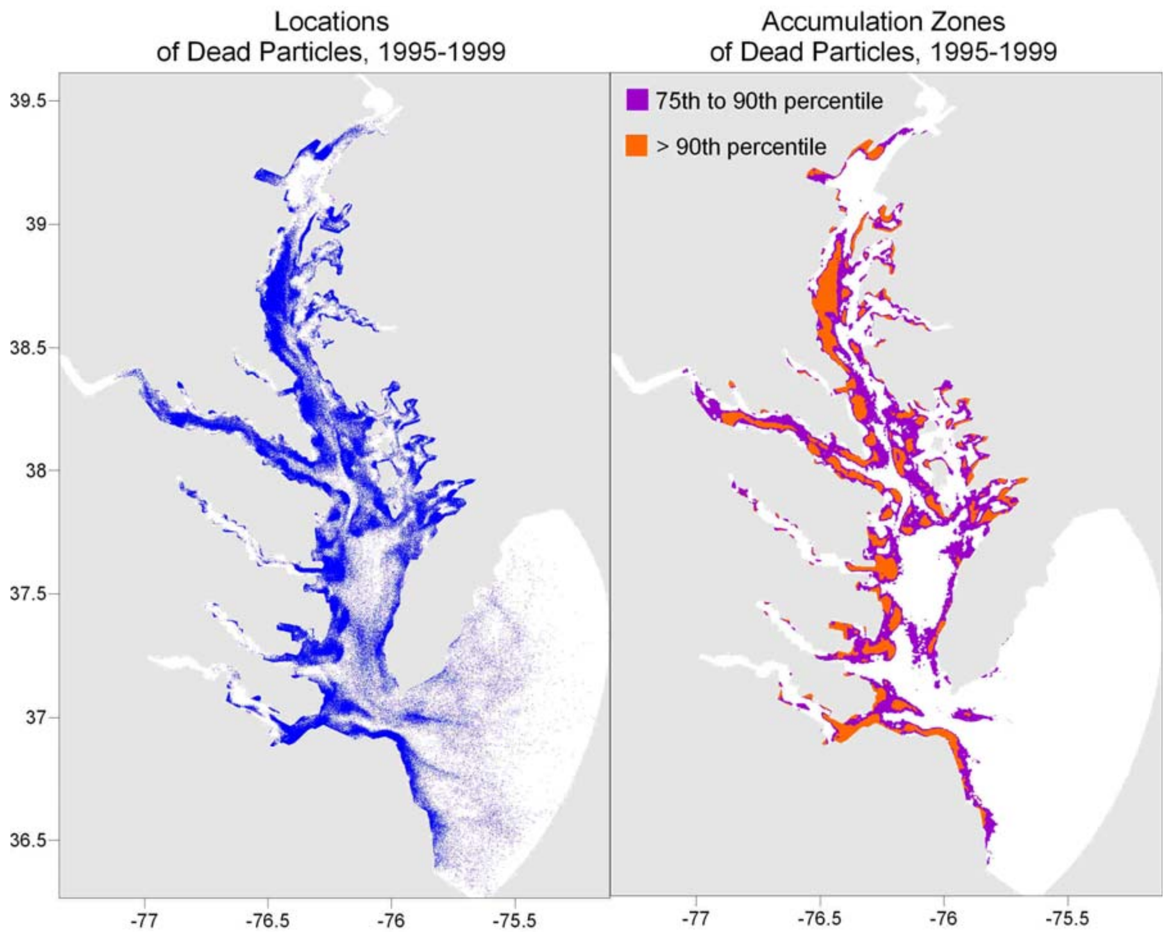


Fig. 11. Location of 'dead' *C. virginica* particles for all model simulations for years 1995-1999 (left panel) and accumulation zones which indicate the locations of highest particle concentrations (right panel).

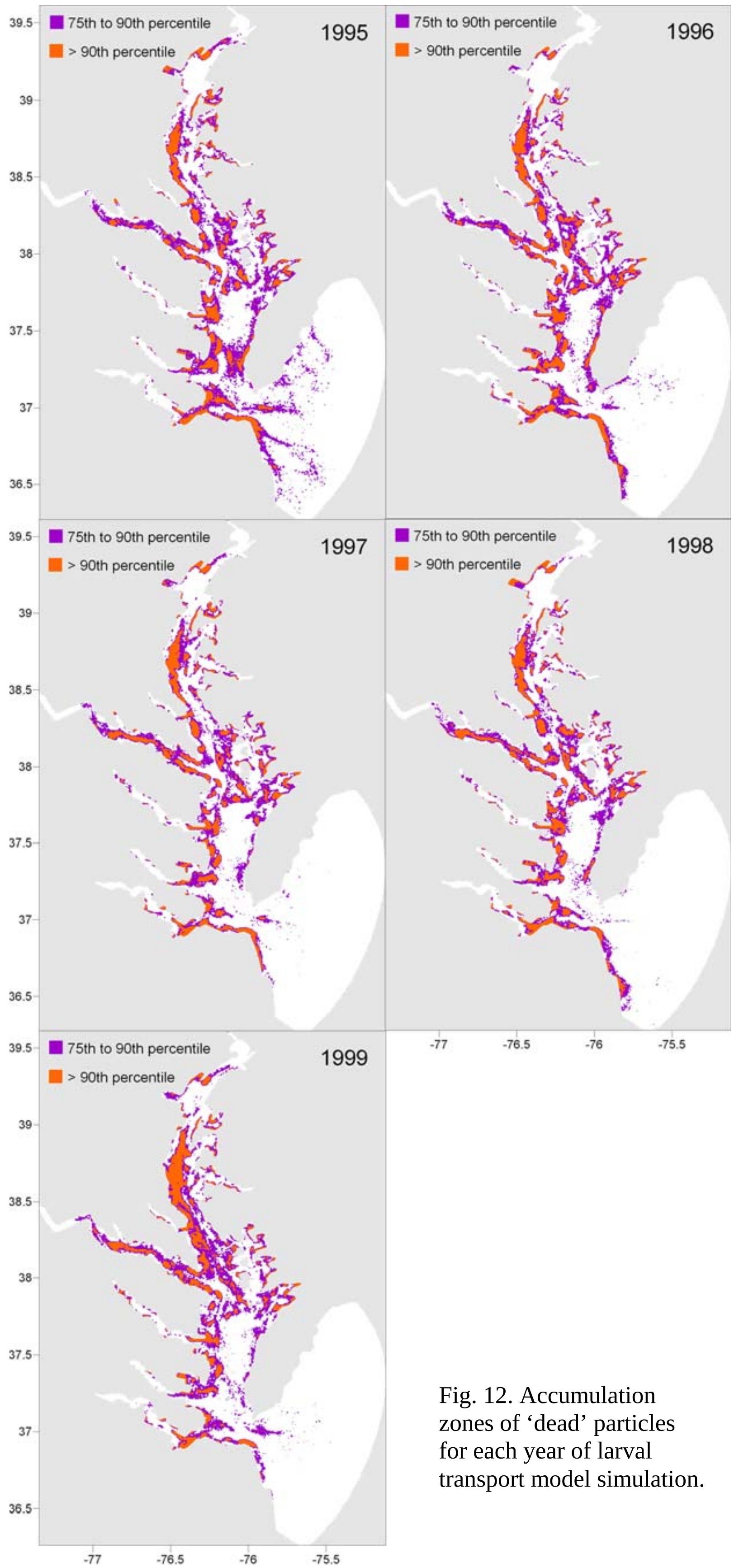


Fig. 12. Accumulation zones of 'dead' particles for each year of larval transport model simulation.

6. Discussion

Although the analyses presented in this report provide information that will support native oyster restoration efforts, it is important to note that transport metrics and accumulation zones reflect solely the influence of circulation patterns and the location of settlement habitat on larval transport. Many aspects of oyster biology were not included in the larval transport model. Therefore, these results should be used in conjunction with an understanding of the vital rates (growth, death, fecundity) of larvae, juveniles, and adults and the influence of physical conditions on them. It is also important to keep in mind that the larval transport model was built to capture Bay-wide processes. Small bathymetric features (<~2 km) that could influence circulation and small trap-like tributaries are not represented in the larval transport model. Therefore, these results should be used with caution when focusing on small regions.

As long as the assumptions associated with the larval transport model are kept in mind, model predictions provide valuable information that will support native oyster restoration activities. The success or failure of restoration efforts aimed at establishing self-sustaining populations will be decided by many factors, one of which will be whether the larvae that are produced by oysters at a restoration site survive, settle, grow and spawn (i.e., they are able to complete their life cycle and contribute to future generations). The larval transport model applies the best available information on circulation patterns and habitat to predict whether larvae produced by oysters at restoration sites have the chance to encounter habitat, and therefore, the chance of closing the life cycle and promoting a self-sustaining population.

Additional analyses of the larval transport model results could be used 1) to estimate how changes in freshwater flow influence transport success (and self recruitment and export scores) and 2) to identify networks of bars within sub-basins which supply larvae to each other. The former application could be paired with information on salinity to identify the regions that have consistent or variable transport success during low and high flow years. The latter application of larval transport model results would provide information that could be used to guide the selection of specific restoration sites and/or sanctuary areas within sub-basins to promote the development of a network of bars that provide larvae to each other (and therefore the chance to develop a self-sustaining population). Finally, larval transport model and estimates of flushing time for small tributaries (Wazniak et al. 2009) could be combined with demographic factors (e.g., growth rates, mortality rates, abundance) to estimate how many oysters are needed to establish a self-sustaining population in small embayments and in sub-basins.

7. Literature Cited

Greenhawk, K. 2005. Development of a Potential Habitat Layer for Maryland Oyster Bottom. Maryland Department of Natural Resources, Fisheries Division Report. August 4, 2005.

North, E. W., R. R. Hood, S.-Y. Chao, and L. P. Sanford. 2005. The influence of episodic events on transport of striped bass eggs to an estuarine nursery area. Estuaries 28(1): 106-121.

North, E. W., R. R. Hood, S.-Y. Chao, and L. P. Sanford. 2006a. Using a random displacement model to simulate turbulent particle motion in a baroclinic frontal zone: a new implementation scheme and model performance tests. Journal of Marine Systems 60: 365-380.

North, E. W., Z. Schlag, R. R. Hood, L. Zhong, M. Li, and T. Gross. 2006b. Modeling dispersal of *Crassostrea ariakensis* oyster larvae in Chesapeake Bay. Final Report to Maryland Department of Natural Resources, July 31, 2006. 55 p.

North, E. W., Z. Schlag, R. R. Hood, M. Li, L. Zhong, T. Gross, and V. S. Kennedy. 2008. Vertical swimming behavior influences the dispersal of simulated oyster larvae in a coupled particle-tracking and hydrodynamic model of Chesapeake Bay. Marine Ecology Progress Series 359: 99-115.

Schlag, Z., E. W. North, and K. Smith. 2008. Larval TRANSport Lagrangian model (LTRANS) User's Guide. University of Maryland Center for Environmental Science, Horn Point Laboratory. Cambridge, MD. 146 pp.

Smith, G. F., D. G. Brude, E. B. Roach, A. Hansen, R. I. E. Newell, and A.M. McManus.. 2005. Assessment of habitat conditions of eastern oyster *Crassostrea virginica* bars in mesohaline Chesapeake Bay. North American Journal of Fisheries Management 25 (4): 1569-1590.

Wazniak, T. M., and E. W. North. 2009. Residence times of small Chesapeake Bay tributaries. Final report to US Army Corps of Engineers, July 15, 2009, 28 p.

8. Appendix A. Summary table of data files

Data file number	Data file name	Format	Graphic/Table
3.1	3.1.Transport success for individual bars 1995-99.xls	Excel, GIS	Fig. 3
3.2	3.2.Interpolated transport success for indiv bars 1995-99.csv	Comma delimited, GIS	Fig. 4
3.3	3.3.Transport success by sub-basin.xls	Excel	Table 1
4.1	4.1.Self recruitment for individual bars.xls	Excel, GIS	Fig. 6
4.2	4.2.Export and self recruitment by sub-basin.xls	Excel	Tables 2 and 3
4.3	4.3.Sub-basin summary and ranks.xls	Excel	Table 4
5.1	5.1.All particles accumulation zones - 1995-1999.csv	Comma delimited, GIS	Fig. 10
5.2	5.2.All dead particles accumulation zones - 1995-1999.csv	Comma delimited, GIS	Fig. 11
5.3	5.3.Dead particles accumulation zones - 1995.csv	Comma delimited, GIS	Fig. 12
5.4	5.4.Dead particles accumulation zones - 1996.csv	Comma delimited, GIS	Fig. 12
5.5	5.5.Dead particles accumulation zones - 1997.csv	Comma delimited, GIS	Fig. 12
5.6	5.6.Dead particles accumulation zones - 1998.csv	Comma delimited, GIS	Fig. 12
5.7	5.7.Dead particles accumulation zones - 1999.csv	Comma delimited, GIS	Fig. 12

9. Appendix B. Response to USACE comments on draft report

USACE comments on Task 1 Draft Report submitted by Elizabeth North and Tom Wazniak, UMCES

1. According to the model, it appears that the upper regions of many rivers have good self recruitment. But, these are also areas where, due to oyster biology, there is very low reproduction. Additionally, the sub-basins appear to have the number of larvae assigned to them based on size. The upper regions often get disproportionately large numbers of larvae compared to the lower regions due to this, which is somewhat misleading. We understand that this is a primarily a hydrodynamic model, but it would be helpful to acknowledge (in the report) that these additional issues (caveats) need to be considered in evaluating the model results.
A discussion of the assumptions of the larval transport model was added to the Introduction section to clarify the fact that the larval transport model does not take into account the negative effect of low salinity on oyster larvae survival. In addition, the Introduction now contains an explanation of the derivation of the number of particles that were released in each sub-basin. Because we recognize that the number of particles released differs between sub-basins and between each habitat polygon, we chose to present the transport, export and natal returns results in terms of percentages, which allow unbiased comparison between regions.

2. Some things that would seem to be intuitive are not found in the model results. For example, it's a bit confusing how an area like the James, which once supplied seed to many areas in the Bay and elsewhere, does not rank higher. This might be due to the higher salinity regime, which supported higher recruitment in the area, or perhaps the model has a few problems in its assumptions. It's hard to tell.
Another explanation for the historically high spats sets in the James River, in addition to favorable salinities, is that the abundances of adult oysters could have been very high so they produced a huge number of larvae. Even if most larvae were transported out of the river system, a large enough spawning population could have resulted in significant numbers of spat settling within the river. Alternatively (or in addition), the hydrodynamic model may not have high enough resolution to simulate retentive eddies if they occur in the James River. Currently Ming Li and colleagues at Horn Point Laboratory are building a higher-resolution hydrodynamic model of the James River. It could be used to determine if increased resolution significantly changes circulation and larval transport predictions.

3. The model shows huge numbers of larvae being transported to the lower bayside eastern shore. What is confusing here is that there are no Baylor grounds over there (i.e., no historical oyster presence). Any insights here would be helpful to interpret this information. The planning team needs to explore the historical information on this. Baylor might have notes on this topic. From first glance, it looks like a good restoration site, based on this model output.

Fig. 7, which is based on approximately 64,000 particles, suggests that dead particles accumulate in large area in lower bayside eastern shore region. Fig. 10, which is based on approximately 1.5 million particles, does not show as large an accumulation of dead particles in this region compared to other areas in the Bay. So perhaps it is not unexpected that there are no Baylor grounds in this region. Even if larvae could be transported to the region, the bottom type may not be suitable for establishment of oyster reefs. For example, if large sand waves continuously shift and cover hard substrate, then oyster reefs may not have the chance to establish. Perhaps it would be wise to concentrate efforts where it is known that oyster established themselves and persisted (i.e., where there was an historical presence).

4. While the model results are positive, NORMP must carefully evaluate the wisdom of directing efforts to such large areas as the Choptank River, Mainstem, or Rappahannock. Addressing the scale issue such that the project can be self-sustaining is going to be a great challenge in systems this large. If the model can make any predictions of (relative) spatial scale needed in these systems it would be helpful. Determining how large such projects need to be, both in area and oyster biomass, will definitely need to be done with a high level of confidence before directing the large amount of money and resources – shell, seed, alternative materials – into such areas.
'What is the area/oyster biomass needed to create a self-sustaining population in tributaries of different sizes?' is an excellent question. The results of the larval transport model can be used to help answer it, but other important factors should be included, including biological processes like salinity-dependent mortality and growth as well as existing population abundance and habitat.

5. It would be helpful to see a list (table?) of some of the more important model assumptions. For example, how were the number of particles decided for each subestuary, or portion thereof?
A list and description of the major model assumptions was added to the Introduction, as was an explanation of the number of particles that were released in each sub-tributary.

6. Paragraph 1 on page 1 needs to be revised to identify the USACE as funding this additional larval transport modeling work for NORMP.
This was completed.

7. It would be helpful to have a summary/conclusions paragraph for each section: Transport success, Self-recruitment and Export Success, and Accumulation Zones.
This was completed.

Disease White Paper

A. SIGNIFICANCE TO OYSTER RESTORATION AND THE MASTER PLAN

The two oyster diseases caused by waterborne parasites (MSX (*Haplosporidium nelsoni*) and Dermo (*Perkinsus marinus*)) are among the most important factors affecting oyster populations and their restoration in the Chesapeake Bay. The presence of disease complicates all other factors that must be addressed to achieve oyster restoration. These diseases have severely reduced the abundance of Eastern oyster populations along the East Coast of the United States (Ford and Tripp, 1996). Disease-caused mortality is one of the major factors responsible for the dramatic declines in oyster landings observed since the early 1980s. The susceptibility of oysters to these diseases is linked to salinity concentrations, which vary annually as a result of changes in climatic conditions. The master plan must explicitly address disease, its relationship to salinity, and the development of disease resistance in the wild population to ensure the sustainability of restoration.

B. SCIENTIFIC BASIS AND STATE OF KNOWLEDGE

1. General

The mechanisms of MSX and Dermo transmission and infection are not well defined, but both diseases are transmitted through the water column to other oysters. Neither disease is transmitted directly from parents to offspring during spawning (Ford et al. 2001). Oysters can become infected by *MSX* or *DermoDermo* shortly after they set; however, infection levels in spat are typically very low. Once infected, however, parasite burdens in spat can become very high. *MSX* generally infects and kills more quickly than *Dermo*. Dermo is transmitted directly from oyster to oyster (Ragone-Calvo et al., 2003a) and transmission is dependent on the density of, and proximity to, infected oysters. Although transmission of Dermo is believed to be highly localized (i.e. less than 15 meters), water currents, predators, and scavengers are thought to extend the transmission range (Paynter 2008). *Oysters* can suffer very heavy *MSX*-caused mortality during their first year of exposure, whereas *Dermo* typically requires 2 or 3 years to attain full epizootic status. Nevertheless, each parasite is capable of killing 90 to 95% of susceptible *oysters* within 2 to 3 years (NN-EIS).

Oysters are infected in both the higher and lower salinity waters (i.e., disease is ubiquitous in the bay). Oyster populations in low salinity waters are more threatened by disease during periodic droughts. During drought periods, salinity increases with the reduction in freshwater inflow. The diseases can kill large numbers of oysters that have not had the opportunity to develop disease resistance.

"Dermo disease is dominant in the region today. MSX disease does intensify during droughts and causes mortality…but Dermo disease is responsible for substantially and consistently more oyster mortality baywide" (CBP 2007).

Despite the increasing prevalence in the Bay of the parasites that are responsible for the two diseases, a unique, 50-year dataset collected by researchers at the Virginia Institute of Marine

Science (VIMS) shows that Chesapeake Bay oysters are developing resistance to the pair of diseases. Ryan Carnegie, a VIMS research scientist in the Shellfish Pathology Lab, indicates that while disease "continues to be a major killer of oysters", fewer oysters are becoming infected by the diseases. For example, 82 percent of the oysters on Wreck Shoal in the lower James River had MSX in 1996. In recent years, the percentage has dipped to below 50 percent. Carnegie says "decreased disease in the wild despite favorable conditions for the parasites is a clear sign of increasing resistance among our native oysters due to long-term exposure." (Malmquist 2009**).**

2. ***Zones***

The parasites have different environmental limits.

3. Dermo disease (P. marinus)

Dermo develops the heaviest infections and kills most readily at salinities >10 ppt, but it survives at much lower salinities (3 ppt) (Chu and La Peyre 1993; Chu et al. 1993; Ragone-Calvo and Burreson 1994). Although Dermo survives low water temperatures and low salinities, its proliferation is highest in the broad upper range of temperatures (15-30 °C) and salinities (10-25 ‰) that are typical of Chesapeake Bay waters (Dungan and Hamilton 1995). Over several years of drought during the 1980s, Dermo extended its Chesapeake Bay distribution into upstream areas where it had been previously rare or absent, and became prevalent and established among those oyster populations (Burreson and Ragone Calvo 1996). Since 1990, at least some oysters in nearly all tested Maryland populations have been found to be infected. Monitoring of restored bars in Maryland (low to mid salinity sites) suggests that Dermo is not necessarily correlated with salinity in the waters tested but that local disease levels and/or water quality issues may be important in regulating local infection pressure (Paynter 2008).

4. MSX disease (*H. nelsoni)*

The life cycle and means of transmission of *MSX* are unknown. *MSX* is rare in oysters living at salinities <10 ppt; in fact, exposure to low salinity can eliminate the parasite from infected individuals (Andrews 1983; Ford 1985). MSX disease is most active when water salinities ≥14 ‰ co-occur with water temperatures of 5-20 °C (Ewart and Ford 1993). Since MSX disease is rare in oysters from waters below 10 ‰ salinity, the distribution range of H. nelsoni infections among Chesapeake Bay oysters varies as salinities change with variable seasonal and annual freshwater inflows. During 1999 through 2002, consistently low freshwater inflows to Chesapeake Bay fostered record upstream range extensions by MSX, and increased disease mortalities during each successive drought year (Tarnowski 2003). During the subsequent years of 2003 through 2006, consistent near- and above-average freshwater inflows reduced salinities of upstream Chesapeake Bay waters, and dramatically reduced the geographic range and impacts of MSX disease to Tangier Sound waters (Tarnowski 2007).

The influence of salinity on disease occurrence has led managers to establish zones in the Chesapeake Bay for oyster management. The 2007 Chesapeake Bay Program Oyster Disease Meeting indicated that it is still generally relevant to associate Zone 1 (5-12 ppt) with lower disease levels, Zone 2 (12-14 ppt) with intermediate disease levels, and Zone 3 (>14 ppt) with higher disease levels. They indicated that this scheme is simplistic and not entirely dependable, in that it should not be rigidly assigned to fixed geographical areas. Maryland waters normally in Zone 1 will become Zone 3 during droughts, for example. It is also not certain that disease levels will be equivalent in areas that are Zone 3 permanently (with oysters possibly adapted to disease and somewhat resistant) and in those that are Zone 3 ephemerally (with oysters more lightly disease-selected and possibly more susceptible). Mortality can be relatively high in Zone 3, but many oysters do survive to market size, particularly in Virginia (CBP 2007).

It is necessary to consider geographical variation in salinity zones to locate oyster restoration projects. One consideration would be to locate projects where they can contribute larvae to locations with different salinity regimes. The 2007 Chesapeake Bay Program Oyster Disease Meeting addressed the question of to what extent larval transport from low-salinity refuges is responsible for the abundance of oysters in higher salinity areas. “It is very unlikely that immigration from low salinity sanctuaries from parasitism is responsible for the abundance of adult oysters in higher salinity waters downstream. Disease-susceptible recruits from such sanctuaries would not be expected to survive long, as noted above.” They also indicated that, “Sanctuaries in Zone 1 can be expected to generate ecological benefits, with intermittent oyster spawning. However, offspring of oysters in this zone are likely to be susceptible to both MSX and Dermo diseases.” The meeting participants also concluded that “The probability that [sanctuaries in zone 3 will promote the development of natural disease resistance] is high if they are truly protected from harvest” (CBP 2007).

5. Development of Disease Resistance

There is definite evidence that oysters can develop resistance to disease in general **(**Needler and Logie 1947) and MSX and Dermo in particular **(**Andrews and Hewatt 1957, Bushek and Allen 1996, Haskin and Ford 1979, Carnegie and Burreson 2011**).** There are strong indications that disease resistance is developing in populations, especially those which are exposed to greater disease prevalence and intensity in the higher salinity waters, and where adults that have developed resistance are not harvested. Available evidence suggests that the current high levels of resistance in present-day Delaware Bay stocks was achieved after extensive *MSX*-caused mortalities occurred on seed beds in the upper bay during two drought years in the mid-1980s (USACE 2009). A number of papers suggest that some localized oyster stocks in the Chesapeake show selective survival despite disease pressure (Andrews, 1968; Burreson 1991; Ragone-Calvo et al., 2003b). Specifically, Carnegie and Burreson (2011) highlighted resistance in oysters in the lower Rappahannock River, and at sites in the James and York Rivers. The 2007 Chesapeake Bay Program Oyster Disease Meeting identified disease resistance developing in native populations: “…data from Virginia suggest that populations from Dermo-enzootic waters are relatively resistant…Size-specific *P. marinus* prevalence data indicate that large oysters exist in Virginia and Delaware Bay populations that remain healthy despite intense disease pressure.” This is also documented to be occurring in North Carolina and Delaware Bay. Also, various unfished oyster subpopulations have responded to disease pressure by developing resistance to disease (Encomio et al. (2005). Population recovery in the face of disease has been demonstrated in higher salinity zones in the Great Wicomico, tributary to the Chesapeake Bay

(Schulte et. al. 2009). However, there has been no systematic effort to document resistance in Chesapeake Bay native oysters (USACE 2009).

The 2007 Chesapeake Bay Program Oyster Disease Meeting indicated that there is strong evidence for MSX disease-resistance in wild oyster populations from Delaware Bay, where droughts have allowed penetration of MSX to reefs furthest up-Bay. With the most susceptible individuals lost to MSX, surviving natural broodstocks are substantially MSX-resistant. In Virginia, MSX is normally present at low prevalence and intensities unless susceptible oysters are deployed, in which case the MSX disease impact is devastating. Natural Virginia oysters clearly appear to harbor some MSX resistance. No equivalent data are available for Maryland (CBP 2007).

The 2007 Chesapeake Bay Program Oyster Disease Meeting indicated that evidence for Dermo disease resistance has been more elusive, including in Delaware Bay. Even among hatchery lines, evolution of Dermo resistance has been slow. In nature, even susceptible oysters may spawn once or twice before dying from Dermo disease, making a reproductive contribution that would retard the development of natural resistance within the larger population. Even in selective breeding programs, however, resistance to Dermo disease has been much slower to develop than was the case for MSX disease. Nonetheless, data from Virginia suggest that populations from Dermo-enzootic waters are relatively resistant, characterized by prevalences and intensities of *Perkinsus marinus* (and *H. nelsoni*) infection, and overall mortality, more similar to domesticated disease-resistant lines than to naïve controls. Size-specific Dermo prevalence data indicate that large oysters exist in Virginia and Delaware Bay populations that remain healthy despite intense disease pressure. A disproportionate reproductive contribution from such "resistant" oysters—assuming such is heritable— may underlie development of Dermo resistance in wild populations. These findings may not apply to Maryland waters, where Dermo disease is normally less prevalent, and thus where selective pressure is lighter (CBP 2007).

In spite of evidence of the development of disease resistance, disease still causes significant mortality in *C. virginica* populations in the Chesapeake Bay.

The 2007 Chesapeake Bay Program Oyster Disease Meeting recommended that a cost-effective and defensible strategy to allow disease resistance to develop "would begin with leaving natural oyster populations alone, creating sanctuaries and enforcing harvest moratoria to allow populations a chance to expand, and disease resistance to evolve." "Natural oyster sanctuaries are valuable in particular because presumptively disease-resistant broodstock will be given more opportunity to spawn in the absence of harvest pressure. Sanctuary populations over time should grow to be enriched for such larger, resistant oysters, which should be viewed as key spawners. Sanctuary reefs should also be viewed as important repositories for natural genetic diversity. Selection and siting of sanctuaries should reflect an understanding of oyster dispersal patterns, and metapopulation structure. Some effort should be directed toward setting aside existing productive reefs, or portions thereof, rather than only creating new habitats and designating them as sanctuaries" (CBP 2007).

6. Use of Domesticated Stock and Transplanting

The master plan must also address whether constructed reefs should be given a "jump start" with spat-on-shell and/or adult oysters to augment natural recruitment and to accelerate the development of natural disease resistance. The master plan will evaluate using native adult broodstock that has survived disease pressure to provide broodstock enhancement and/or these spat-on-shell. The progeny of these surviving adult oysters would be more likely to also have some level of disease resistance.

The 2007 Chesapeake Bay Program Oyster Disease Meeting indicated that "Genetic issues aside, there is no compelling argument for use of domesticated oysters [artificially selected for disease tolerance, such as CROSBreed and DEBY, (oysters bred to resist disease)] in ecological oyster restoration, given 1) the absence of evidence that planting of domesticated oysters yields improved survival, or higher subsequent recruitment; and 2) the comparable disease resistance and survival of natural strains in the field; and 3) the cost of hatchery seed. It is unknown whether domesticated MSX- and Dermo-resistant lines would be as resilient as diverse natural populations in the face of future environmental or disease (viral, parasitic, etc.) challenges. Nor do we know the costs or trade-offs of fast growth and disease resistance in domesticated lines."

Regarding the question of whether infected seed should be moved under any circumstances, and suitable criteria for doing so, the 2007 Chesapeake Bay Program Oyster Disease Meeting indicated that, "While transplantation of infected natural seed is not advisable in general, anthropogenic parasite dispersal associated with the movement of lightly infected oysters may be relatively insignificant against a larger backdrop of natural parasite dispersal and transmission. If infected oysters must be transplanted for repletion purposes, they should be transplanted at small size to areas characterized by similar or higher disease levels."

C. APPLICATION TO THE MASTER PLAN

All oysters in the CB are exposed to disease – exposure is persistent in high salinity areas and intermittent in low salinity areas – and the only way for resistance to develop is for oysters to be exposed to disease. The master plan will apply a genetic rehabilitation strategy that involves stocking and protecting oyster sanctuaries of sufficient size and over a broad range of environmental conditions to allow disease resistance to develop in the wild population.

Sanctuaries

A network of permanent sanctuaries will be established spanning salinity zones to develop population level disease resistance. This approach is consistent with the January 30, 2008 Maryland Oyster Advisory Commission Report, which indicated that, "Focusing ecological restoration efforts in a large scale, interconnected fashion (river system wide) is the strategy most likely to allow large populations of oysters to persist in the face of disease and other stressors." Also consistent with that report and reflecting the variability of salinity conditions in the bay, the network of sanctuaries will be designed to be resilient in the face of climate change; that is, reefs will be established in various salinity zones (areas with salinity in the 5 to 12 ppt range and areas with salinity greater than 12 ppt) within the Bay and targeted tributaries. Larvae, and their genetic resistance to disease, will be transported among reefs within the estuary through hydrodynamic larval transport. During periodic droughts, reefs established in lower salinity areas may be exposed to disease and may require restocking. However, stocking reefs in the lower salinity areas with spat-on-shell derived from disease tolerant parent stock (derived from either hatcheries or from the wild populations within a similar salinity regime) may help minimize mortality, accelerate disease resistance, and diminish the need for restocking.

Seeding and Stocking

The genes of disease resistant wild broodstock will be spread to target tributaries through a stocking program. Restoration sites will be seeded with sufficient numbers of large adult wild oyster broodstock that have survived disease and/or hatchery derived spat-on-shell or spat collected from areas (within the same salinity regime) where a proportion of the parent broodstock on sanctuaries has survived disease.

Adult wild broodstock and spat collected from wild areas will not be planted in areas with a lower salinity regime than that of its origin. To decrease the potential effects of genetic bottlenecking among hatchery-produced, disease-resistant oysters, an approach called rotating brood stock is recommended. This approach entails obtaining new broodstock each year from wild stocks that are displaying evidence of disease resistance for hatchery production of spat-on-shell. Although, the feasibility and effectiveness of this approach has not been evaluated, the approach appears to merit further investigation because it might contribute to increasing the rate of propagation of disease resistance within a local oyster stock.

Trap Estuaries

Hydrodynamics of the local waters in which restoration is attempted is an additional factor that can further enhance the long-term success of oyster restoration projects and development of disease resistance. Tidal action can retain oyster larvae, or flush them downstream, possibly even out of the local area entirely. Trap estuaries are tidally-influenced areas of rivers in which the tidal movements act to retain the oyster larvae produced by local spawning stock and limit downstream flushing. To further enhance recruitment and maximize the benefits of broodstock seeding, oyster restoration projects should first be constructed in retentive systems or "trap estuaries."

Spat-on-Shell Production

The recruitment that occurs when the broodstock oysters spawn or the spat-on-shell develop to sexual maturity, will enhance base oyster populations that have higher levels of disease resistance. The reefs that receive the greatest concentration of this recruitment will serve as "incubator reefs," providing the seed source for other trap estuaries. Spat-on-shell produced on incubator reefs would then be used as part of a larger secondary stocking program. The hope is to increase survival in the face of disease and accelerate the spread of the disease resistant trait. Ultimately, the genetic rehabilitation strategy is intended to produce introgression (a form of genetic assimilation) of disease-resistant genes into the natural population.

Can this strategy work? There is evidence that USACE's Great Wicomico restoration project population is continuing to grow in the face of disease (Schulte et al. 2009a). Great Wicomico bars have been populated by significant numbers of large adult broodstock oysters, which have persisted for over 5 years. Over 100 million adult oysters in these sanctuaries are making significant contributions to recruitment in the system. During 2007 and 2008, over 42,000 bushels of spat-on-shell (20,000 bushels in 2007 and 22,000 in 2008) were purchased from lease-holders in the Great Wicomico by Virginia to augment populations in other river systems (Coan, Yeocomico, Rappahannock, and Nomini). During this time, the GWR was the only viable source of spat-on-shell in Virginia waters. No other regions of the lower Bay except the Great Wicomico had sufficient recruitment to make moving the spat-on-shell economically viable. It is estimated that approximately 25 percent of the public ground harvest in 2008 and 2009 were the result of the subsequent harvest of this spat-on-shell, which had been planted on public grounds in the lower Rappahannock River as well as several Potomac River tributaries. While there is no specific monitoring data, it is suspected that the increased oyster survival to market size is tied to the genetic make-up of these progeny as well as favorable climatic conditions.

Questions, such as how many reefs should be built, how many should be seeded with broodstock oysters, what strain of oyster, what size oyster, and how many should be applied to each seeded reef, all would need to be answered in the site-specific subsequent decision documents in order to maximize chances for success and long-term sustained production of benefits.

In summary, the NORMP will evaluate:

1. seeding of restored sites with spat-on-shell derived from hatcheries or obtained from the wild population (from areas in a similar salinity regime) from disease tolerant parent stock
2. stocking of restoration sites with sufficient numbers of large adult wild oyster broodstock that have survived disease and/or spat-on-shell collected from areas (within a similar salinity regime) where a proportion of the parent broodstock on sanctuaries has survived disease,
3. using ‘incubator reefs’ to provide a seed source for restoration work, and
4. transplanting of spat-on-shell produced on incubator reefs to areas in the Bay with similar salinity conditions.

REFERENCES

Abbe, G.R., C.B. McCollough, L.S. Barker and C.F. Dungan. 2008. Performances of two disease-tolerant oyster strains in the Patuxent River, Maryland, 2003-2007. *Journal of Shellfish Research* 27:985 (abstract).

Andrews, J.D. 1968. Oyster mortality studies in Virginia VII. Review of epizootiology and origin of *Minchinia nelsoni*. *Proceedings of the National Shellfisheries Association* 58: 23-36.

Andrews, J.D. 1983. *Minchinia nelson* (MSX) infections in the James River seed oyster area and their expulsion in spring. Estuarine, Coastal and Shelf Science 16: 255-269.

Andrews, J.D. 1996. History of *Perkinsus marinus*, a pathogen of oysters in Chesapeake Bay. *Journal of Shellfish Research* 15:13-16.

Andrews, J.D. and W.G. Hewatt. 1957. Oyster Mortality studies in Virginia. II. The fungus disease caused by *Dermocystidium marinum* on oysters of Chesapeake Bay. *Ecological Monographs* 27:1-25.

Andrews, J.D. and J.L. Wood. 1967, Oyster mortality studies in Virginia. VI. History and distribution of *Minchia nelsoni*, a pathogen of oysters, in Virginia. *Chesapeake Science* 8:1-13.

Audemard, C., L.M. Ragone Calvo, K.T. Paynter, K.S. Reece and E.M. Burreson. 2006. Real-time PCR investigation of parasite ecology: in situ determination of oyster parasite *Perkinsus marinus* transmission dynamics in lower Chesapeake Bay. *Parasitology* 132:827-842.

Burreson, E.M. 1991. Effects of *Perkinsus marinus* infection in the eastern oyster, *Crassostrea virginica*: I. Susceptibility of native and MSX-resistant stocks. *Journal of Shellfish Research* 10:417-423.

Burreson, E.M. and S.E. Ford. 2004. A review of recent information on the Haplosporia, with special reference to *Haplosporidium nelsoni* (MSX disease). *Aquatic Living Resources* 17:499-517.

Burreson, E.M and L.M. Ragone Calvo. 1996. Epizootiology of *Perkinsus marinus* disease in Chesapeake Bay, with emphasis on data since 1985. *Journal of Shellfish Research* 15: 17-34.

Burreson, E.M., N.A. Stokes and C.S. Friedman. 2000. Increased virulence in an introduced pathogen: *Haplosporidium nelsoni* (MSX) in the eastern oyster *Crassostrea virginica*. *Journal of Aquatic Animal Health* 12:1-8.

Bushek, D. and S.K. Allen, Jr. 1996. Host-parasite interactions among broadly distributed populations of the eastern oyster *Crassostrea virginica* and the protozoan *Perkinsus marinus*. Mar. Ecol. Prog. Ser. 139:127-141.

Carnegie, R.B., and E,M, Burreson. 2009. Status of the Major Oyster Diseases in Virginia 2008: A Summary of the Annual Monitoring Program. Virginia Institute of Marine Science, The College of William and Mary, Gloucester Point, VA 23062.

Carnegie, R.B., and E. M. Burreson, 2011. Declining impact of an introduced pathogen: *Haplosporidium nelsoni* in the oyster *Crassostrea virginica* in Chesapeake Bay. Marine Ecology Progress Series 432: 1-15.

Chesapeake Bay Program. 2007. Oyster Management Plan Meeting Relating to Oyster Disease. Potomac River Fisheries Commission, Colonial Beach, VA. June 5, 2007.

Chu, F.E. and J.F. La Peyre. 1993. *Perkinsus marinus* susceptibility and defense-related activities in eastern oysters *Crassostrea virginica*: temperature effects. Dis Aquat Org 16:223–234.

Chu F.E., J.F. La Peyre, and C.S. Burreson. 1993. *Perkinsus marinus*infection and potential defense-related activities in eastern oysters, *Crassostrea virginica*: salinity effects. J Invertebr Pathol 62:226–232.

Dungan, C.F. and R.M. Hamilton. 1995. Use of a tetrazolium-based cell proliferation assay to measure effects of in vitro conditions on *Perkinsus marinus* (Apicomplexa) proliferation. Journal of Eukaryotic Microbiology 42:379-388.

Encomio, V.G., S.M. Stickler, S.K. Allen Jr., and F.-L. Chu. 2005. Performance of 'Natural dermo-resistant' oyster stocks- survival, disease, growth, condition, and energy reserves. Journal of Shellfish Research 24(1): 143-155.

Ewart, J.W. and S.E. Ford. 1993. History and impact of MSX and dermo diseases on oyster stocks in the Northeast region. NRAC Fact Sheet No. 200, 8pp. Univ. of Massachusetts, North Dartmouth, MA.

Ford, S.E. 1985. Effects of salinity on survival of the MSX parasite *Haplosporidium nelsoni* (Haskin, Stauber and Mackin) in oysters. *Journal of Shellfish Research* 5, 85-90.

Ford, S.E, and H.H. Haskin. 1982. History and epizootiology of *Haplosporidium nelsoni* (MSX), an oyster pathogen in Delaware Bay, 1957-1980. *Journal if Invertebrate Pathology* 40:118-141.

Ford, S.E, and H.H. Haskin. 1987. Infection and mortality patterns oin strains of oystyers *Crassostrea virginica* selected for resistance to the parasite *Haplosporidium nelsoni* (MSX). *Journal of Parasitology* 73:368-376.

Ford, S.E. and M.R. Tripp. 1996. Diseases and Defense Mechanisms. *In* V.S. Kennedy, R.I.E. Newell, and A.F. Eble, editors. The Eastern Oyster: *Crassostrea virginica*. College Park, Maryland: Maryland Sea Grant College Program. pp 581-660.

Ford, S.E, Z. Xu and G. Debrosse. 2001. Use of particle filtration and UV irradiation to prevent infection by *Haplosporidium nelsoni* (MSX) and *Perkinsus marinus* (Dermo) in hatchery-reared larval and juvenile oysters. *Aquaculture* 194:37-49.

Haskin, H.H. and S.E. Ford 1979. Development of resistance to *Minchina nelsoni* (MSX) mortality in laboratory-reared and native oyster stocks in Delaware Bay. *Marine Fisheries Review* 41(1-2):54-63.

Haskin, H.H., L.A. Stauber and J.A. Mackin. 1966. *Minchinia nelsoni* n. sp. (Haplosporida, haplosporidiidae): causative agent of Delaware bay oyster epizootic. *Science* 153:141-1416.

Mackin J.G. 1951. Histopathology of infection of *Crassostrea virginica* (Gmelin) by *Dermocystidium marinum* Mackin, Owen, and Collier. *Bulletin of Marine Science of the Gulf and Caribbean* 1:72-87.

Mackin, J.G., H.M. Owen and A. Collier. 1950. Preliminary note on the occurrence of a new protistan parasite, *Dermocystidium marinum* n. sp. in *Crassostrea virginica* (Gmelin). *Science* 111: 328-329.

Malmquist, D. 2009. Long-term study shows oysters developing disease resistence. VIMS website: news and events. [Online] Accessed September 1 2010. Available at: http://www.vims.edu/newsandevents/topstories/oyster_disease_resistance.php.

McCollough, C.B., B.W. Albright, G.R. abbe, L.S. Barker and C.F. Dungan. 2007. Acquisition and progression of *Perkinsus marinus* infections by specific pathogen-free juvenile oysters (*Crassostrea virginica* Gmelin) in a mesohaline Chesapeake Bay tributary. *Journal of Shellfish Research* 26:465-477.

Needler, A.W.H. and R.R. Logie**.** 1947. Serious mortalities in Prince Edward Island oysters caused by a contagious disease. *Trans. Roy. Soc. Can*. 41(2), Sect. 5: 73–89.

Paynter, K.T. 2008. A 10-Year Review of Maryland's Hatchery-based Oyster Restoration Program- 1997-2006: A Summary of Monitoring and Research conducted by the Paynter Laboratory at the University of Maryland.

Perkins, F.O. 1996. The structure of *Perkinsus marinus* (Mackin, Owen and Collier, 1950) Levine, 1978 with comments on taxonomy and phylogeny of *Perkinsus* spp. *Journal of Shellfish Research* 15:67-87.

Ragone-Calvo, L.M. and E.M. Burreson. 1994. Characterization of overwintering infections of *Perkinsus marinus* (Apicomplexa) in Chesapeake Bay Oysters. Journal of Shellfish Research 13: 123-130.

Ragone Calvo, L.M., G.W. Calvo and E.M. Burreson. 2003a. Dual disease resistance in a selectively bred eastern oyster, *Crassostrea virginica*, strain tested in Chesapeake Bay. *Aquaculture* 220:69-87

Ragone Calvo, L.M., C.F. Dungan, B.S. Roberson and E.M. Burreson. 2003b. Systematic evaluation of factors controlling *Perkinsus marinus* transmission dynamics in lower Chesapeake Bay. *Diseases of Aquatic Organisms* 56:75-86.

Ragone Calvo, L.M., R.L. Wetzel and E.M. Burreson. 2000. Development and verification of a model for the population dynamics of the protistan parasite, *Perkinsus marinus*, within its host, the eastern oyster, *Crassostrea virginica*, in Chesapeake Bay. *Journal of Shellfish Research* 20:231-241.

Ray, S.M. and A.C. Chandler. 1955. Parasitological Reviews: *Dermocystidium marinum*, a parasite of oysters. *Experimental Parasitology* 4(2):172-200.

Schulte, D.M, R.P. Burke , and R.N. Lipcius. 2009. Unprecedented restoration of a native oyster metapopulation. Science 325: 1124-1127.

Sunila, I., R.M. Hamilton and C.F. Dungan. 2001. Ultrastructural characteristics of the in vitro cell cycle of the protozoan pathogen of oysters, *Perkinsus marinus*. *Journal of Eukaryotic Microbiology* 48:384-361.

Tarnowski, M. (ed.) 2003. Maryland Oyster Population Status Report: 2002 Fall Survey. . Maryland Department of Natural Resources, Annapolis, MD, 32 pp. http://www.dnr.state.md.us/fisheries/commercial/oysters/fallsurvey/FSintro.html

Tarnowski, M. (ed.) 2005. Maryland Oyster Population Status Report: 2003 and 2004 Fall Surveys. Maryland Department of Natural Resources, Annapolis, MD, # 17-1072005-62, 33 pp. http://www.dnr.state.md.us/fisheries/commercial/oysters/fallsurvey/FSintro.html

Tarnowski. M. (ed.). 2007. Maryland Oyster Population Status Report: 2006 Fall Survey. Maryland Department of Natural Resources, Annapolis, MD, # 17-7272007-233.44 pp. www.dnr.state.md.us/fisheries/commercial/oysters/fallsurvey/fs06webver.pdf

Tarnowski. M. (ed.). 2008. Maryland Oyster Population Status Report: 2007 Fall Survey. Maryland Department of Natural Resources, Annapolis, MD, # 17-7302008-328, 36 pp. www.dnr.state.md.us/fisheries/commercial/oysters/fallsurvey/FSintro.html

United States Army Corps of Engineers (USACE). 2009. Final Programmatic Environmental Impact Statement for Oyster Restoration in Chesapeake Bay Including the Use of a Native and/or Nonnative Oyster .

Villalba, A., K.S. Reece, M. Camino Ordas, S.M. Casas and A. Figueras. 2004. Perkinsosis in molluscs: a review. *Aquatic Living Resources* 17:411-432.

Reproduction White Paper

A. SIGNIFICANCE TO OYSTER RESTORATION AND THE MASTER PLAN

This white paper will focus on reproduction within oyster populations and strategies to jumpstart reproduction. Oyster biology and reproduction are critical factors to consider in recommending and developing potential restoration projects in the master plan. Physical factors such as salinity, temperature, and dissolved oxygen have strong influences on both reproduction and survival of larvae, spat, and adult oysters. Because parent broodstock is severely limited in the Bay, reproduction must be supplemented. The following topics relevant to reproduction will be addressed (broader discussion of topics such as salinity are provided in subsequent white papers):

1. Oyster biology/reproduction
2. Physical and biological influences on reproduction
3. Larval distribution
4. Strategies to jump start population reproduction

B. SCIENTIFIC BASIS AND STATE OF KNOWLEDGE

1. Oyster Biology/Reproduction

The oyster's energetic investment in reproduction is prodigious, with an individual female capable of producing many millions of eggs. *C. virginica* is protandric and, as such, usually spawns as a male the first year. Andrews (1979) reported that in the James River 90% of oysters smaller than 35 mm shell height, and as young as 6 weeks post-settlement, functioned as males in the season in which they settled. As individuals grow, the proportion of functional females in each size class increases, with an excess of females occurring among larger animals (Galtsoff 1964). Cox and Mann (1992) reported a significantly greater number of male than female eastern oysters from four locations in the James River. Conversely, previous data from one of these locations had demonstrated a sex ratio of approximately unity for oysters larger than 60 mm shell height (Morales-Alamo and Mann 1989).

Reproductive activity is seasonal and in temperate regions is generally dictated by temperature. Spawning occurs predominantly during the warm season, although other factors, such as phytoplankton blooms, may also play a role. Members of the genus *Crassostrea* shed their gametes directly into the water where fertilization occurs, and larval life is spent entirely in the water column.

The waterborne larval stage of oysters allows them to disperse from the immediate site of the parental stock, enhances genetic mixing, and allows the colonization of new locations. The larvae are both dispersed and concentrated by water currents and wind. At the end of the larval stage, usually 2 to 3 weeks, the oysters "set." Food availability and temperature can affect the length of the larval stage. Larvae appear to migrate vertically, particularly at later stages, tending to concentrate near the bottom during the outgoing tide and rising in the water column during the incoming tide, thus increasing their chance of being retained in the estuary (Kennedy 1996; Shumway 1996). Larval mortality rates are estimated to be close to 99% (NRC 2004). It is important that larvae locate and settle on a suitable substrate within this 2 to 3 week period, and before they are flushed out of the area of suitable habitat. The substrate may be another oyster, a piece of shell, granite rip-rap, wood or concrete pilings, or any other solid "clean" (minimal sedimentation or fouling) surface. The concentrating effect of wind and currents, and the fact that larvae prefer to settle where there are other oysters, results in large assemblages on suitable substrates (NRC 2004).

Loss of a great majority of oyster reefs (>90% in many coastal areas) has significantly reduced the amount of hard surface bottom areas in areas like Chesapeake Bay (Smith, et.al. 2005). Oyster larvae will settle on most hard materials in the aquatic environment, as long as the material is not covered with sediment or colonized by other organisms, except for organisms that cohabitate with oysters. Natural materials like "shucking house" oyster shell, fossil shell dredged from river bottoms, and clam shells have typically been used to construct oyster restoration projects however these are limited and largely non-renewable resources. Due to the increasing scarcity of shells in many areas and its limited life span, alternative materials such as granite, concrete, limestone marl, etc. provide an attractive alternative to shell (Burke 2007; Schulte, et.al. 2010; Lipcius, et.al. 2006).

The clean surfaces of newly constructed shell reefs can become covered with fouling organisms and silt within a period as short as a few weeks to months. For this reason, timing reef construction to coincide with spawning events is a strategy that should be carefully considered in oyster reef restoration.

As documented by Rose et al. (2006), the prolific fecundity of this species might allow for a rapid regeneration of historic numbers if not for the low density of remaining breeders in a severely degraded environment with intense disease pressure (Boesch et al. 2001; Burreson and Ragone Calvo 1996; Jackson 2001).

Small oysters provide some reproduction before reaching sizes where they may experience high disease and fishing mortality. The number of eggs produced is proportional to the size of the individual oyster (Davis and Chanley 1955). Galtstoff (1930) counted the eggs released by individual eastern oysters and found that a single female could produce from 15 to 115 million eggs in one spawning. He estimated that as many as 500 million eggs may be spawned by a female during the season. Later, Galtsoff (1964) reported values of 10 to 20 million eggs as typical for a single spawn, with occasional spawning as many as 100 million. Cox and Mann estimated fecundity in James River oysters as a mean fecundity of 4 to 9 million eggs per female, depending on body size and the sampling site.

Oyster fertilization is density dependent. Using an equation described in prior literature (Mann and Evans, 1998), we have the following:

Fe = 0.0049 X D^.72
Fe = fertilization efficiency, D = oyster adult density per square meter.

2. Physical and Biological Influences on Reproduction/Fecundity

a. Salinity/Temperature

Temperature and salinity are the two main environmental factors affecting survival, growth, and reproduction of oysters (Shumway 1996, Thompson et al. 1996, NRC 2004). Development of eggs and larvae appears to be progressively reduced when the salinity falls below about 12 ppt and becomes negligible below about 8 ppt. Salinities below 5 or 6 ppt can inhibit gametogensis (Butler 1949, Loosanoff 1953). It is possible that recruitment in the low salinity waters could be accomplished by transport of late stage larvae (which are more tolerant to low salinity) from higher salinity areas.

Reproduction of *C. virginica* is seasonal and largely influenced by temperature. Gametogenesis begins in the spring and spawning occurs from late May to late September in the mid-Atlantic (Shumway 1996, Thompson et al. 1996). Small oysters (10 to 20 mm) sometimes develop gametes, almost always sperm (NRC, 2004). Under favorable growth conditions in the mid-Atlantic, this may occur during the late summer after setting, although it is uncertain whether such individuals actually spawn or produce embryos because they do not ripen until after the normal spawning period. In the southeastern United States, sexual maturity is typically reached about 3 months after setting (NRC 2004).

Galtstoff (1930) counted the eggs released by individual eastern oysters and found that a single female could produce from 15 to 115 million eggs in one spawning. He estimated that as many as 500 million eggs may be spawned by a female during the season. Later, Galtsoff (1964) reported values of 10 to 20 million eggs as typical for a single spawn, with occasional spawning as many as 100 million. Cox and Mann (1992) estimated fecundity in James River oysters as a mean fecundity of 4 to 9 million eggs per female, depending on body size and the sampling site.

3. Larval Distribution

Factors affecting larval survival and settlement include food, predation, suspended silt, and salinity (Loosanoff et al. 1948, Baldwin et al. 1991, Ulanowicz et al 1980, Loosanoff 1959). Larval mortality rates are estimated to be close to 99% (NRC 2004). Although adult oysters remain fixed in one location, their eggs and larvae spend 2-3 weeks as free-swimming plankton. During this planktonic stage, the young oysters pass through different stages of development, growing from fertilized eggs, to trochophores, to veligers, and finally to pediveligers, the stage at which larvae search for suitable substrate to which they will cement themselves, leaving the water column and becoming fixed on the bottom. This "settlement" of the larvae signals the end of the larval dispersal stage and the beginning of the juvenile stage. A suite of physical and biological factors influence larval survival and subsequent settlement of oyster larvae. Circulation patterns are controlled by tides as well as freshwater flow and wind which can change between years, months, weeks and even days. These patterns, and larval behavior responses, influence the direction and distance that larvae could be transported.

4. Strategies to "Jump-Start" Population Reproduction

a. Stocking Rates

Stocking rates on restored reefs can vary widely and are largely determined by remnant broodstock populations and their larval production and retention within any given system as well as physical parameters such as salinity. When broodstocks are low, higher levels of stocking may be required to augment and "jump start" population growth on restored reefs. There is very little if any scientific data to guide the appropriate level of stocking on restored oyster reefs. Restoration efforts in Maryland have seeded restored sanctuary reefs with 2 million spat per acre and harvest bars with 1 million spat per acre. However, recent monitoring has shown a high level, approximately 50%, of initial mortality. A large portion of this high mortality occurs during planting. It has been determined that the shells holding the hatchery set spat settle in such a way that the spat on the underside of the shell are smothered and die. In response to this, the Oyster Recovery Partnership and the University of Maryland are advising that the number of spat planted per acre on a sanctuary be increased to 4 to 5 million and that plantings only be performed on optimal bottom substrates. Ultimately, the goal is to ensure a density of oysters with an appropriate age (young to mature) structure and sex ratio (male to female) to maintain fecundity and provide the necessary water filtration and vertical relief to prevent the bar from being smothered with sediment. Winslow (1882) provided guidance from his extensive surveys of Tangier and Pocomoke Sound on age structure. He recommended that for every 1000 mature oysters there should be 1500 young oysters to provide the necessary brood stock to maintain the fecundity of the reef.

High salinity regions (>12 ppt) that experience good regular spat sets despite the current depleted oyster populations, may not need to be seeded or may only require one initial planting to jumpstart restoration of the reef. However, in lower and middle salinity waters (5-12 ppt) that have experienced a nearly complete collapse of reproductive success, initial planting of spat may be followed by plantings in subsequent years if natural recruitment does not sufficiently augment planted oyster populations.

An oyster restoration project recently constructed in the Lynnhaven River, Virginia in 2008 was seeded with one bushel of spat-on-shell/m^2 of reef constructed. The concentration of spat per bushel was approximately 1000-2000 (Dave Schulte, pers. comm.). On high relief reefs (~8 to 15 inches) constructed in the Great Wicomico River in 2004, initial spatset derived from wild broodstock was found at a concentration of approximately 2000 spat per square meter of restored reef. This initial spatset resulted in densities in 2007 and 2009 of 200 oysters/m^2 when a reef was 10% HRR to over 1000 oysters/m^2 when a reef was 90% HRR (Schulte et al. 2009a). The Great Wicomico project exceeds recently proposed criteria for sustainability (Powers et al. 2009): (i) it comprises multiple year classes at high abundance, which buffers year-to year variation in spat settlement; (ii) it is composed of young and old adults that have survived disease challenge; (iii) the reefs are accreting (that is, growing) at a rate that will provide settlement habitat for future generations; and (iv) it receives sufficient spat settlement and recruitment to sustain the population over the long term.

b. Broodstock Enhancement

The addition of adult oysters will be important to some restored reefs to enhance recruitment to the reef and to the surrounding area. Large natural oysters can be harvested and aggregated on reefs to enhance fertilization success. This strategy worked successfully in Virginia where large, but scattered, oysters from Tangier Sound were aggregated on a reef in the Great Wicomico

River (David Schulte, pers. comm.). In September 2009, VMRC approved another year of a buyback program of large oysters, measuring over 4.25 inches, in one of the Rappahannock River rotational harvest zones. These large oysters are then placed in sanctuaries with the Rappahannock River. If natural recruitment is low then it may be necessary to add adults to a reef in high density to jumpstart recruitment.

c. Use of Wild vs. Genetically Manipulated Stocks - As part of Alternative 2 (Enhance Restoration) in the *Final Programmatic Environmental Impact Statement (PEIS) for Oyster Restoration in Chesapeake Bay Including the Use of a Native and/or Nonnative Oyster* (USACE 2009), the use of disease-resistant hatchery strains as brood stock to produce spat for planting as a means of increasing the population was evaluated. The following describes the evaluation as presented in the PEIS:

DEBY and CROSSBreed are two disease-resistant strains of Eastern oyster presently available from hatcheries in the Bay area. Evidence suggests that "domesticated" lines like DEBY and CROSSBreed have faster growth rates and greater resistance to MSX than "wild" oysters in Chesapeake Bay. Allen and Hilbish (2000) suggested that spat produced from such selected strains of brood stock would have greater longevity on restoration reefs, perhaps "re-establishing overlapping year classes of adults." Allen et al. (2003) suggested that a process called "genetic rehabilitation" involving supportive breeding using disease-resistant brood stock could amplify the presence of alleles that confer disease resistance in the "wild" population. The potential benefit of using such disease-resistant strains in Alternative 2 is uncertain and controversial.

The consensus among participants at a workshop entitled "Revisiting Genetic Considerations for Hatchery-Based Restoration of Oyster Reefs" held in 2007 was that the absence of documented evidence that planting domesticated oysters has yielded improved survival or higher subsequent recruitment is a compelling argument against the use of domesticated oysters in ecological oyster restoration. The participants recommended a precautionary approach to any use of artificially selected strains of oysters (Hare 2006). Participants did not support continued pursuit of "genetic rehabilitation" of Chesapeake Bay oyster stocks using artificially selected oyster strains. They also concluded that the development of alternative strains of the Eastern oyster for use in restoration should not be pursued because selection is, by definition, a bottlenecking process; therefore, artificial selection for disease resistance would create strains with limited flexibility for coping with environmental change. They argued that preserving and enhancing local wild stocks that exhibit some level of natural disease resistance would be a preferred means of encouraging the development of disease resistance rather than to risk swamping the genetic diversity of the wild stock with domesticated hatchery spat.

No data are available to determine if domesticated strains of the Eastern oyster that are resistant to MSX and Dermo would be as resilient as wild populations to future environmental challenges or disease (viral, parasitic, etc.) or if planting an artificially selected strain could swamp the genetic diversity of the wild stock. In a study of the Olympic oyster, Camara (2008) showed a relationship between decreased survival and increased relatedness of the parents (inbreeding) that could be inferred to support the likelihood of a genetic bottleneck in populations subjected to artificial selection for disease resistance. Disease-resistant strains could become numerically *dominant in locations where they are stocked and, thus, could maintain their genetic integrity over multiple generations. Progeny produced in those locations, however, would be dispersed throughout adjacent areas. If wild stock were present in high proportions in the areas where the progeny set, genetic dilution would be likely and would reduce disease-resistance characteristics. The genetic integrity of a disease-resistant strain would be easily compromised in any location if a large natural set of wild oysters occurred, such as in a drought year. Cross-breeding of the wild stock with the disease-resistant strain could result in rapid genetic dilution of disease resistance.*

The preponderance of evidence suggests that using hatchery-produced, disease-resistant spat…would not significantly enhance the potential outcome for the size of the population and might have a detrimental long-term effect on the genetic diversity of the Bay's oyster population. Recent evidence of the development of disease resistance in wild stock prompted the suggestion to obtain new hatchery brood stock each year from wild stocks that are displaying such evidence This approach, using what might be termed rotating brood stock, would decrease the potential effects of genetic bottlenecking among hatchery-produced disease-resistant oysters. No detailed assessment of the feasibility or effectiveness of this approach was available during PEIS preparation, but the approach appears to merit further investigation because it might contribute to increasing the rate of propagation of disease resistance within a local oyster stock.

C. APPLICATION TO THE MASTER PLAN

Oyster biology and reproduction are critical factors to consider in recommending and developing potential restoration projects in the master plan. The purpose of substrate restoration and restocking is to establish stable populations of oysters with multiple year classes that grow and reproduce at sufficient rates to become self-sustaining. To further enhance recruitment and maximize the benefits of broodstock seeding, oyster restoration projects should first be constructed in what are termed "trap estuaries." These are smaller tributaries or other embayments that have circular gyres or small outlets into the Chesapeake Bay proper (discussed at length in scale white paper).

In addition, the master plan will consider and recommend various methods to jumpstart reproduction, tailored to on site salinity and disease level including:

- seeding,
- shell/substrate repletion,
- broodstock enhancement, and
- the use of wild stocks that appear to be displaying some degree of disease resistance.

The approaches to developing self-sustaining, reproducing oyster populations may be modified depending on the salinity regime in which the restoration work is taking place. One of the fundamental differences in the approach as outlined below is that recruitment may need to be augmented more consistently in the lower salinity waters where annual recruitment is generally lower. This augmentation would most likely take place via spat-on-shell stocking.

Low to Moderate Salinity Zones (<12 ppt Salinity)
The master plan will recommend the following to establish oyster populations in low salinity (<12 ppt) waters that naturally experience only intermittent low recruitment events, often separated by many years:

- Provide substrate as needed and stock using spat on shell at a rate of 4 to 5 million spat per acre (~1,000 to 1,200/m^2) (consistent with the Oyster Recovery Partnership recommendation and recent stocking efforts in Lynnhaven River).
- Substrate should be stocked immediately following planting to avoid degradation.
- Use adult wild stock from endemic disease areas to produce the spat-on-shell in hatcheries, to take advantage of any naturally developed disease resistance, that could be passed on to progeny.
- Monitor and, as needed, restock at initial stocking rate, 2 to 3 years following initial planting to provide a multi-age population
- Monitor (pre- and post-construction) to assess natural recruitment, oyster population characteristics, mortality, and condition to determine the need for additional stocking (especially important to determine whether significant mortality is occurring and to determine its cause: disease, predation, poaching, siltation/bottom shoaling, competition from biofouling organisms, etc.).

High Salinity Zones (>12 ppt Salinity)
The master plan will recommend the following to establish oyster populations in high salinity (>12 ppt) waters where oyster recruitment rates are higher:

- Provide substrate as needed.
- Plant substrate immediately prior to spawning season. Where natural recruitment is sufficient, may not need seeding. Where reefs were not planted and either natural recruitment is not occurring and/or substrate degradation is occurring, consider adding new material and/or restocking.
- Monitor the population to assess natural recruitment, oyster density and condition and determine the need for stocking (especially important to determine whether significant mortality is occurring and to determine its cause: disease, predation, poaching, siltation/bottom shoaling, competition from biofouling organisms, etc.).
- As part of monitoring and adaptive management, where applicable, determine reason(s) for lack of recruitment (silted substrate or insufficient larvae) and then act accordingly (i.e., provide clean substrate and/or oyster stocking). Consider application of additional reef material and/or restocking at initial rate of 4 to 5 million spat per acre.
- Stock and aggregate large natural oysters harvested from areas with demonstrated disease tolerance to enhance fertilization success.
- High salinity waters, with depleted stocks, may need to be seeded if sufficient natural spatset is not occurring as predicted based on spatfall survey data.
- Use large adult wild stock from endemic disease areas to produce the spat-on-shell in hatcheries, as these adults may have developed some level of disease resistance, which they could pass on to their progeny.

REFERENCES

Allen, S.K. Jr., R.D. Brumbaugh, and D. Schulte. 2003. Transforming Chesapeake Bay. Virginia Marine Resource Bulletin 35: 2-8.

Allen, S.K. Jr. and T.J. Hilbish. 2000. Genetic Considerations for hatchery-based restoration of oyster reefs. A summary from the Sept 21-22, 2000 Workshop held at Virginia Institute of Marine Science and sponsored by Aquaculture Genetics and Breeding Technology Center, Chesapeake Bay Foundation, Chesapeake Research Consortium, and Virginia Institute of Marine Science. Glouchester Point, Virginia.

Andrews, J.D. 1979. Pelecypoda: Ostreidae. Pages 293-342 in A. C. Giese and J.S. Pearse (eds.) Reproduction of Marine Invertebrates, Vol 5. Academic Press, NY.

Baker, S. M. & R. Mann. 1992. Effects of hypoxia and anoxia on larval settlement, juvenile growth, and juvenile survival of the oyster, Crassostrea virginica. Biol. Bull. 182:265-269.

Baker, S. M. & R. Mann. 1994. Description of metamorphic phases in the oyster, Crassostrea virginica, and the effects of hypoxia on metamorphosis. Mar. Ecol. Prog. Series 104:91-99.

Baldwin, B.S. and R.I.E. Newell. 1991. Omnivorous feeding by planktotrophic larvae of the eastern oyster *Crassostrea virginica*. Marine Ecology-Progress Series 78: 285-301.

Barber, B.J., S.E. Ford, and R.N. Wargo. 1991. Genetic variation in the timing of gonadal maturation and spawning of the Eastern oyster, *Crassostrea virginica* (Gmelin). *Biological Bulletin* 181(2): 216-221.

Barber, B.J., and R. Mann. 1994. Comparative physiology of Eastern oyster, *Crassostrea virginica* (Gmelin, 1791), and Pacific oyster, *Crassostrea gigas* (Thunberg, 1793): Growth, mortality and effects of the parasite, *Perkinsus marinus*. *Journal of Shellfish Research* 13(1): 109-114.

Boesch D, Burreson E, Dennison W, Houde E, Kemp M, Kennedy V, Newell R, Paynter K, Orth R, and Ulanowicz R, 2001. Factors in the decline of coastal ecosystems. Science 293: 1589–1590.

Burke, R. P. 2007. Lynnhaven River Artificial Reef Performance Report. Virginia Institute of Marine Science, Gloucester Point, VA.

Buroker, N.E. 1983. Population genetics of the American oyster *Crassostrea virginica* along the Atlantic coast and the Gulf of Mexico. *Marine Biology* 75(1): 99-112.

Burreson EM and Ragone Calvo L, 1996. Epizootiology of Perkinsus marinus disease of oysters in Chesapeake Bay, with emphasis on data since 1985. J Shellfish Res 15: 17–34.

Bushek, D., and S.K. Allen, Jr. 1996. Host-parasite interactions among broadly distributed populations of the Eastern oyster *Crassostrea virginica*, and the protozoan *Perkinsus marinus*. *Marine Ecology Progress Series* 139: 127-141.

Butler, P.A. 1949. Gametogenesis in the oyster under conditions of depressed salinity. Biol. Bull. 96: 263-269.

Calabrese, A. and H.C. Davis. 1970. Tolerances and requirements of embryos and larvae of bivalve mollusks. Helgolander Wiss. Meeresunters 20:553-564.Carnegie, R.B. and E. M. Burreson. 2009. Status of Major Oyster Diseases in Virginia 2006-2008. A Summary of the Annual Oyster Disease Monitoring Program. Virginia Institute of Marine Science, College of William and Mary.

Camara, M.D., S. Evans, and C.J. Landgon. 2008. Patental relatedness and survival of Pacific oysters from a naturalized population. Journal of Shellfish Research 27: 323-336.

Cox, C. and R. Mann. 1992. Temporal and spatial changes in fecundity of eastern oysters. Crassostrea virginica (Gmelin, 1791) IN THE James River, VA J. Shellfish Res. 11: 49-54.

Dame, R.G. 1976. Energy flow in an intertidal oyster population. Est. Coast. Mar. Sci. 4: 243-253.

Davis, H.C. 1958. Survival and growth of clam and oyster larvae at different salinities. *Biological Bulletin* 114: 296-307.

Davis, H.C., and A. Calabrese. 1964. Combined effects of temperature and salinity on development of eggs and growth of larvae of *M. mercenaria* and *C. virginica*. *Fishery Bulletin* 63: 643-655.

Davis, H.C. and P.E. Chanley. 1955. Spawning and egg production of oysters and clams. Biol. Bull. (Woods Hole) 110: 117-128.

Dittman, D.E., S.E. Ford, and H.H. Haskin. 1998. Growth patterns in oysters, *Crassostrea virginica*, from different estuaries. *Marine Biology (Berlin)* 132(3): 461-469.

Fegley, S.R., S.E. Ford, J.N. Kraeuter, and D.R. Jones. 1994. *Relative Effects of Harvest Pressure and Disease Mortality on Eastern Oyster Population Dynamics in Delaware Bay*. Final Report No. NA26FL0588. National Oceanic and Atmospheric Administration, National Marine Fisheries Service Oyster Disease Research Program, Haskin Shellfish Research Laboratory, Port Norris, New Jersey.

Finucane, J. H. & R. W. Campbell II. 1968. Ecology of American oysters in Old Tampa Bay, Florida. Florida Scientist 31: 37-46.

Ford, S.E., and H.H. Haskin. 1982. History and epizootiology of *Haplosporidium nelsoni* (MSX), an oyster pathogen in Delaware Bay, 1957-1980. *Journal of Invertebrate Pathology* 40(1): 118-141.

Ford, S.E., and M.R. Tripp. 1996. Diseases and Defense Mechanisms. Pp. 581-660 in *The Eastern Oyster*: Crassostrea virginica, V.S. Kennedy, R.I.E. Newell, and A.F. Eble, eds. Maryland Sea Grant College Program, College Park, Maryland.

Galtsoff, P.S. 1930. The oyster industry of the Pacific coast of the United States. Appendix 8 Rep. U.S. Comm. Fish. 1929: 367-400.

Galtsoff, P.S. 1964. The American oyster *Crassostrea virginica* Gmelin. Fish. Bull. 64: 1-480.

Hare, M. P., S. K. Allen Jr., P. Bloomer, M. D. Camara, M. D. Carnegie, J. Murfree, M. W. Luckenbach, D. Merritt, C. Morrison, K. T. Paynter, K. S. Reece, and C. G. Rose. 2006. A genetic test for recruitment enhancement in Chesapeake Bay oysters, Crassostrea virginica, after population supplementation with a disease tolerant strain. Conservation Genetics 7: 717-734.

Haskin, H.H., and S.E. Ford. 1986. Report to the Bureau of Shellfisheries, New Jersey Department of Environmental Protection on the Delaware Bay Oyster Research Program 1984-1986. Rutgers University. Port Norris, New Jersey.

Hoese, H. D. & R. Ancelet. 1987. Anoxia induced mortality of oysters, Crassostrea virginica, associated with a spoil bank bisecting a bay. J. Shellfish Res. 6: 41-44.

Ingle, R. M. 1951. Spawning and setting of oysters in relations to seasonal environmental changes. Bull. Mar. Sci. Gulf and Carib. 1: 111-135.

Jackson JBC, 2001. What was natural in the coastal oceans? Proc Natl Acad Sci USA 98: 5411–5418.

Kennedy, V. S. 1996. Biology of larvae and spat. In: Kennedy, V. S., R. I. E. Newell, and A. E.Eble, eds. The Eastern Oyster: *Crassostrea virginica*. Maryland Sea Grant College, College Park, Maryland. 734 pp.

Lipcius, R. N. and R. P. Burke. 2006. Abundance, biomass and size structure of Eastern oyster and hooked mussel on a modular artificial reef in the Rappahannock River, Chesapeake Bay. Special Report in Applied Marine Science and Ocean Engineering, No. 390.

Loosanoff, V.L 1953 Behavior of oysters in water of low salinities. Proc. Natl. Shellfish Assoc. 43: 135-151.

Loosanoff, V.L. 1959. *Condylostoma* – an enemy of bivalve larvae. Science. 129: 147.

Loosanoff, V.L., and C.A. Nomejko. 1951. Existence of physiologically different races of oysters, *Crassostrea virginica*. *Biological Bulletin* 101: 151-156.

Loosanoff, V.L. and F.D. Tommers. 1948. Effect of suspended silt and other substances on rate of feeding of oysters. Science 107: 69-70.

MacKenzie, C.L., Jr. 1970. Causes of oyster spat mortality, conditions of oyster setting beds, and recommendations for oyster bed management. *Proceedings of the National Shellfisheries Association* 60: 59-67.

Mann, R. and D.A. Evans. 1998. Estimation of oyster, *Crassostrea virginica*, standing sock, larval production and advective loss in relation to observed recruitment in the James River, Virginia. Journal of Shellfish Research 17: 239-253.

May, E. B. 1972. The effect of floodwater on oysters in Mobile Bay. Proc. Natl. Shellfish Assoc. 62: 67-71.

Morales-Alama, R. and R. Mann. 1989. Anatomical features in histological sections of *C. virginica* as an aid in measurements of gonad area for reproductive assessment J. Shellfish Res. 8: 71-82.

NRC (National Research Council). 2004. Nonnative Oysters in the Chesapeake Bay. Washington DC: The National Academies Press.

Nelson, T.C. 1928. On the distribution of critical temperatures for spawning and for ciliary activity in bivalve mollusca. Science 67: 220-221.

Oyster, Crassostrea virginica, in Chesapeake Bay. Journal of Heredity 2006:97(2): 158–170.

Powers, S.P., Peterson, C.H., J.H. Grabowski, and H.S. Lenihan. 2009. Success of constructed oyster reefs in no-harvest sanctuaries: implications for restoration. Mar. Ecol. Prog. Ser. 389: 159-170.

Quick, J. A., Jr. & J. G. Mackin. 1971. Oyster parasitism by Labyrinthomyrxa marina in Florida. Florida Depart. Nat. Res. Marine Research Laboratory Professional Paper Series. No.13.55 pp.

Reeb, C.A., and J.C. Avise. 1990. A genetic discontinuity in a continuously distributed species: Mitochondrial DNA in the American oyster, *Crassostrea virginica*. *Genetics* 124(2): 397-406.

Roegner, G.C., and R. Mann. 1995. Early recruitment and growth of the American oyster *Crassostrea virginica* with respect to tidal zonation and season. *Marine Ecology-Progress Series* 117(1-3): 91-101.

Rose, C.G., K.T. Paynter, and M. P. Hare. 2006. Isolation by Distance in the Eastern Oyster, *Crassostrea virginica*, in Chesapeake Bay. J. Heredity 97 (2): 158-170.

Schulte, D. M., Burke, R. P. and R. N. Lipcius. 2009a. Unprecedented restoration of a native oyster metapopulation. Science 325: 1124-1127.

Schulte, D., G. Ray, and D. Shafer. 2009b. Use of alternative materials for oyster reef construction. EMRRP Technical Notes Collection (ERDC TN-EMRRP-ER-12). Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Sellers, M.A. and J.G. Stanley. 1984. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (North Altnatice) – American oyster. U.S. Fish and Wildlife Service. FWS/OBS-82/11.23. U.S. Army Corps of Engineers, TR EL-82-4. 15pp.

Shumway, S.E. 1996. Natural environmental factors. Pp. 467-513 in *The Eastern Oyster:* Crassostrea Virginica, V.S. Kennedy, R.I E. Newell, and A.F. Eble. Maryland Sea Grant College Program, College Park, Maryland.

Shumway, S.E., T. L. Cucci, R. C. Newell, and C. M. Yentsch. 1985. Particle selection, ingestion, and absorption in filter-feeding bivalves. *Journal of Experimental Marine Biology and Ecology* 91: 77-92.

Smith, G.F., D.G. Bruce, E.B. Roach, A. Hansen, R.I.E. Newell, and A.M. McManus. 2005. Assessment of recent habitat conditions on eastern oyster *Crassostrea virginica* bars in mesohaline Chesapeake Bay. North American Journal of Fisheries Management 25: 1569-1590.

Sparks, A. J., J. L. Boswell & J. G. Mackin. 1957. Studies of the comparative utilization of oxygen by living and dead oysters. Proc. Natl. Shellfish Assoc. 48: 92-102.

Stauber, L.A. 1950. The problem of physiological species with special reference to oysters and oyster drills. *Ecology* 31: 109-118.

Thompson, R.J., R.I.E Newell, V.S. Kemmedy and R. Mann. 1996. Reproductive processes and early development, p. 335-370 in The Eastern Oyster Crassostrea virginica, Newell, R.I.E., V.S. Kennedy and A.F. Eble (eds) Maryland Sea Grant College, College Park, MD.

Ulanowicz, R.E., W.C. Caplins and E.A. Dunnington, 1980. The forecasting of oyster harvest in central Chesapeake Bay. Est. Coast. Mar. Sci. 11: 101-106.

USACE. 2009. Final Programmatic Environmental Impact Statement for Oyster Restoration in Chesapeake Bay Including the Use of a Native and/or Nonnative Oyster.

Wilson, C.,Scotto, L.,Scarpa, J.,Volety, A.,Laramore, S.,Haunert, D. 2005. Survey of water quality, oyster reproduction and oyster health status in the St. Lucie Estuary. Journal of Shellfish Research, January 1, 2005.

Winslow, F. 1882. Report on the oyster beds of the James River, Va., and of Tangier and Pocomoke Sounds, Maryland and Virginia. U.S. Coast and Geodetic Survey Report for 1881:1-87.

Oyster Restoration Scale White Paper

A. SIGNIFICANCE TO OYSTER RESTORATION AND THE MASTER PLAN

It is known that a once extensive network of subtidal oyster reefs existed in the Chesapeake Bay, but only a very small remnant of that reef structure and viable population currently exists. The existing oyster habitat is in such poor condition that recruitment is limited due to lack of attachment sites for planktonic oyster larvae. Almost all the former oyster habitat is now sand or much finer silt and mud, which oysters do not typically find suitable as attachment substrates. In addition, the wild stock is at extremely low density which further reduces reproductive efficiency, overall recruitment, and ultimate sustainability of oyster populations. Only very low population densities relative to the historic population are likely to persist on the remnant oyster habitat throughout the Chesapeake Bay, and little recovery of the habitat is expected to occur naturally. The master plan must define the appropriate scale of restoration for each hydraulically separate tributary or sub-section of the Bay to ensure that the restored habitat and any existing habitats in the segment will be self-sustaining and contribute larvae and other benefits to surrounding portions of the Bay. In addition, self-sustaining reefs are less costly over time, i.e., will require less stocking in the future, and growing reefs will require less acres in need of restoring to reach goals, etc.

Scale, as defined in this paper, is the approximate number of acres of habitat in a given area or tributary required to develop a self-sustaining population. While the specific placement and distribution of reefs within these areas/tributaries is also important, that identification requires a more complete understanding of local hydrodynamics which will be addressed in the site-specific implementation documents that will follow the master plan.

Past restoration efforts (with the exception of the Great Wicomico) have not achieved a restored, self-sustaining, native oyster population in the Chesapeake Bay for a variety of reasons. One of the most significant shortfalls has been a failure to address scale - previous efforts were too small and too widely dispersed. The most comprehensive analysis of past restoration efforts was coordinated by Maryland Sea Grant and is summarized in *Native Oyster (Crassostrea virginica) Restoration in Maryland and Virginia: An Evaluation of Lessons Learned 1990-2007* (ORET 2009). Restoration actions differed widely at each site and included bagless dredging, bar cleaning, hatchery seed transplant, substrate addition, wild seed transplant, with and without monitoring. These activites were employed singularly and in various combinations on 10,398 acres in MD and 2,214 ac in VA. Wild seed transplant was the largest effort in MD, being carried out on 6,896 ac, mostly prior to 2000. In VA, substrate addition constituted the greatest application on 1,749 ac.

The Yates Survey of 1906-1911 is the most comprehensive account of historic oyster resources in MD, even though it is recognized that the population was already showing signs of degradation at that time. The Yates Survey identified 779 named reefs on 214,772 acres. ORET (2009) identified past restoration efforts on 10,398 ac in MD, which accounts for restoring 4.8% of the Yates surveyed grounds. It can be assumed that the wild seed transplant efforts targeted fishery improvements rather than ecological restoration. Therefore, if those acres are removed from the picture, that reduces the attempted restoration to just 1.6% of historic acreage. In 1894, the Baylor Survey mapped 232,016 ac of oyster habitat in VA. The 2,214 ac of restoration performed in VA amounts to addressing approximately 1% of historic acreage. The USACE team has compared the Baylor grounds to the more detailed, Moore survey (1909) and Winslow survey (1882), and estimated that only 47% of the Baylor grounds and 43% of the Winslow grounds contained oyster habitat. Even with that in consideration, restoration efforts have only addressed 2% and 11.3% of historic acreage in VA and MD, respectively.

Contextually, it also needs to be considered, that these acres were scattered across the Maryland and VA tributaries to the Bay and not concentrated in any way. Further, there is no adjustment of the total restored acres for multiple actions on individual acres, likely resulting in an overestimation of acres restored. That is, if two actions were performed on the same acre at the same time, ORET (2009) recorded this as 2 acres of restoration. Given this, it can be assumed that an even smaller percentage of historic acreage has actually received restorative actions. As evident from ORET (2009), past efforts did not reach an appropriate scale necessary to restore either a critical biomass or critical area of spatial complexity (Mann and Powell 2007). Both are necessary to successfully restore a sustainable oyster population. With nearly 99% gamete mortality (Rumrill 1990; Morgan 1995), a large number of oysters are needed to jumpstart the population. Additionally, the Eastern oyster population is composed of numerous metapopulations. The connectivity within the metapopulations and among metapopulations within the Bay adds spatial complexity to the resource and is just beginning to be understood. A significant amount of area is necessary to restore connectivity and spatial complexity. The wide distribution of the historic population within tributaries and throughout the Bay provided a resilient network that enabled the oyster to thrive and survive in the face of various natural challenges and harvest pressures.

There are a few investigations on the extent of oyster habitat degradation. Between 1999 and 2001, Smith et al. (2005) surveyed 39 km^2 of bottom in the lower Choptank River and adjacent western Bay shore that was classified as supporting productive oyster populations in 1911. Their investigations estimated that over 90% of that area has been degraded to mud, sand, or heavily sedimented oyster shell. In the late 1980s, Seliger and Boggs (1988) compared the Yates Survey (Yates 1913) and their survey obtained with an echosounder calibrated by sampling with dredge and by scuba diver, and found that only 14% of the surface was still covered by oysters and shells in Chester River, Broad Creek, and Tred Avon River. At a similar time, Haven and Whitcomb (1986) showed that only 21.8% of Virginia oyster bars from the beginning of the century still survived. Whitcomb and Haven (1987) found only 19.5% of original public oyster grounds remained in Pocomoke Sound using a sonar and verification by sampling with hydraulic patent-tongs. Gouletequer et al. (1994) conducted an intensive systematic survey of eight oyster bars in Choptank River in 1989-1991. They found only 48% of original listed acreage from Yates survey was present. The oyster population was publicly considered degraded at the time of all of these investigations in the late 1980s that projected habitat losses ranging from 52 to 86%.

The plan presented in the master plan targets the recovery of a keystone species (oysters), but also involves an ecosystem restoration objective. Ecosystem restoration, by definition, implies that recovery is expected to occur among a variety of living organisms and the physical environment in which they live. The goal is to achieve recovery to as near its natural or historical condition as possible. Since, historically, oyster reefs were distributed throughout the bay tributaries where they provided ecosystem services, scaling projects should also consider a similar distribution in order to achieve full ecosystem recovery. Halpern's (2003) review of empirical work and literature concludes that marine reserves, regardless of size, and with few exceptions, lead to increases in density, biomass, individual size, and diversity in all functional groups. However, while small reserves show positive effects "…we cannot and should not rely solely on small reserves to provide conservation and fishery services…and it is likely that at least some large reserves will be needed." It is assumed that fully functional biogenic oyster reefs will provide significant ecosystem services, and that this goal can be achieved throughout the system by scaling and locating projects appropriately. In addition, hydrodynamic evaluations (discussed in a separate white paper) must also be considered when it comes to deciding where to place reef structure.

For these reasons, restoration projects presented in the master plan must be designed to address important scale issues related to both reef size/structure (physical component) and oysters populating these reefs (biogenic component).

This white paper outlines the various steps that the master plan will use to arrive at answering the question: "At what scale must oyster reefs be developed (i.e., how many acres of habitat) in various areas/tributaries of the Bay in order to achieve self-sustaining oyster populations that support the master plan goal?"

B. SCIENTIFIC BASIS AND STATE OF KNOWLEDGE

There is no generally accepted method or approach to estimate the proper scale of oyster restoration projects. Research on Marine Protected Areas (MPAs), which function similarly to the oyster sanctuaries being considered in the master plan, provides some general guidelines that are applicable to oyster restoration outlined in the master plan. In practice, MPAs are defined areas where natural and/or cultural resources are given greater protection than the surrounding waters. In the United States, MPAs span a range of habitats including the open ocean, coastal areas, inter-tidal zones, estuaries, and the Great Lakes. They also vary widely in purpose, legal authorities, agencies, management approaches, level of protection, and restrictions on human uses. The official federal definition of an MPA is: "any area of the marine environment that has been reserved by federal, state, tribal, territorial, or local laws or regulations to provide lasting protection for part or all of the natural and cultural resources therein." – Executive Order 13158 (May 2010). (It should be noted however that no MPAs for oysters currently exist in Chesapeake Bay and none are being recommended here. MPA is used here because it is generally recognized and the methodology for determining the size of MPAs seems to be applicable to the oyster scaling approach.)

MPAs are often designated to assist in the recovery of target species, and the MPA range of protected habitat typically applied (20-70%) (NRC 2001) can be considered as a range of sanctuary size for oyster recovery. Halpern (2003) discussed issues related to the sizing of marine reserve in his review of the scientific literature concerning the topic. He indicated that the goals of fishery managers in establishing reserves often include targets for total catch outside the reserve and ensuring that all species are present and abundant enough to be self-sustaining.

These goals are consistent with the master plan goal of restoring an abundant, self-sustaining oyster population throughout the Chesapeake Bay that performs important ecological functions (e.g. reef community, nutrient cycling, spatial connectivity, water filtration) and contributes to an oyster fishery. Halpern indicated that small reserves may be insufficient because they may not provide significant export functions and that "for reserves to serve as larval sources they must be large enough to sustain themselves as well as supply…target areas." Similarly, past efforts in oyster restoration in the Chesapeake Bay that established small, widespread reefs have generally not been successful. To be consistent with the master plan goal, the recommended sanctuary size should be large enough to be self-sustaining and export larvae.

Lipcius et al. (2008) described the importance of position in the estuary and hydrodynamic characteristics of the reef setting to establishing a network of reefs. Source reefs, which self-replenish with larvae, and putative reefs (those that do not consistently self-replenish or provide larvae to other reefs, but become sources when environmental conditions change) must be part of the restored reef network in a tributary. These reefs must be of sufficient size, distribution, and number to restore self-sustaining populations. Halpern indicated that the susceptibility of small reserves to catastrophic events is another potential drawback of small reserves and Mann and Powell (2007) indicated that the best approach to restoring oysters would be to ensure that reproductively capable populations are distributed throughout the Chesapeake Bay. So, not only must individual restoration sites be large enough to be self-sustaining as individual sites, support an estuarine community, and export larvae, but they must be distributed sufficiently with the Bay as a whole and within the particular tributary to respond to anthropogenic and climatic events (including freshets and droughts). These factors dictate that a relatively large area of sanctuaries must be established in any distinct sub-segment of the Bay to establish a self-sustaining population.

A specific guideline for the appropriate scale to establish self-sustaining oyster populations has not been established; therefore, this document presents an approximate guideline based on the known requirements for reefs to be self-sustaining with recommendations for phased implementation, monitoring, and adaptive management to refine the recommendation as new, tributary specific information is developed. The recommended scale in this report is appropriate as a general guideline throughout the Bay and appropriate for planning and programming purposes.

C. APPLICATION TO THE MASTER PLAN

The following section describes the approach developed for the master plan to estimate the appropriate scale of oyster sanctuaries in the tributaries of the Chesapeake Bay.

Step 1 – Use of Historic Information to Identify Reef Extent

Restoration is defined as achieving some level of ecological recovery compared to what existed in the historical past. Therefore, Step 1 in arriving at scale is to determine the approximate number of acres of oyster reefs that were present in the historical past in the Chesapeake Bay and tributaries. It is well known that oyster reefs have been significantly diminished in waters throughout the Chesapeake Bay from their original extent and relief. Overfishing and disease have reduced the oysters to less than 1% of their historic numbers (Jordan and Coakley 2004; Newell 1988). As further evidence of diminished population size, Rose, et al. (2006) identify a subtle isolation by distance (IBD) among the few remaining remnant oyster populations in Chesapeake Bay. The authors indicate that, in addition to hydrodynamic features determining local recruitment (Andrews 1979), larval behavior may be as important as hydrography and that impacts from population enhancement efforts will be concentrated near where resources are invested.

Neither the Yates (Yates 1913) nor Baylor (Baylor 1894) surveys were truly accurate in delineating the original extent of oyster reefs. Baylor's objective was not to delineate the beds themselves but rather to map the boundaries of areas designated by local commissioners or representatives of each oyster-producing county. They were more political than biological boundaries. Baylor stated in official communications with the state that a very considerable area of barren bottom, amounting to many thousands of acres, was included within the public grounds he delineated (Moore 1909). Unfortunately, there are few good quality historic era maps that provide information on the actual extent of viable oyster beds that could be compared to the Baylor or Yates surveys. In Virginia, there is one dated 1909 for the James River produced by Dr. H.F. Moore, U. S. Bureau of Fisheries. Similarly, F. Winslow surveyed oyster beds in Tangier Sound in Maryland in 1878 (McCormick-Ray 1998). The Moore survey undertook a very thorough, quantitative assessment of the extent and condition of the natural oyster rocks throughout all existing Baylor polygons in the James at the request of Claude A. Swanson, then Governor of Virginia. The master plan uses the Moore James River survey map to assess the actual extent of viable reefs in the James River compared to the Baylor polygons and the Winslow Tangier Sound survey map to assess the actual extent of viable reefs in Tangier Sound compared to the Yates grounds. This was accomplished for Virginia by:

1. digitizing the information on the Moore map to make it GIS compatible,
2. comparing the Moore map to the Baylor polygons and carefully assessing where reefs trailed off the Baylor polygons (clearly occurring in many of the polygons).
3. estimating the total original reef acreage,
4. then calculating the percentage of the Baylor polygons that actually contained oyster reefs and the total reef acreage, which includes the portions outside of the Baylor polygons.

As predicted, the actual reefs identified by Moore are smaller than the Baylor polygons, but because Baylor used straight lined polygons, a small percentage of the viable oyster beds fall outside the Baylor areas. GIS provides a comparison of the two to get a better handle on this. We performed a similar analysis for Maryland comparing the Winslow survey to the Yates polygons.

After performing this evaluation using GIS, we determined that within the Baylor polygons (26,129 acres), approximately 47% (12,275 acres) contained viable oyster reefs based on the Moore maps. A similar analysis for Tangier Sound using the Yates surveys revealed that the Winslow surveyed hard bars made up approximately 42% of the Yates Bars in Tangier Sound. In the absence of comparable historical maps, the master plan will use these percentages as a surrogate to apply to all other Baylor and Yates polygons throughout the Virginia and Maryland portions of the bay respectively to arrive at approximate historical acreage.

Step 2 – Using Marine Protected Area Target Percentages to Arrive at Scale

Step 2 in determining scale is to decide what percentage of the reefs that existed in the historical past would have to be restored in order for oysters within a given area or tributary to become self-sustaining. Marine Protected Areas (MPAs) are often designated to assist in the recovery of target species, and the MPA range of protected habitat typically applied (20-70%) can be considered as a range of habitat for oyster recovery. It should be noted however that no MPAs for oysters currently exist in Chesapeake Bay and none are being recommended here. MPA is used here because it is generally recognized and the methodology for determining the size of MPAs seems to be applicable to the oyster scaling approach.

In practice, MPAs are defined areas where natural and/or cultural resources are given greater protection than the surrounding waters. In the United States, MPAs span a range of habitats including the open ocean, coastal areas, inter-tidal zones, estuaries, and the Great Lakes. They also vary widely in purpose, legal authorities, agencies, management approaches, level of protection, and restrictions on human uses. The official federal definition of an MPA is: "any area of the marine environment that has been reserved by federal, state, tribal, territorial, or local laws or regulations to provide lasting protection for part or all of the natural and cultural resources therein." – Executive Order 13158 (May 2010).

As mentioned previously, MPA's can be anywhere from 20 to 70% of an organism's original extent. Restored oyster sanctuaries to date throughout the Chesapeake Bay (with two exceptions: Great Wicomico River and Lynnhaven River) have fallen far short of this recommended areal extent. In order to successfully influence the stock/recruit relationship, sanctuaries will need to be much larger and more numerous than have been built in the past. Sufficient reef scale and the living oyster populations of reefs provide both recruitment and attachment substrate in sufficient numbers/quantities to sustain oyster population growth and abundance. Without oyster populations and reef structure of sufficient scale, disease mortality, reef degradation (i.e., shell loss), and high recruit mortality for lack of sufficient hard substrate, will make population sustainability difficult if not impossible. In general, larger estuary systems will require proportionally larger spatial scale of reef structure in them for the reefs to become sustainable living features within the system. When oysters spawn, the larvae must find attachment substrate or they will die. The larger the system, the more open water larvae must navigate, and the more attachment substrate per unit of river bottom will be required. Most areas of the bay are severely limited in the amount of hard attachment substrate and will require significant augmentation in the form of oyster shell, or alternative substrate material. The small scale restoration efforts that have taken place in the past in these large river systems have simply not been large enough to be sustained over time.

In the case of the oyster, a gregarious, reef forming sessile invertebrate, the needed sanctuary percentage is likely to be on the lower end of the MPA % spectrum, compared to finfish for example. Large, motile predatory fish that produce fewer but larger young per adult, such as sharks, usually require larger areas of protection.

Step 3 – Use Example Project to Determine Percentage Historical Acreage to Restore

The only restoration effort thus far to achieve a sustainable population of oysters over an extended period of time (approximately 6 years) is the USACE Great Wicomico River restoration effort. That project restored approximately 40% of the original reef extent within a hydrodynamically restricted system (Schulte et al. 2009). As mentioned previously, marine reserves typically encompass 20 to 70% of historical acreage of the resource. Habitat losses of at least 52% (Seliger and Boggs 1988; Haven and Whitcomb 1986; Whitcomb and Haven 1987; and Goulletquer et al. 2004) upwards to 90 % (Smith et al. 2005) have been documented.

Step 4 – Developing Scale Using Both Historical Extent and MPA Percentage

Considering that sessile bivalves would be expected to fall on the lower end of the MPA range, but also recognizing the reasons presented above that support the need for significant and expansive oyster habitat to achieve sustainability, the master plan is proposing a restoration target ranging from 20-40% of historic (corrected) acreage within a tributary. This equates to 8-16% of the Yates and Baylor Grounds (if uncorrected). In recognition that one number will not fit perfectly in every circumstance, the master plan is recommending a range that should be revised to a precise number by the follow-on specific tributary investigations. In systems that are more open hydrodynamically, it may be necessary to restore a greater percentage of the original reef area. The recommended 20-40% will be a target that should be refined and adapted once a system is studied in detail prior to restoration, or through phased implementation, or as lessons are learned through monitoring of completed projects.

The final step in arriving at scale, is to determine historical extent from all the mapped Baylor and Yates grounds in targeted priority locations, and then to apply the percentage (20-40%) to that number. Figure 1 depicts the process of developing scale using this approach.

The proposed approach for determining approximate scale will not fit perfectly in every circumstance. This approach can only be used to give a generic and rough approximation of scale and is not intended to be used for anything other than that purpose. When individual projects are developed in detail in the follow-on documents to the master plan, the final scale will be refined using site-specific information. During the implementation phase, if projects are built in phases within a DSS, monitoring and adaptive management will allow projects to be scaled up or scaled back in a DSS depending on biogenic reef structure development, larval recruitment, and adult broodstock survival and performance. The 20-40% figure provides a good preliminary estimate of the scale of restoration that is likely to successful in a tributary. The individual reefs must be large enough to be self-sustaining, export larvae to other reefs (both other sanctuaries and harvest areas), and provide ecosystem services, and be distributed throughout the estuary to be resilient. These goals are not likely to be achieved on a scale that does not achieve at a minimum 20-40% of the historic habitat.

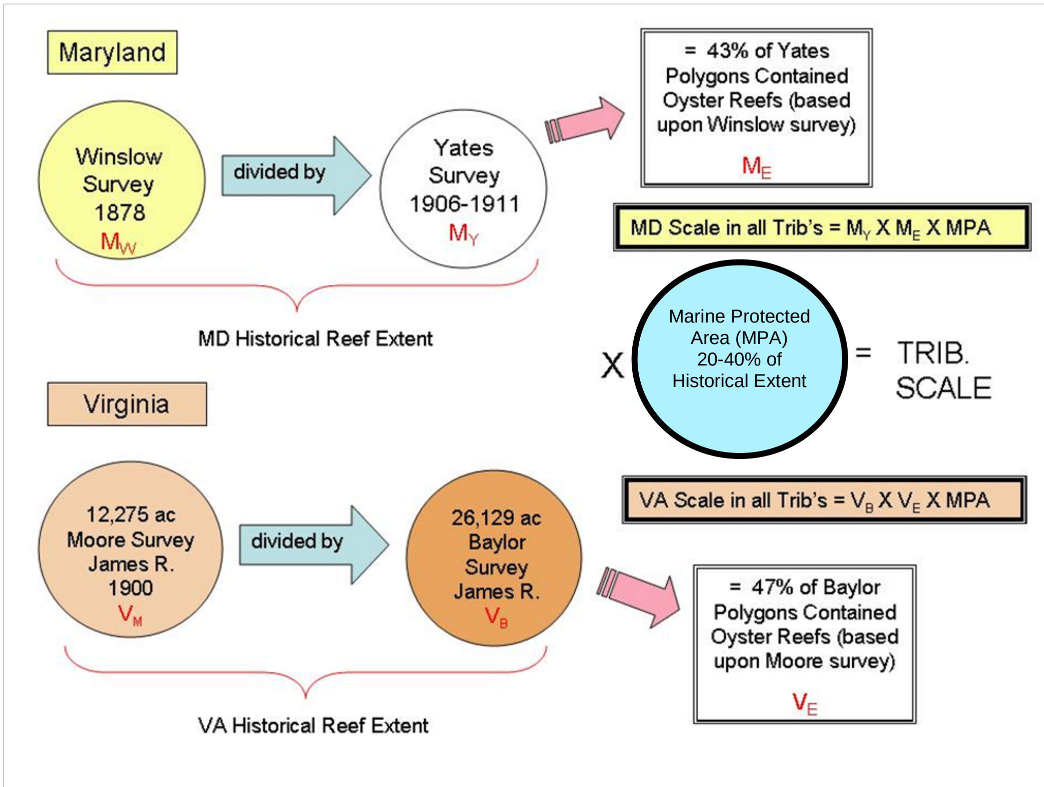


Figure 2. Proposed approach for determining scale

REFERENCES

Andrews, J.D. 1979. Pelecypoda: Ostreidae. In:Reproduction of marine invertebrates (Giese AC and Pearse JS, eds), New York: Academic Press; 293-341.

Baylor, J.B. 1894. Method of defining and locating natural oyster beds, rocks, and shoals. Oyster Records (pamphlets, one for each Tidewater, VA county, that listed the precise boundaries of the Baylor Survey). Board of Fisheries of Newport News, VA.

Goulletquer, P., Heral, M., and J. Prou. 1994. Combined effects of temperature-salinity on larval survival of the Eastern Oyster Crassostrea virginica in the Maryland portion of the Chesapeake Bay. Haliotis 23: 71-86.

Halpern, B.S. 2003. The impact of marine reserves: Do reserves work and does reserve size matter? Ecol Apps 13(1) Supplement, pp.S117-S137.

Haven. D.S. and J.P. Whitcomb. (1986). The public oyster bottoms in Virginia: an overview of their size, location, and productivity. American Malacologitcal Union Bulletin, Special edition 3: 17-23.

Jordan, SJ and JM Coakley. 2004. Long term projections of eastern oyster populations under various management scenarios. J Shellfish Res 23:63-72.

Kimmel, D. G. and R. I. E. Newell. 2007. The influence of climate variation on eastern oyster (Crassostrea virginica) juvenile abundance in Chesapeake Bay. Limnol. Oceanogr. 52(3): 959-965.

Lipcius, R.N., D.B. Eggleston, S.J. Schreiber, R.D. Seitz, J. Shen, M. Sisson, W.T. Stockhausen, and H.V. Wang. 2008. Importance of metapopulation connectivity to restocking and restoration of marine species. Reviews in Fisheries Science, 161(1-3): 101-110.

Mann, R. and E.N. Powell. 2007. Why oyster restoration goals in the Chesapeake Bay are not and probably cannot be achieved. Journal of Shellfish Research. 26(4): 905-917.

McCormick-Ray, A.G. 1998. Oyster reefs in 1878 seascape pattern-Winslow revisited. Estuaries, Vol. 21, No. 4B, pp. 784-800.

Moore, H.F. 1909. Condition and Extent of Oyster Beds of James River, Virginia. US Bureau of Fisheries Document No. 729, US Government Printing Office, Washington, D.C.

Morgan, S.G. 1995. Life and death in the plankton: larval mortality and adaptation. In: L. McEdward, Editor, *Ecology of Marine Invertebrate Larvae*, CRC Press, Boca Raton (1995), pp. 279–322.

National Research Council (NRC). 2001. Marine Protected Areas: Tools for Sustaining Ocean Ecosystem, 2001. Committee on the Evaluation, Design, and Monitoring of Marine Reserves and Protected Areas in the United States, Ocean Studies Board, National Research Council, 288 pgs.

Newell, R.I.E. 1988. Ecological changes in Chesapeake Bay: Are they the result of overharvesting the eastern oyster (*Crassostrea virginica*). *In* M.P. Lynch and E.C. Krome, editors. Understanding the Estuary: Advances in Chesapeake Bay Research. Solomons, Maryland: Chesapeake Research Consortium Publication 129. CBP/TRS 24/88. pp 536-546.

Oyster Restoration Evaluation Team (ORET). 2009. Metadata Analysis of Restoration and Monitoring Activity Database. J.G. Kramer and K.G. Sellner (eds.), Native Oyster (*Crassostrea virginica*) Restoration in Maryland and Virginia. An evaluation of lessons learned 1990-2007. Maryland Sea Grant Publication #UM-SG-TS-2009-02; CRC Publ. No. 09-168, College Park, MD. 40 pp.

Rose, C.G., K.T Paynter, and M.P. Hare. 2006. Isolation by distance in the Eastern Oyster, Crassostrea virginica, in Chesapeake Bay. Jour Heredity 97 (2): 158-170.

Rumrill, S. S. 1990. Natural mortality of marine invertebrate larvae, *Ophelia* **32** (1990) (1–2), pp. 163–198.

Schulte, D. M., Burke, R. P. and R. N. Lipcius. 2009. Science 325: 1124-1127.

Seliger, H.H., and J.A. Boggs. 1988. Evidence for loss of suitable benthic habitats for oysters intributaries of the Cheapeake Bay. In: Understanding the Estuary: Advances in Chesapeake Bay Research. Chesapeake Research Consortium, Publication 129. CBP/TRS 24/88: 111-127.

Smith, G.F., D.G. Bruce, E.B. Roach, A. Hansen, R.I.E. Newell, A. M. McManus. 2005. Assessment of recent habitat conditions of Eastern Oyster *Crassostrea virginica* bars in mesohaline Chesapeake Bay. North American Journal of Fisheries Management. 25(4): 1569-1590.

Southworth, M., Harding, J. M. and R. Mann. 2009. The Status of Virginia's public oyster resource 2008. Molluscan ecology program, Virginia Institute of Marine Science, Gloucester Point, Virginia. 53 pp.

Southworth, M. and R. Mann. 1998. Oyster reef broodstock enhancement in the Great Wicomico River, Virginia. Journal of Shellfish Research. 17(4):1101-1114.

Whitcomb, J.P. and D.S. Haven.1987. The physiography and extent of public oyster grounds in Pocomoke Sound, Virginia. Journal of Shellfish Research. 6: 55-65.

Winslow, F. 1882. Report on the oyster beds of the James River, Va., and of Tnagier and Pocomoke Sounds, Maryland and Virginia. U.S. Coast and Geodetic Survey Report for 1881:1-87.

Yates, C.C. 1913. Survey of the Oyster bars [by county of the State of Maryland]. Dept. of Commerce and Labor, Coast and Geodetic Survey, Washington, D.C., US Government Printing Office.

Predation White Paper

A. SIGNIFICANCE TO OYSTER RESTORATION AND THE MASTER PLAN

Oysters provide food for numerous predatory species, including flatworms, crabs, oyster drills, starfish, and certain finfish. Oyster predators suffer more from exposure to the elements than do oysters. Therefore, intertidal oysters are subjected to less predation than oysters which grow subtidally. However, Cownose rays, which feed subtidally, have recently become major predators on oyster reefs in the Chesapeake Bay.

In addition, a very real predator of oysters is man. Control of this predator/poacher is problematic. Losses due to poaching can be as high as 5,000 to 10,000 shellfish per hour depending on harvesting method. Enforcement is difficult and poaching often goes unnoticed.

Both predation and poaching can result in serious negative effects on restored oyster habitat. Because these activities not only remove living animals but also disturb and remove shell material, they can compromise the biological and physical integrity of the reef habitat. Since all reefs that will be constructed by USACE will be permanent sanctuaries these potential negative impacts, and possible preventative measures, will be addressed in the master plan.

B. SCIENTIFIC BASIS AND STATE OF KNOWLEDGE

1. *Oyster Predators*

Predation on oysters is an important interaction in the Bay ecosystem. For example, blue crabs (*Callinectes sapidus*), Cownosed rays (*Rhinoptera bonasus*), and at least one species of bird, the American oystercatcher (*Haematopus palliates*), prey on oysters directly. Humans are major predators of oysters, and harvest of oysters by humans has historically been biologically, economically, and culturally important in the Chesapeake Bay region (Newell 1988).

Blue crabs are opportunistic predators; they exploit prey species at sizes that are most common in each of the habitats they visit (Micheli 1997). Although adult oysters are too large for blue crabs to open and prey upon (reviewed in White and Wilson-Ormond 1996), crabs feed readily and opportunistically on juvenile oysters (Eggleston 1990).

Numerous avian species in the Chesapeake Bay watershed use benthic species as a primary food source. An important representative species is the American oystercatcher (*Haematopus palliates*). Oystercatchers are large shorebirds with strong white or black-and-white markings. They consume oysters and other shellfish and have powerful, brightly colored bills that they use to open the shells of bivalves. Oystercatchers were once hunted almost to extinction but are now conspicuous shorebirds found throughout the Chesapeake Bay region.

(from: Eastern Oyster Biological Review Team. 2007. Status review of the eastern oyster (*Crassostrea virginica*). Report to the National Marine Fisheries Service, Northeast Regional Office. February 16, 2007. 105 pp.)

A number of fish species such as black drum and cownose rays occasionally cause extensive damage to oyster beds, and diving ducks have also been documented as consumers of oyster tissue (Galtsoff 1964). Black drum have been documented to heavily impact seeded oyster reefs in Louisiana in both spring and early fall (Brown et al. 2003). There are many commensal organisms that make up a healthy oyster reef community. While many of these species reside on the outer surfaces of the oyster's shell, some species such as boring sponges and clams and mud worms, perforate the inner shell surface causing the oyster to expend extra energy maintaining the integrity of the shell cavity.

Cownose Rays (*Rhinoptera bonasus)* are considered an open ocean (pelagic) species, but can inhabit inshore, shallow bays and estuaries. They prefer warm temperate and tropical waters to depths of 72 feet. Many gather in Chesapeake Bay during the summer months.
Like other rays, their mouth is located on the underneath side. Cownose rays feed on bottom-dwelling shellfish, lobster, crabs, and fish. To locate their prey, these rays have electroreceptors on their snout as well excellent senses of smell and touch. They will also stir up the bottom with their flexible wing tips or use their nose to root around in the mud or sand. Once they find their prey, they flap their wings rapidly to move the sand aside. At the same time, they suck water and sand into their mouth and blow it out through their gills to create a depression in the sand that allows easier access to their food. They have very strong teeth arranged in flat plates that are perfect for crunching hard-shelled prey. These rays spit out the shells of the animals they eat, and only swallow the soft body parts. These animals stir up the bottom sediments with their wings, thereby exposing bivalves which they then crush with their teeth and consume.

Shellfish Prey-size Selectivity - Captive cownose rays were subjected to replicate feeding trials to examine prey selectivity and ability to forage on different sizes of oysters and hard clams by Fisher (2009). Oyster trials utilized single cultchless oysters. Prey handling investigation was performed through underwater videotaping of various sized oysters and clams. The results of shellfish size predation (and through observed ray foraging and prey selectivity behavior) suggest that rays are opportunistic animals which will feed on whatever food is available regardless of size. It was observed that the adult rays used in this study were most successful preying on shellfish with shell depths <32mm, which was further observed (via underwater video) to be linked to ray mouth/jaw morphology.

Gastropod mollusks, primarily whelks of the genus Busycon and Busycotypus, can be significant predators on oysters and hard clams planted in subtidal areas. It has been demonstrated that the presence of the knobbed whelk (*Busycon carica*) can inhibit hard clam growth in the vicinity of the clam bed even if it cannot directly prey on the population (Nakaoka 1996). With the recent introduction of the Veined Rapa whelk (*Rapana venosa*) into the Mid-Atlantic area, another large gastropod predator is now on the scene.

OYSTER REEF INHABITANTS AND PREDATORS

OYSTER BAR PREDATORS	NAME	DESCRIPTION
	Oyster Drill (*Urosalpinx cinerea; Eupleura caudata*)	A snail that bores a hole in the oyster by using its drill-like radula in conjunction with acidic secretions from a gland in its foot. It takes 8 hours for the snail to make a hole in the shell 2 mm thick. It then extends its proboscis through the hole and nibbles on the oyster tissue.
	Oyster Snail (*Odostomia sp.*)	A small cone-shaped snail. Light in color that sits on the lip of the oyster shell. It extends its proboscis inside to feed on mucous and tissue fluids.
	Boring Sponge (*Cliona sp.*)	The boring sponge is a thick, bright yellow sponge. They grow on oyster beds and other mollusk colonies throughout the Bay. It is called the "boring sponge" because it bores holes into an oyster's shell. This weakens the shell and can sometimes kill the oyster.
	Starfish (Asterias sp.)	The starfish pulls the two shells or valves of a bivalve apart with its five arms and inserts its stomach into the exposed shell cavity. As enzymes are released, the oyster is digested and absorbed by the starfish. A starfish can consume up to three adult bivalves per day and at least 15 oyster spat per day
	Cownose Ray (*Rhinoptera bonascus*)	Often observed in areas with sandy or soft bottom. Known to prey on a variety of shellfish. Often large schools. Leaves 2- to 3-foot depressions with shell fragments.
	Blue Crab (*Callinectes sapidus*)	Preys heavily on shellfish, including oysters and hard clams. Found intertidal and shallow subtidal habitats.
	Oystercatcher (*Haematopus palliatus*)	The diet of coastal oystercatchers includes estuaries bivalves (such as oysters), gastropods and polychaete worms. On rocky shores they prey upon limpets, mussels, gastropods and chitons. Other prey items include echinoderms, fish, and crabs.

2. Extent of Predator Problem and Predator Exclusion Devices

Currently there is no commercial fishery for cownose rays in the Northern Atlantic, but it has been considered due to high predation by the rays of commercial oyster beds. Cownose rays are considered a "pest" species by members of the shellfish industry because the rays' feeding behavior is thought to damage commercial shellfish beds. There are many problems associated with a cownose ray fishery, including a potential decline in the population and a harvesting process that is both difficult and expensive.

Bottom screens are one of the best exclusion devices to protect shellfish from crustacean and gastropod predators. They are also the best protection from ray damage. Rays can enter a culture area lay over the screens, and beat their wings to uncover the clams but they are unable to consume the clams through the screening. However, the exposed clams may become prey for other predators such as small mud crabs, hence the importance of regularly tending the screens.

In general, the most effective way to reduce shellfish losses is to exclude the predators from the bivalves, using a variety of materials. The manner in which predator exclusion devices are used depends on experience of the culturist site, seed size, and kinds of predators present. Each culturist will use the control materials in a slightly different way so as to maximize shellfish growth potential while minimizing loss to predators. Even the most expensive predator control methods will fail, however, if the operator does not use them appropriately and diligently.

(from Leavitt, D. F. and W.P. Burt. 2000. Control of predators on cultured shellfish: Exclusion strategies. Northeastern Regional Aquaculture Center. University of Massachusetts Dartmouth. NRAC Bulletin No. 00-007.)

The most reliable option available to shellfish farmers is to provide a barrier to prevent specific predators from gaining access to their prey, also known as the crop. This can be in the form of a physical barrier, such as a cage surrounding the shellfish or a fence enclosing the growing area, or a spatial barrier, such as growing shellfish in suspended culture systems to prevent benthic, non-swimming predators from gaining access to the culture system. As suggested above, barrier systems can be effective against some types of predators and less effective against others. For example, straight vertical fencing was tested exclusively in the early 1950's as a means to exclude the booming green crab (*Carcinus maenas*) populations from devastating soft shell clam (*Mya arenaria*) resources in Maine. The fences were 18" wire mesh strung vertically along stakes placed in the tidal flat. Although the fencing prevented crabs from preying on clams, the work required to maintain the fencing and the recruitment of juvenile crabs into the enclosed culture area, where they subsequently grew to a size that was able to prey on soft shell clams, diminished the shellfish manager's enthusiasm for vertical fencing.

A more effective means to exclude surface crawling predators, i.e. crabs, is netting or screening placed over the planting area. A net with a mesh size smaller than the size of the bivalves planted under it not only excludes predators but it also prevents the seed clams or oysters from washing out of the system if exposed to any wave or high current action. The placement of the netting is dependent on the species being cultured. For oysters, or other epifaunal shellfish, the netting can be laid down on the sediment and the seed oysters placed on top of one-half of the netted area. The other half of the net is then folded over the top of the oyster bed and the edges are sealed down by burial and/or by wire staples. The oyster "envelopes" are then in place and will exclude those predators larger than the mesh size of the net. In either case, maintenance is paramount to the successful exclusion of predators when using netting. The first concern is small predators that have recruited under the net and subsequently grown to a size large enough to consume your shellfish.

The other concern is to remove biofouling that can reduce water flow under the net and across the planted clams to the point where it can lead to impaired productivity and even mortality.

3. *Poaching*

Historical and Current – Extent of Problem Poaching

The following is taken from the Maryland Oyster Advisory Commission (OAC) Report, 2008 (OAC 2008):

Currently, there is no single factor more important to the future of ecologic restoration and aquaculture than to address and dramatically reduce the ongoing illegal oyster harvesting activities. All stakeholder groups, including commercial watermen, current leaseholders and environmental organizations and government agencies, agree that illegal harvesting is a problem that needs to be resolved. The problem has been part of the oyster industry since the 1800s, leading to creation of the Oyster Navy, forerunner of today's Natural Resources Police (NRP). Unfortunately over the last seventeen years, while the NRP has lost over 40% of its personnel, the conservation enforcement demands placed on its staff has only increased with its state park and homeland security obligations. As such, the unit has been spread very thinly which has resulted in rampant theft of oysters in all areas of the state's waters.

Many state authorized committees and commissions have called for NRP resources to be increased. The Fisheries Management Task Force and the Aquaculture Coordinating Council have requested additional law enforcement resources for the last two legislative sessions to "advance aquaculture". All are in agreement that without a change in current enforcement policies, increased police presence in helping to guard the bays, oyster recovery and private aquaculture efforts will likely not succeed. In addition, prosecutors and judges must understand that the illegal removal of oysters, especially those "purposely cultivated" is theft of public and/or private property. In this regard, prosecutors frequently fail to understand the severity of the crime when viewed against other criminal acts in society. Judges similarly look upon natural resource violations as minor offenses with the fines, when paid, are often set so low that they looked upon merely as a "cost of doing business" by those who illegally harvest oysters.

Monitoring of restored bars in Maryland from 1997-2006, showed that many of the sanctuary sites were impacted by illegal harvest (Paynter 2008). Incidentally, harvesting proved to be damaging to the oysters remaining on the bar. Harvest activity on three sites in the Choptank

River resulted in well over 50 percent mortality of the remaining unharvested oysters (Paynter 2008).

4. *Poaching Control*

a. Laws/Regulations and Enforcement – The Maryland OAC Report (OAC 2008) outlined a list of law enforcement and policy recommendations that the OAC recommended that the state legislature and management agencies review and adopt via legislation or regulation to minimize illegal harvesting activities in Maryland's portion of the Chesapeake and Coastal Bays.

These specific recommendations included:

- Prohibiting the use of power dredges in Maryland on non-leased areas unless specifically authorized by DNR.
- Applying buffer areas around sanctuary bars.
- Holding seafood buyers responsible for possessing and/or selling undersized oysters to include ongoing inspections by NRP for compliance.
- Clearly requiring dockside vouchers for sale of lease bottom oysters.
- Increasing current fine schedule for oyster related offenses, with a specific emphasis on undersized and unculled oysters and harvesting in prohibited, protected and leased areas to include modifying the current policy of 'graduated violations' for harvesting within a sanctuary (distance from boundary) to one standard violation.
- Authorizing NRP to seize the vessel and/or equipment upon arrest and/or ticket issuance, if harvester(s) onboard are taking oysters/clams without a commercial license, operating with a suspended license or committing theft in prohibited, protected and leased area.
- Enabling TFL license suspension by a court conviction as well as through an administrative hearing upon receiving a citation.

The Aquaculture Coordinating Council drafted a list of potential recommendations that the OAC concurrently supported including:

- Assigning one/two prosecutors to handle all natural resource cases statewide or train one prosecutor in each county to handle these specialized cases. MDNR/NRP would provide training to these prosecutors regarding Natural Resource law.
- Establishing a dedicated day each month in each county to hear natural resource cases.
- Coordinating with the state's Attorney General's office to develop a system for complex conservation cases.
- As stated in the Legal Review Report, giving judges the discretion to assess restitution on the defendant for egregious crimes.
- Recognizing that additional NRP staff funding is limited, consideration should be given to deploying:
  - ✓ Vessel Monitoring System (VMS) tracking devices on all commercial watermen vessels and require the system to be in operation anytime the vessel leaves the dock.
  - ✓ Remote vessel monitoring systems that would integrate into NRPs video surveillance network.

Other deterrents to poaching include using alternative substrates to build reefs in permanent sanctuaries such as granite or concrete. Use of these alternative materials would make it much more difficult to using traditional methods of harvesting such as patent tongs, or dredging.

C. APPLICATION TO THE MASTER PLAN

In all oyster restoration work that is proposed, consideration must be given to both predation and poaching. As described above, there are several exclusion devices that may effectively curtail, or at least limit, oyster losses on constructed reefs due to predation. In developing future projects, consideration must be given to the effectiveness and costs associated with these exclusion devices. Consideration must also be given to the inevitability that some predation will take place on constructed reefs. This could be addressed through adaptive management, or in the initial seeding of reefs to overcompensate for these inevitable losses.

When evaluating seeding of constructed reefs, it will be important to consider various size classes of spat on shell and/or materials that used for seeding reefs. Alternative materials such as granite and concrete, while more costly, may be less subject to predation than shell. Other questions remain unanswered including whether there are locations in the bay that are more subject to predation than others. This may require further research during the development of individual implementation plans.

Poaching has always been, and will continue to be, a problem on restored reef sanctuaries. The Maryland OAC recommended various laws and enforcement measures that could help to minimize this problem. Virginia and Maryland legislators must enact these recommendations to more forcefully deter poaching. In addition, careful consideration should be given in the master plan to constructing reef sanctuaries using alternative materials such as concrete or granite. Use of alternative materials will make it more difficult to poach oysters using traditional harvesting equipment.

Emerging technologies to deter predation are emerging in the aquaculture industry, particularly in clam aquaculture. The continued research and future application of these emerging technologies should be supported by the master plan. Through their research arms, agencies such as NOAA, could provide support to the master plan through this research.

REFERENCES

Brown, K.M., G.W. Peterson, P.D. Banks, B. Lezina, C. Ramcharan, and M.McDonough. 2003. Olfactory deterrents to black drum predation on oyster leases. Journal of Shellfish Research 22:589-595.

Carlton, J.T., J.K. Thompson, L.E. Schemel, and F.H. Nichols. 1990. Remarkable invasion of San Francisco Bay (California, USA) by the Asian clam *Potamocorbula amurensis*. I. Introduction and dispersal. Marine Ecology-Progress Series 66: 81-94.

Eggleston, D.B. 1990. Foraging behavior of the blue crab, *Callinectes sapidus* on juvenile oysters, *Crassostrea virginica*: effects of prey density and size. Bulletin of Marine Science 46: 62-82.

Fisher, Robert. 2009. Evaluating Behavioral Responses of Cownose Rays (*Rhinoptera bonasus*) to Electrosensory Repellents and to Conduct Shellfish Prey-size Selectivity Trials on Captive Rays, VA Sea Grant College Program, VA Institute of Marine Science, College of William and Mary. Submitted to: United States Army Corps of Engineers, Norfolk District.

Galtsoff, P.S. 1964. The American oyster *Crassostrea virginica* Gmelin. Fish. Bull. 64: 1-480.

Hines, A.H., A.M. Haddon, and L.A. Wiechert. 1990. Guild structure and foraging impact of blue crabs and epibenthic fish in a subestuary of Chesapeake Bay. Marine Ecology-Progress Series 67: 105-126.

Leavitt, D. F. and W.P. Burt. 2000. Control of predators on cultured shellfish: Exclusion strategies. Northeastern Regional Aquaculture Center. University of Massachusetts Dartmouth. NRAC Bulletin No. 00-007.

Luckenbach, Mann, and Wesson. 1999. Oyster Reef Habitat Restoration: A Synopsis and Synthesis of Approaches. Proceedings from the Symposium, Williamsburg, VA (1995).

Maryland Oyster Advisory Commission (OAC). 2008. Maryland Oyster Advisory Commission 2008 Report: Concerning Maryland's Chesapeake Bay Oyster Management Program. Available online at: http://www.dnr.state.md.us/fisheries/oysters/

Micheli, F. 1997. Effects of experience on crab foraging in a mobile and a sedentary species. Animal Behaviour 53: 1149-1159.

Nakaoka, M., 1996. Size-dependent survivorship of the bivalve *Yoldia notabilis* (Yokohama, 1920): the effect of crab predation. J. Shellfish Res. 15 (2): 355–362.

Newell, R.I.E. 1988. Ecological changes in Chesapeake Bay: Are they the result of overharvesting the eastern oyster (*Crassostrea virginica*). *In* M.P. Lynch and E.C. Krome, editors. Understanding the Estuary: Advances in Chesapeake Bay Research.

Solomons, Maryland: Chesapeake Research Consortium Publication 129. CBP/TRS 24/88. pp 536-546.

Newell, R.I.E., V.S. Kennedy, and K.S. Shaw. 2007a. Comparative vulnerability to predators, and induced defense responses of native and nonnative oysters. Marine Biology 152: 449-460.

Paynter, K.T. 2008. A 10-Year Review of Maryland's Hatchery-based Oyster Restoration Program- 1997-2006: A Summary of Monitoring and Research conducted by the Paynter Laboratory at the University of Maryland.

Roegner, G.C. and R. Mann. 1995. Early recruitment and growth of the American oyster *Crassostrea virginica* with respect to tidal zonation and season. Mar. Ecol. Prog. Ser.117: 91-101.

White, M.E. and E.A. Wilson-Ormond. 1996. Predators, pests, and competitors. *In* V.S. Kennedy, R.I.E. Newell, and A.F. Eble, editors. The Eastern Oyster *Crassostrea virginica*. College Park, Maryland: Maryland Sea Grant College Program. pp 559-579.

C-2: WATER QUALITY DATA COMPILATION

Attachment 2-A: Chesapeake Bay Native Oyster Restoration Master Plan Geographic Information System Data Compilation

By Versar

CHESAPEAKE BAY NATIVE OYSTER RESTORATION MASTER PLAN GEOGRAPHIC INFORMATION SYSTEMS DATA COMPILATION

PREPARED FOR:

U.S. Army Corps of Engineers
10 South Howard St.
Baltimore, Maryland 21201

PREPARED BY:

Slacum, Jr., H. W. and Methratta, E. T.
Versar, Inc.
Ecological Sciences & Applications Division
Applied Ecosystem Assessment Group
9200 Rumsey Road
Columbia, MD 21045

OVERVIEW

A total of 24 spatially-referenced data layers were gathered together for the USACE Native Oyster Restoration Master Plan (NORMP) and compiled into a geographic information system (GIS). These data were primarily provided by the USACE Norfolk District, the Virginia Institute of Marine Sciences, and the Maryland Department of Natural Resources (MDDNR). Decisions on whether to include particular data sets were made based upon discussions among the members of the NORMP team. The major data types include historical habitat, restoration, private leases, bathymetry, historic spat set, and submerged aquatic vegetation (SAV). All layers are projected with NAD 1983 UTM Zone 18.

For each layer, the file name, a brief summary, and a thumbnail photo are provided. In all cases, the original file name was preserved to maintain continuity between those who provided the data and those who will be using the data in the future. If the layer was not originally projected with NAD 1983 UTM Zone 18, the projection was carried out in ArcGIS and the suffix "_utm" was added to the file name. For all layers, the associated meta-data were evaluated and gaps were identified. When definitions for attributes were missing, efforts were made to acquire additional metadata. For GIS layers that lack complete metadata, the contact information of the source of the data is provided. Of the 24 layers, there were 3 that lacked metadata almost entirely, preventing a determination of what the layer is depicting. These 3 layers were categorized as "unknown," and contact information for their sources is provided. The historic oyster spat data were provided to Versar by MDDNR as an excel spreadsheet from which Versar generated a point shapefile and metadata. Appendix A provides the meta-data for all layers for which meta-data were available. All GIS layers are projected in UTM 18 and loaded into a personal geodatabase using ArcGIS version 9.3.

SUMMARY TABLE

.

GIS File Name	Data Type	State
1. Yatesbrs_utm	Historic Habitat	MD
2. BBSurvey_utm	Historic Habitat	MD
3. Mdoysbrs_utm	Historic Habitat	MD
4. Chesapeake_Bay_habitat_v1_utm	Historic Habitat, Restoration, and Private Lease	MD and VA
5. Baylor_grds	Historic Habitat	VA
6. bottom	Historic Habitat	VA
7.Yates_Baylor_utm	Historic Habitat	MD and VA
8. restoration	Restoration	VA
9. Habitat_Site	Restoration	VA
10. oyster_rock	Restoration	VA
11. Habitat_Area_utm	Restoration	VA
12. oys_targets2_utm	Restoration	VA
13. condemed	Restoration	VA
14. Bayplantings_utm	Restoration	MD
15. dnrrepletion_utm	Restoration	MD
16. Mdsancres_utm	Restoration	MD
17. MD_lease_bars_utm	Private Lease	MD
18. private_lease	Private Lease	VA
19. Bathy	Bathymetry	MD and VA
20. hist_spat_set2_utm	Historic Spat Set	MD
21. SAV2007	Submerged Aquatic Vegetation	MD and VA
22. pots_phase1_utm	Unknown	VA
23. baylor83_utm	Unknown	VA
24. botall83	Unknown	VA

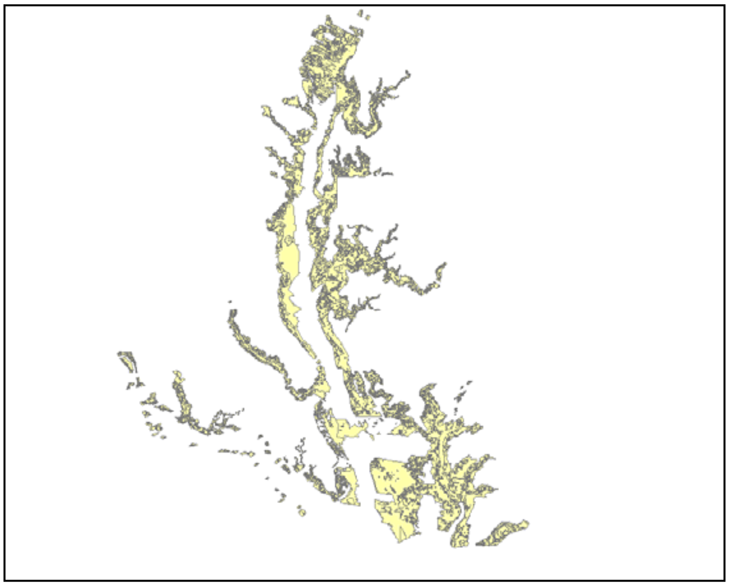
HISTORICAL OYSTER HABITAT

Maryland

1. File Name: Yatesbrs_utm
Metadata Summary: Appendix A-1

The Yates (1911) survey was the first official survey of oyster habitat in the Maryland portion of Chesapeake Bay. Based on the information gathered in this survey, the first official coarse-scale maps of oyster hard bottom habitat in Maryland were constructed. Authorized in 1906 (Kennedy and Breisch 1983) in response to declining catch per unit effort of oysters (Graves 1912), the goal of the Yates survey was to delineate areas for public oyster harvest based upon bottom type. Catch had declined nearly 30% between 1884 and 1906 from 686,700 m^3 of live oysters in the shell in to 201,432 m^3 (Graves 1912). Employing a dragged chain methodology, the Yates survey produced maps which were used to designate several additional areas as public oyster ground. By 1974, the public oyster ground was producing only 128,184 m^3 of oysters annually (MDDNR 1989) and there was a growing consensus that many of the areas delineated by the Yates survey were not productive enough to be reserved for public oyster harvest exclusively. Several fishers were particularly interested in determining which areas might be designated for soft clam (*Mya areneria*) harvesting and private oyster leases (Smith et al. 2001).

2. File name: BBSURVEY_utm
Metadata Summary: Appendix A-2



In 1974, the Maryland Bay Bottom Survey (MBBS) was authorized by the State of Maryland. The goal of the MBBS was to delineate natural oyster bars, soft clam areas, and "barren bottoms" (sensu Smith et al. 2001) which could be leased to private individuals for the aquaculture of oysters or other species. The scope of the survey was to assess the bottom within and adjacent to the public oyster grounds identified in the Yates Survey (1911). The MBBS used mechanical grab sampling (15% of the survey with patent tongs), sounding poles (10% of the survey) and hydroacoustic methods (75% with dragged microphones) for bottom type classification. Patent tong grabs sampled 1 m^2 area and the depth of the sample was dependent upon the type of substrate. Survey depth ranged from 2 to 9 m. The survey was initiated in 1975 and completed in October 1982 except for the Potomac River which was surveyed between July 1983 and November 1983. The Potomac River portion of the survey was conducted separate from the MBSS because of the joint management of this region by both Maryland and Virginia. Although oyster bars on both sides of the river were surveyed, only oyster bars in the Maryland tributaries were charted. Overall, the MBSS surveyed 2591.9 km^2, covering 42% of the Maryland portion of the Chesapeake Bay, and of this, 1858 km2 was outside of the boundaries delineated by Yates (Smith et al. 2001). Six categories were used to classify substrate. Of these, three delineated oyster habitat: cultch, cultch with sand, and cultch with mud. The remaining three categories consisted of sand, mud and consolidated hard sediment.

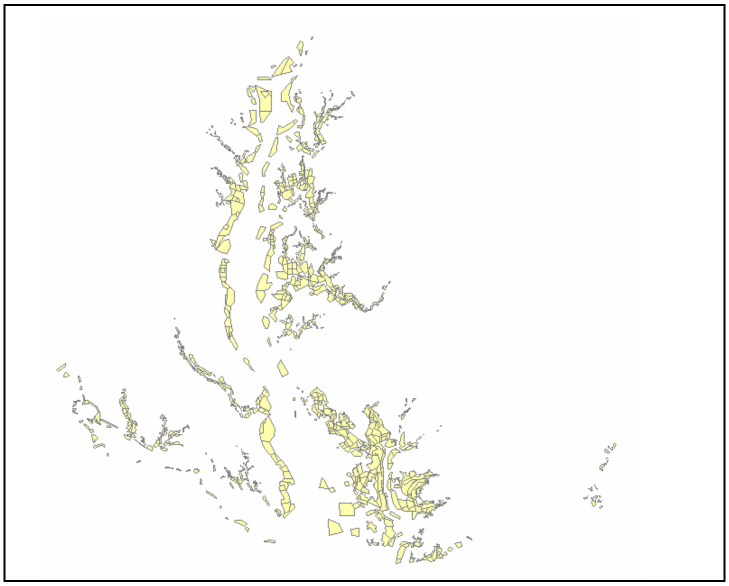
Oyster bars identified in the MBBS were drawn as polygons onto 37 transparent sheets of *Mylar*. The transparencies were drawn to the scale of the Maryland Natural Oyster Bar (NOB) charts (MDDNR 1983), however, they lack any geographic reference information such as latitude or longitude and have therefore not been of use as a comprehensive resource management tool (Smith et al. 2001). All of the transparencies were completed by the end of 1983. The MBBS habitat information has instead been used primarily to designate new legal natural oyster bar boundaries. The new NOB boundaries started to become effective in 1982 but the original bottom classifications were never published.

In 2001, Smith et al. digitized the original MBBS data into a GIS format using MapInfo® software. MBBS habitat designations were validated by comparing raw MBBS field data with the categorical bottom types of the MBBS depictions for two locations (Cook's Point and Sandy Hill) in the Choptank River. Bottom designations for polygons were generally consistent with the raw bottom type data from the original patent tong samples. The percentage of cultch by volume from the original MBBS patent tong sample was compared to the MBBS bottom types assigned to Cook's Point and Sandy Hill. The results of this comparison suggested that qualitative methods were used by MBBS to categorize cultch bottom types. Comparisons were also made between MBBS patent tong samples and samples collected with similar gear during the Maryland DNR Oyster Stock Assessment Program (OSAP 1993) for Cook's Point and Sandy Hill. The OSAP dataset was also used to validate the shape of the MBBS cultch polygons. After standardizing to account for different units of sampling between the two surveys, both the MBBS and OSAP surveys were found to be skewed toward samples with low cultch density. However, the frequency distribution of cultch density differed between the two surveys and the reason for this was not known. Therefore, comparisons with the OSAP data were unable to determine the accuracy of MBBS bottom categorization. Nor was a relationship found between OSAP areas and the shapes of the MBBS cultch polygons. SCUBA dives were conducted in 1998 to assess surface and subsurface composition at 9 MBBS sites. Divers visually assessed surface cultch, probed subsurface sediment with a knife, and collected sediment samples to a depth of 15 cm for traditional grain size analysis. A benthic sled outfitted with color and black and white cameras was towed through the nine areas. The combination of diver surveys, underwater videography, and sediment analysis indicated that much of the area defined by MBBS as cultch had little surface shell. However, dense shell was noted below surface sediments. Acoustic sub-bottom profiling was conducted at Cook's Point and Sandy Hill to identify bottom depth and depth of sub-bottom density discontinuities. This study found that oyster bars are found in places where sub-bottom terraces emerge from soft sediment or at main channel margins.

Table X. Bottom types polygons digitized from MBBS by Smith et al. 2001 (reproduced from Smith et al. 2001, Table 2). Shell is synonymous with oyster cultch.

Bottom Type	**# of Polygons**	**Area (km^2)**
Sand and Shell	1,999	201.9
Shell	1,958	477.7
Sand	1,177	838.5
Mud and Shell	1,155	205.2
Mud	845	733.4
Hard Bottom	409	135.2
Total	7,543	2,591.9

3. File Name: Mdoysbrs_utm
Metadata Summary: Appendix A-3



Representation of historic oyster bottom as charted prior to the present, legally designated Natural Oyster Bars (NOB's), using source materials from 1906 to 1977. / This file was created for Maryland DNR planning purposes, specifically for the purpose of managing Maryland's oyster. / Boundaries were generated using MapInfo software based on a variety of spatial and non-spatial resources.

4. File Name: Chesapeake_Bay_habitat_v1_utm
Metadata Summary: Appendix A-4

Greenhawk (2005) wrote, “This data layer consists of compilation of several historic habitat datasets in Maryland and Virginia with some modifications. For Maryland, these historic layers include the Yates Survey, the Maryland Bay Bottom Survey, DNR repletion sites, Maryland leased bars, and sanctuaries and reserves. For Virginia, these layers included Virginia leased bars and sites identified as potential areas for oyster restoration. Details on how these layers were compiled are given by Greenhawk (2005). The cultch area data set was created for use by DNR scientists, managers, and modelers involved in work related to the preparation of an environmental impact statement entitled ‘Development of an Environmental Impact Statement for Introducing Non-Native Oyster Species into the Chesapeake Bay, Including an Evaluation of Native Oyster Restoration Alternatives.’

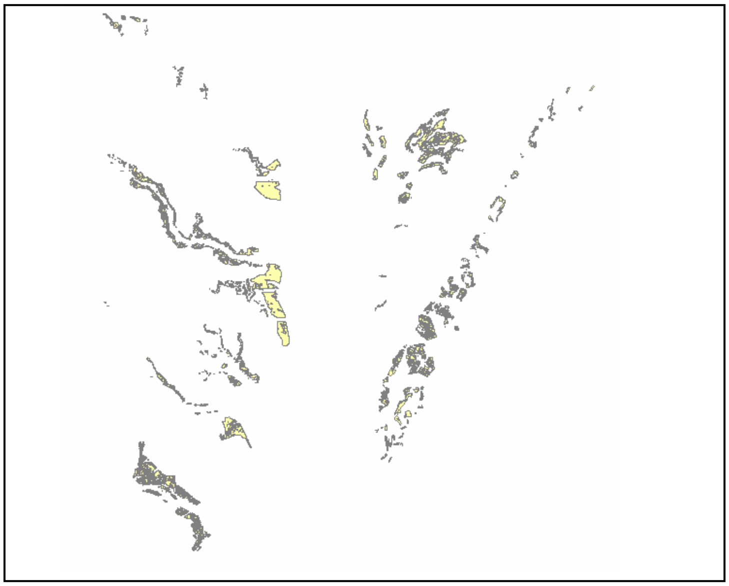
The creation of this file was necessitated by of the lack of a recent comprehensive oyster bar survey in either Maryland or Virginia and an awareness that significant oyster habitat loss has occurred in recent years. To develop this layer, the area and the habitat quality of oyster bars throughout Chesapeake Bay was adjusted to account for this loss of habitat as determined in historical surveys. For Maryland, the area and habitat quality of each oyster bar determined in a comprehensive field survey (Maryland Bay Bottom Survey, mid 1970s through early 1980s) was adjusted by the results of a survey conducted between 1999 and 2000 (Smith et al. 2001) of the size and habitat quality of a small subset of these bars. In Virginia, adjustments to a comprehensive historical oyster bar survey were made based on recent experience in the field. This data set was developed as input to model the distribution and abundance of oysters in Chesapeake Bay. A re-survey of oyster habitat in Maryland and Virginia is needed prior to initiation of any site specific or regional management activities requiring accurate delineation of Chesapeake Bay oyster bars.”

Virginia

5. File Name: baylor_grds
Metadata Summary: Appendix A-5

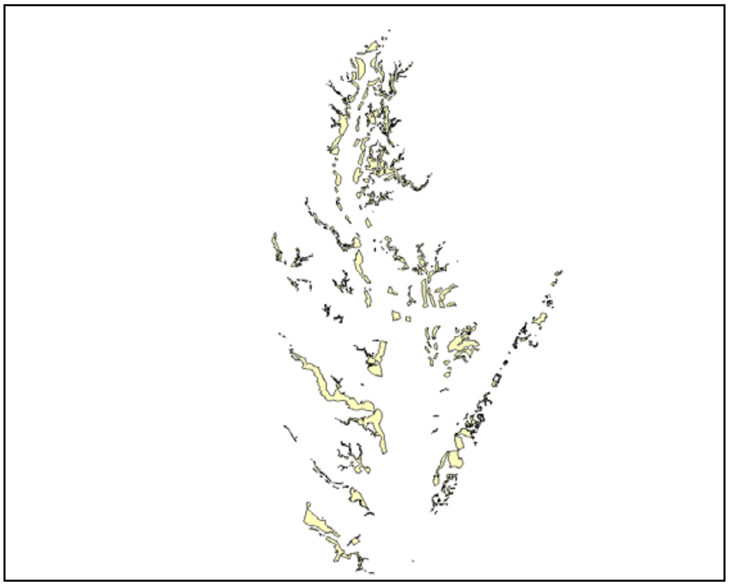
The first coarse-scale maps of Chesapeake Bay oyster hard bottom habitat in Virginia were constructed by Baylor (1894) and were based on surveys conducted during 1892-1893. The Baylor Survey (1894) delineated the bounds of naturally productive oyster bars in the Virginia portion of the Chesapeake Bay. Locations where oysters had been present historically were delineated based on the recollection of participating watermen. Other data for extant bars such as reef geometry, bottom type, and biological data were not collected. The study delineated 210,074 acres (at least 391 known reefs), which included both naturally productive oyster bottom as well as unproductive areas (Moore 1910). Legal boundaries for public oyster grounds were based on the Baylor survey. Since the original survey, 32,274 acres have been added to the public grounds as a result of petition or legislative action (Haven, Hargis, and Kendall 1978). Of these, approximately 199,000 acres are within the Chesapeake Bay system and 43,000-44,000 are located on the side of the Eastern Shore bordering the Atlantic Ocean.

6. File Name: bottom
Metadata Summary: Appendix A-6



The first comprehensive survey of oyster bottom in the VA portion of the Chesapeake Bay was conducted by Haven (1981) during 1978-1981. The survey employed electronic positioning gear and a recording fathometer to establish depth contours. A sonic bottom drag was used to locate and outline reefs and to gather bottom type data. Sampling with patent tongs was used to estimate oyster density, oyster shell density, and for further bottom type characterization. The survey yielded a series of charts and tables that depicted outlines of existing oyster reefs, acreages of bottom types, estimates of living oysters and oyster shells, setting potentials, and occurrences of diseases and predators. The results of the survey were published in a series of reports (Haven et al. 1978, Haven et al. 1981, Haven and Whitcomb 1983, 1989, Whitcomb and Haven 1987). About 203,405 acres of Virginia's 243,000 acres of public (Baylor) bottoms were evaluated by the Haven survey including those on the marine coast of the Eastern Shore.

7. File Name: Yates_Baylor_utm
Metadata Summary: Appendix A-7

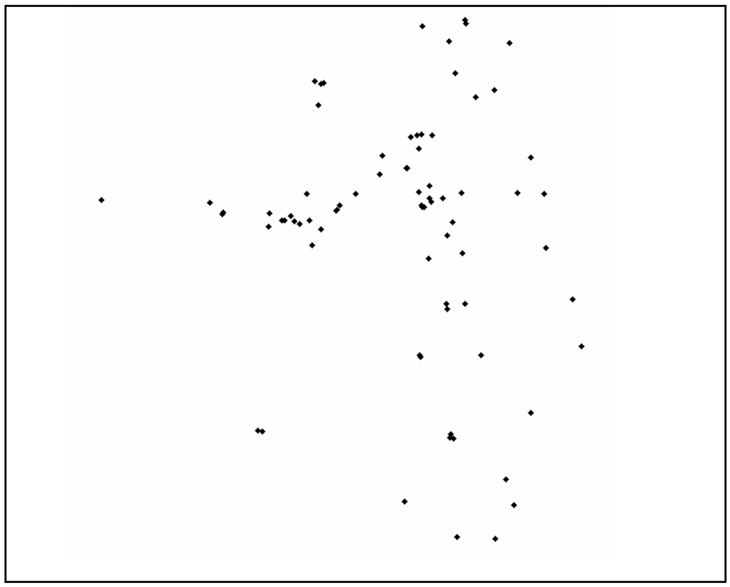


Polygon delineation of Maryland oyster bottom as surveyed by C.C. Yates, circa 1906, plus those surveyed by Baylor in 1892-1893. To create this compilation, the "baylor_grds" file was appended to the "Yatesbrs" file by using the "union" function in the Editor toolbox in ArcGIS version 9.3. All of the associated attributes are from the "Yatesbrs" file. For the attributes associated with the Baylor grounds survey, see the file "baylor_grds."

OYSTER RESTORATION

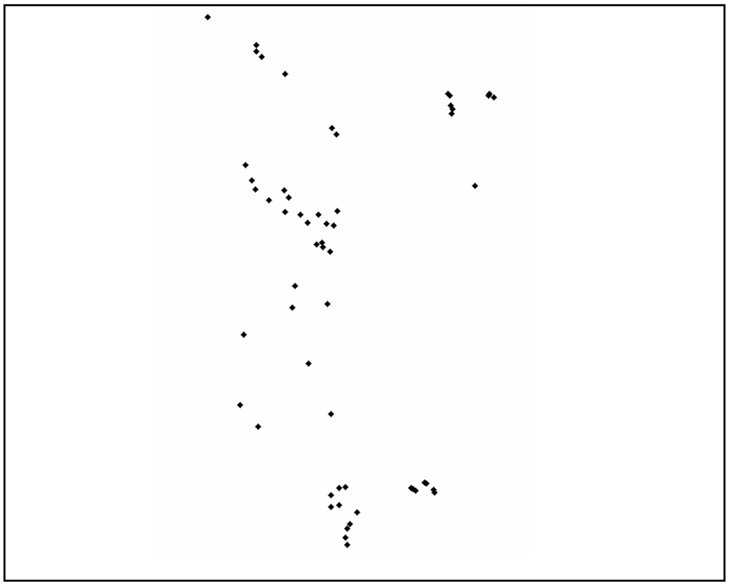
Virginia

8. File Name: restoration_utm
Metadata Summary: Appendix A-8



Habitat restoration sites were compiled from lat/longs, town name locations, and site maps for the Habitat Restoration Project funded by the CBP Living Resources Subcommittee.t.

9. Layer Name: Habitat_Site
Metadata Summary: Appendix A-9



3D Oyster Reefs; 4-20-06 - Moved Tangier Reefs 5R, 6R, 7R1, 7R2, and 7R3 to locations as depicted by surveys. See landform directory. MH

10. File Name: oyster_rock
Metadata Summary: Appendix A-10

These data depict oyster rock that could be used to build oyster grounds.

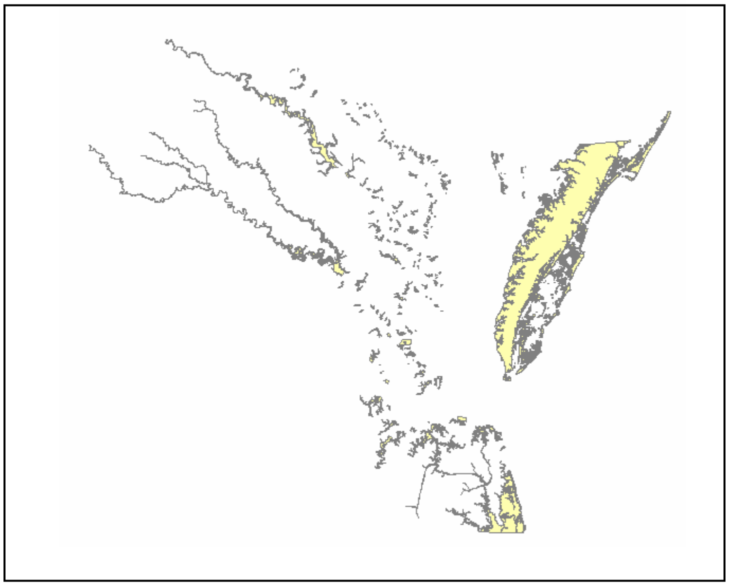
11. File Name: Habitat_area_utm
Metadata Summary: Appendix A-11

Proposed restoration areas are developed in the office as a collaboration of the team based on existing data which may include bathymetry, bottom type, imagery, navigation channels, buoys and charts, and leased oyster grounds. Once in the field, the proposed areas are groundtruthed and modified as necessary to meet certain requirements. When an area is removed based on new findings, it is clipped from the polygon and saved to capture areas that may not be ideal for restoration. Time and money is spent to locate ideal oyster restoration areas - it is important not to lose any information gained from field surveys or investigations. / The purpose of this feature class is to identify constructed and capture locations where proposed native oyster restoration sites have been investigated.; Proposed areas are for planning purposes only and should be treated as such. Areas attributed with constructed are the actual constructed locations and were used to created construction maps. However, it should be noted that the construction location does not guarantee the exact location of shell placement. Due to the inaccurate method for placing shell, the actual location of shell is most likely a subset of that construction location. Changes can be detected by comparing before and after surveys of the construction.

12. File Name: oys_targets2_utm
Metadata Summary: Appendix A-12

This project uses GIS modeling and best professional judgment to identify sites suitable for the construction of oyster reefs to support the oyster reef restoration program in Virginia's portion of the Chesapeake Bay. Criteria in Version 2 include: in addition to using the criteria for the first version of shell bottom or oyster rock, baylor public oyster ground, salinity > 9.999ppt and water depth between 1 and 6 meters. A GIS analysis was done using these data and results in this shapefile show the best potential sites for oyster reef restoration.

13. File Name: comdemed
Metadata Summary: Appendix A-13



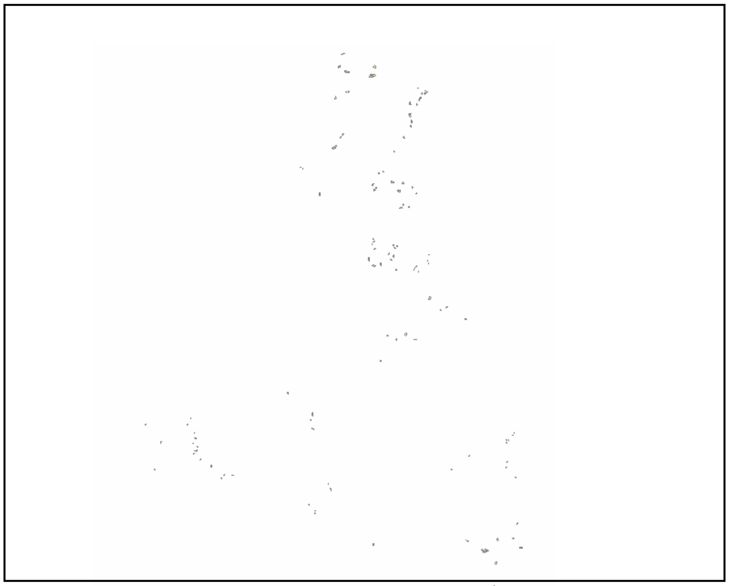
Condemned Oyster Areas / file created by VIMS with VMRC data / data may or may not be current.

Maryland

14. File Name: Bayplantings_utm
Metadata Summary: Appendix A-14

Spatial file containing polygon information for oyster repletion activities conducted by Md. DNR between 1958 and 1999. / This file was created for Maryland DNR planning purposes, specifically for the purpose of managing Maryland's oyster resource.

15. File Name: dnrrepletion_utm
Metadata Summary: Appendix A-15



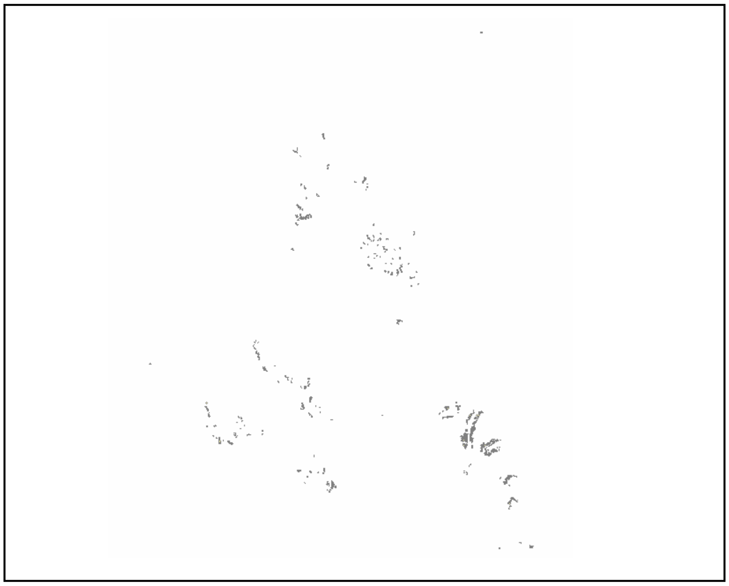
Polygon delineation of annual oyster repletion activities undertaken by the Maryland Department of Natural Resources, Shellfish Program. / This file was created for MDNR planning purposes, specifically for the purpose of tracking the activities of the Department's Shellfish Repletion Program. / Dataset was derived from coordinates collected by MDNR's Shellfish Program personnel in the field as material was deployed. Beginning in 1999, coordinates were taken from DGPS (Northstar DGPS model 951XD); prior to 1999, coordinates were taken from Loran.

16. File Name: Mdsancres_utm
Metadata Summary: Appendix A-16

Polygon representation of oyster recovery activities undertaken in Maryland's oyster sanctuaries and reserves. / File was created for the purpose of tracking oyster recovery efforts in Maryland's oyster sanctuaries and reserves. / File was created by Kelly Greenhawk, MDNR, Fisheries Service, Cooperative Oxford Laboratory but is maintained and distributed by Eric Campbell, MDNR, Fisheries Service, Shellfish Program. File is updated on a continual basis, as planting forms are submitted by the various Maryland partners. Due to the occasional receipt of incomplete forms, some fields in this file may be missing data, or may contain incomplete information. Records are flagged as suspect in this instance, in either the field COMMENTS or in the field OBJCOMM.

PRIVATELY LEASED OYSTER BARS

17. File Name: MD_lease_bars_utm
Metadata Summary: Appendix A-17



"The Natural Oyster Bar/lease lines shown are for oyster management purposes only. For the official boundary(ies) consult the current official Natural Oyster Bar Chart."

The oyster bars/leases in this product are part of the conversion of the present mylar based Natural Oyster Bar Charts to digital format. They are based on bars that were delineated by the Bay Bottom Survey from 1975-1985, and amendments, Potomac River Oyster Survey of 1928, and amendments, and the Potomac River Bottom Survey of 1994, and amendments. They may differ from the bars shown on the current official mylar based Natural Oyster Bar Charts. Leases are based on the conversion of the coordinates from the original lease documents. They are based on surveys dating from 1912 to the present. Coordinates based on early surveys were converted by NADCON to NAD 83-91 values. Surveys performed after 1995 were done by GPS in the same coordinates. It is the responsibility of the licensee to verify that this data is current. This office does not automatically notify licensees of changes/updates to this data.

Some leases have corner points that fall on the shoreline. In these instances this file may exhibit lines that cross the shoreline, or that connect from point to point over the water. In these cases the true extent of the lease should be verified from the lease document.

Any requests for all or part of this data must be referred to the State of Maryland, Department of Natural Resources. The data is copyrighted by the State of Maryland, Department of Natural Resources.

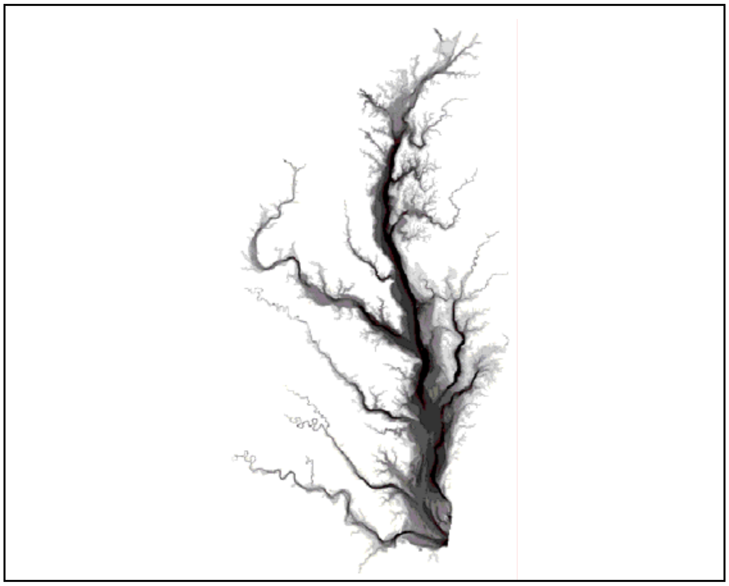
The data was available only in DXF format, with coordinates in NAD 1983 (1991 adjustment) Maryland Zone 1900 State Plane coordinate Meters. The dataset was provided by Louis Wright (MDNR, Natural Resources Police) as a CAD line file. It was converted to a polyline shapefile and then to a polygon shapefile using tools in ArcGIS.

18. File Name: private_lease
Metadata Summary: Appendix A-18

Depicts Private Oyster Lease Boundaries. Compiled by VIMS with VMRC data. Precision is single. Data is good for general location but not analysis.

BATHYMETRY

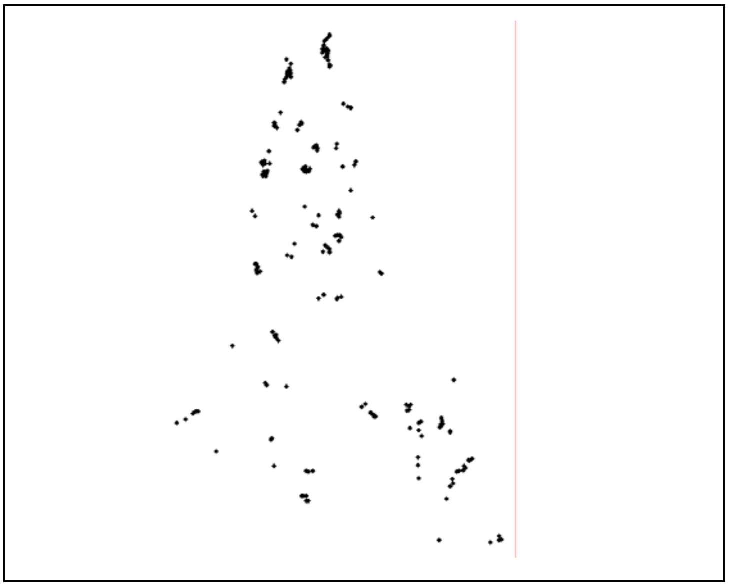
19. File Name: Bathy
Metadata Summary: Appendix A-19



This dataset contains bathymetric one meter low water contours for the mainstem Chesapeake Bay. The contours were generated by ArcInfo using surveys from the National Oceanic and Atmospheric Administration (NOAA) Hydrographic Survey Data CD-ROM. The one meter low water contours were generated by interpolating the Hydrographic surveys (~3.5 million soundings) and generating contours.

HISTORIC OYSTER SPAT SET

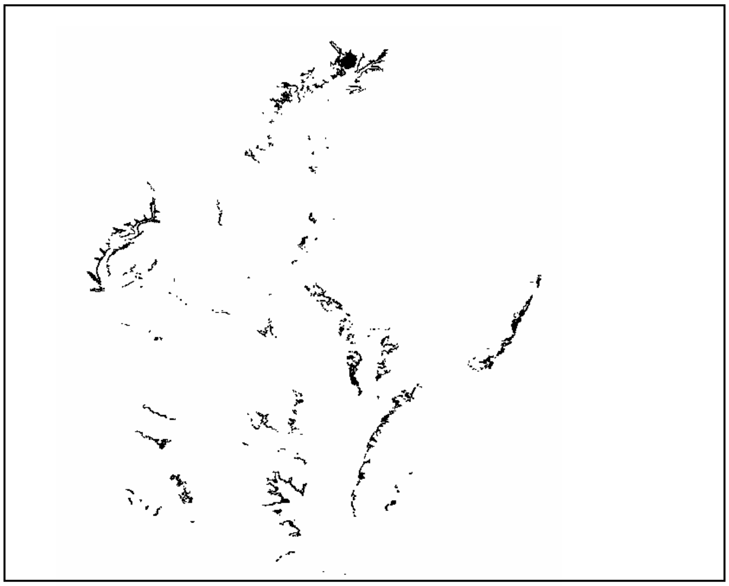
20. File Name: hist_spat_set2_utm
Metadata Summary: Appendix A-20



This data set depicts historic oyster spat set on the "key bars" in the Maryland portion of the Chesapeake Bay from 1939 through 2008. These data are collected annually by the Maryland Department of Natural Resources (MDDNR) during the annual fall oyster dredge survey. Data are expressed as numbers of spat per bushel of material.

SUBMERGED AQUATIC VEGETATION (SAV)

21. File Name: SAV2007
Metadata Summary: Appendix A-21



The 2007 Chesapeake Bay SAV Coverage was mapped from 1:24,000 black and white aerial photography to access water quality in the Bay. Each area of SAV was interpreted from the rectified photography and classified into one of four density classes by the percentage of cover. The SAV beds were entered into an ArcInfo GIS coverage using the quality control procedures documented below.

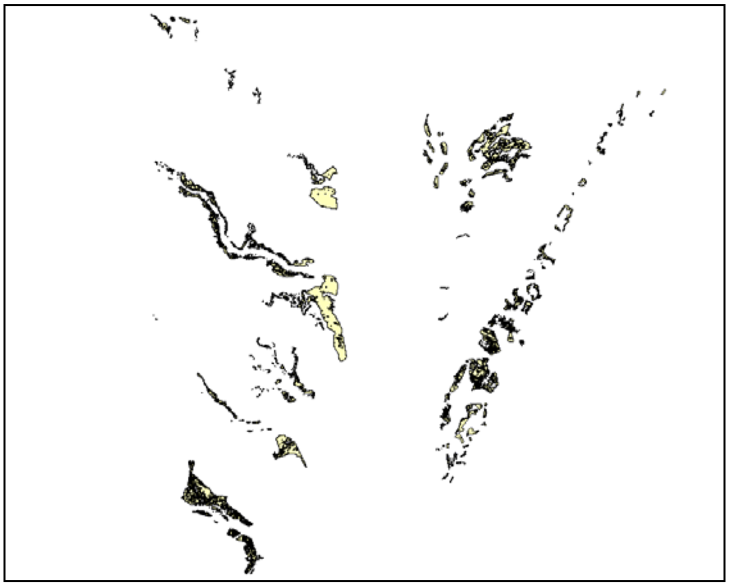
UNKNOWN

The files listed in this section had no metadata on which to base a description. For each file, the file name and a thumbnail photo are provided. Although the list of attributes for these files in provided in Appendix A, few attributes had definitions and very little other metadata were provided.

22. File Name: pots_phase1_utm
Metadata Summary: Appendix A-22

23. File Name: baylor83_utm
Metadata Summary: Appendix A-23

24. File Name: botall83
Metadata Summary: Appendix A-24



References

Baylor, J. B. 1894. Method of defining and location of natural oyster beds, rocks, and shoals. Oyster records. Richmond: Board of Fisheries of Virginia.

Graves, C. 1912. Fourth report of the Shellfish Commission of Maryland. Baltimore: King Bros. Inc.

Greenhawk, K. N. 2005. Development of a potential habitat layer for Chesapeake Bay oyster bottom. Maryland Department of Natural Resources, Fisheries Division. 49 pages.

Haven, D.S., W.J. Hargis, Jr., and P.C. Kendall. 1978. The oyster industry of Virginia: Its status, problems and promise. *VIMS Special Papers in Marine Science* No. 4: 1-1024.

Haven, D. S., J. P. Whitcomb, J. M. Zeigler, and W. C. Hale.1979. The use of sonic gear to chart locations of natural oyster bars in Lower Chesapeake Bay. *Proceedings of the National Shellfish Association* 69: 11-14.

Haven, D. S. and J. P. Whitcomb. 1983. The origin and extent of oyster reefs in the James River. Virginia Journal of Shellfish Research 3: 141-151.

Kennedy, V. S. and L. L. Breisch. 1983. Sixteen decades of political management of the oyster fishery in Maryland's Chesapeake Bay. *Journal of Environmental Management* 16: 53-171.

Maryland Department of Natural Resources (MDDNR). 1989. Harvest statistics.

Moore, H.F. 1910. Condition and extent of the oyster beds of James River. U.S. Bureau of Fisheries Document No. 729. Washington, DC. 84 pages plus 2 charts.

Maryland DNR Oyster Stock Assessment Program (OSAP). 1983.

Smith, G. F., K. N. Greenhawk, D. G. Bruce, E. B. Roach, and S. J. Jordan. 2001. A digital presentation of the Maryland oyster habitat and associated bottom types in the Chesapeake Bay (1974-1983).

Whitcomb, J. P. and Haven, D. S. 1987. The physiography and extent of public oyster grounds in Pocomoke Sound, VA. *Journal of Shellfish Research* 6: 55-65

Yates, C. C. 1911. Survey of the oyster bars [by county of the State of Maryland]. Department of Commerce and Labor-Coast and Geodetic Survey. Washington DC: U.S. Government Printing Office.

APPENDIX A

A-1. Meta-Data for "Yatesbrs_utm"

Title	**Yatesbrs_utm**
Abstract	Polygon delineation of Maryland oyster bottom as surveyed by C.C. Yates, circa 1906.
How should this data set be cited?	Maryland Department of Natural Resources, Fisheries Service, Sarbanes Cooperative Oxford Laboratory, 1911.
Online Links:	http://dnrweb.dnr.state.md.us/gis/data/index.html
Does the data set describe conditions during a particular time period?	01-Jan-1906 until 31-Dec-1911
What is the general form of this data set?	Polygon shapefile

Data

FID	Internal feature number
Shape	Feature geometry
YATESNAME	Name given to oyster bar by Yates.
NUMCORNS	Number of corner coordinates published for oyster bar.
REFCODE	Reference code - Volume number and page number coordinates were taken from.
COUNTY	Two letter code for county within which oyster bar lies.
CENTROIDX	Longitude of centroid value, expressed in negative decimal degrees and calculated from MapInfo.
CENTROIDY	Latitude of centroid value, expressed in negative decimal degrees and calculated from MapInfo.
CALCDACRES	Size of oyster bar, in acres, calculated in MapInfo.

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Maryland Department of Natural Resources 580 Taylor Avenue, Tawes State Office Building Annapolis, MD 21401 USA
Who also contributed to the data set?	Maryland Department of Natural Resources
To whom should users address questions about the data?	Kelly Greenhawk DP Programmer / Analyst Sarbanes Cooperative Oxford Laboratory, 904 South Morris Street Oxford, MD 21654 USA 410-226-0078 (voice) 410-226-0120 (FAX)
Who wrote the metadata?	Maryland Department of Natural Resources
Dates	Last modified: 29-Jun-2005
Metadata author	Maryland Department of Natural Resources Kelly Greenhawk DP Programmer / Analyst Sarbanes Cooperative Oxford Laboratory, 904 South Morris Street Oxford, MD 21654 USA 410-226-0078 (voice) 410-226-0120 (FAX) kgreenhawk@dnr.state.md.us
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-2. Meta-Data for "BBSURVEY_utm"

Title	**BBSURVEY_utm**
Abstract	Polygon dataset characterizing bottom type designations determined by MDNR's Acoustic Bay Bottom Survey conducted from 1974 to 1983. Bottom type designations include cultch, mud, sand, leased bottom, hard bottom, mud with cultch and sand with cultch. Note: The data in this file is up to 30 years old and areas designated as "cultch bottom" when this survey was conducted have likely degraded. For this reason, it is very likely that many of the areas shown as cultch in the dataset are no longer valid. The data in this file should only be used as a general guide.
How should this data set be cited?	Maryland Department of Natural Resources, 04-Feb-2003
Online Links:	http://dnrweb.dnr.state.md.us/gis/data/index.html
Does the data set describe conditions during a particular time period?	1974-1983
What is the general form of this data set?	Polygon shapefile
	Data
FID	Internal feature number
Shape	Feature geometry
BOT_TYPE	Numeric bottom type code, 1 through 7 as follows: 1 = mud; 2 = sand; 3 = sand with cultch; 4 = mud with cultch; 5 = cultch; 6 = hard bottom; 7 = leased bottom (leased bottom was not surveyed, only charted.)
BOTTOM	Textual description of bottom type as follows: "MUD", "SAND", "MUD WITH CULTCH", "SAND WITH CULTCH", "CULTCH", "HARD BOTTOM", AND "LEASED"
BORDER	Field contains "I" for "incomplete" if any part of the polygon's border overlaps the mylar's border

HOLES	Number of "holes" in the polygon object. Holes are either caused by physical features such as islands, where the surveyors could not work, or other bottom types
Acres	

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Maryland Department of Natural Resources 580 Taylor Avenue, Tawes State Office Building Annapolis, MD 21401 USA
Who also contributed to the data set?	Maryland Department of Natural Resources
To whom should users address questions about the data?	Kelly Greenhawk DP Programmer / Analyst Sarbanes Cooperative Oxford Laboratory, 904 South Morris Street Oxford, MD 21654 USA 410-226-0078 (voice) 410-226-0120 (FAX)
Who wrote the metadata?	Maryland Department of Natural Resources
Dates	Last modified: 29-Jun-2005
Metadata author	Maryland Department of Natural Resources Kelly Greenhawk DP Programmer / Analyst Sarbanes Cooperative Oxford Laboratory, 904 South Morris Street Oxford, MD 21654 USA 410-226-0078 (voice) 410-226-0120 (FAX) kgreenhawk@dnr.state.md.us
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-3. Meta-Data for "Mdoysbrs_utm"

Title	**Mdoysbrs_utm**
Abstract	Representation of historic oyster bottom as charted prior to the present, legally designated Natural Oyster Bars (NOB's), using source materials from 1906 to 1977.
How should this data set be cited?	Maryland Department of Natural Resources, Fisheries Service, Cooperative Oxford Laboratory, Mapping and Analysis Project.
Online Links:	http://dnrweb.dnr.state.md.us/gis/data/index.html
Does the data set describe conditions during a particular time period?	1906-1977
What is the general form of this data set?	Polygon shapefile
	Data
FID	Internal feature number.
Shape	Feature geometry
BARCODE	Six character barcode, broken down as follows: First three characters represent tributary bar lies within and last three characters represent code for bar; all barcodes end with either "0" or "1"
REGION	This field is based on that used by Meritt (1977) and represents the area of the Maryland bay in which the oyster bar lies.
BARNAME	Principal name used to refer to oyster bar. When alternative names were available for an area, those found on the Natural Oyster Bar Charts of 1983 (NOBs) took precedence.
LABCODE	Four letter barcode used at the Sarbanes Cooperative Oxford Laboratory. Code is provided for the 64 oyster bars that are sampled on an annual basis by MDNR for disease analysis.
COUNTY	Two letter county code; county within which bar lies; when oyster bars straddled the boundary between two counties, the bar was assigned to the county within which the majority of its acreage falls.
YATESBRS	Logical field - A "Y" in this field indicates that the oyster bar was an original Yates bar (or part of a Yates bar) as charted prior to 1911. Boundaries for these bars were obtained from Yates' original coordinates.

OTHERNAMES	Other names that were found from multiple data sources for the same oyster bar location. Multiple names are listed in string fashion, and delineated by commas.
ACRES	Oyster bar acreage calculated using MapInfo software
AREA_SQM	Oyster bar size calculation in square meters using MapInfo software
XCOORD	Longitude of bar's centroid coordinates, expressed in negative decimal degrees
YCOORD	Latitude of bar's centroid coordinates, expressed in decimal degrees
UOB	"Y" if oyster bar has no defined boundaries and star symbol is used to indicate relative position of bar
LONGIT	Longitude of bar's centroid coordinates, expressed in n degrees, minutes and seconds
LATITU	Latitude of bar's centroid coordinates, expressed in n degrees, minutes and seconds

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Maryland Department of Natural Resources 580 Taylor Avenue, Tawes State Office Building Annapolis, MD 21401 USA
Who also contributed to the data set?	Maryland Department of Natural Resources
To whom should users address questions about the data?	Kelly Greenhawk DP Programmer / Analyst Sarbanes Cooperative Oxford Laboratory, 904 South Morris Street Oxford, MD 21654 USA 410-226-0078 (voice) 410-226-0120 (FAX) kgreenhawk@dnr.state.md.us
Who wrote the metadata?	Maryland Department of Natural Resources
Dates	
Metadata author	Maryland Department of Natural Resources Kelly Greenhawk DP Programmer / Analyst

	Sarbanes Cooperative Oxford Laboratory, 904 South Morris Street Oxford, MD 21654 USA 410-226-0078 (voice) 410-226-0120 (FAX) kgreenhawk@dnr.state.md.us
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-4. Meta-Data for "Chesapeake_Bay_habitat_v1_utm"

Title	**Chesapeake_Bay_habitat_v1_utm**
Abstract	The dataset described in this document was created for use by Department scientists, managers, and modelers involved in work related to the preparation of an environmental impact statement entitled "Development of an Environmental Impact Statement for Introducing Non-Native Oyster Species into the Chesapeake Bay, Including an Evaluation of Native Oyster Restoration Alternatives". See Greenhawk (2005) for more details.
How should this data set be cited?	Maryland Department of Natural Resources, Dec-2005
Online Links:	http://dnrweb.dnr.state.md.us/gis/data/index.html
Does the data set describe conditions during a particular time period?	1906-2005
What is the general form of this data set?	Polygon shapefile
	Data
FID	Internal feature number.
Shape	Feature geometry.
ID	Unique numeric identifier (1 through 8,480).
CX	Longitude value of the centroid, expressed in decimal degrees.
CY	Latitude value of the centroid, expressed in decimal degrees.
A	Area of habitat polygon, expressed in acres.
B	Basin name from Chesapeake Bay Oyster Population Estimation project (Maryland basins: CHESTER, CHOPTANK, EASTERN BAY, LITTLE CHOPTANK, MD MAINSTEM, MD POTOMAC, PATUXENT, or TANGIER; Virginia basins: EASTERN SHORE/TANGIER, GREAT/LITTLE WICOMICO, JAMES, PIANKATANK, POQUOSON/BACK, RAPPAHANNOCK, VA MAINSTEM, VA POTOMAC, or YORK/MOBJACK).

N	Numeric NOAA waterbody code (212, 217, 218, 220, 224, 225, 226, 228, 230, 231, 232, 235, 236, 237, 239, 243, 245, 246, 248, 249, 251, 252, 253, 254, 257, 258, 259, 267, 268, 270, 271, 273, 276, 278, 279, 301, 306, 307, 308, 309, 311, 313, 314, 315, 316, 317, 321, 322, 324, 327, 328, 329, 332, 333, 335, 336, 337, 338, 339, 343, 345, 346, 347, 351, 353, 354, 355, 358, 363, 364, 366, 367, 368, 369, 371, 372, 374, 375, 379, 380, 381, 382, 391, or 392).
S	Source code for origin of habitat polygon (MH=Maryland habitat; ML=Maryland lease; VH=Virginia habitat; VL=Virginia lease).
HT	Alphabetic code representing the habitat type for Maryland habitat polygons (B=Maryland Bay Bottom Survey; P=Planting; Y=Yates bar). Only Maryland habitat polygons will have a value in the HT field.
LID	Lease identifier; 3 digit lease identifier(assigned by MDNR, NRP), followed by a dash, followed by an acreage value. LID field will be blank for Virginia leases.
ALT	EIS alternative number for which lease will be used (4-EIS alternative nuber 4; 5-EIS alternative number 5; 45-EIS alternative numbers 4 and 5). Sixty Maryland leases have a value in the ALT field, the remaining records are blank.
CLOS_STAT	RESTRICTED = closed by MDE due to high fecal coliform levels; SANCTUARY = closed by MDNR
CLOSNAME	CONDEMNED="Restricted" or condemned to shellfish harvesting except for relay harvesting. Shellfish may be relayed with VMRC stamp to approved waters for 15 days per Code of Va., then harvesting for sale/consumption; PROHIBITED=Shellfish harvesting is not allowed in "Prohibited" waters. Typically those waters surrounding an STP outfall; SEASONALLY CONDEMNED=Harvesting in shellfish waters "seasonally condemned" otherwise known as "Conditionally Approved" is 'Restricted' or 'Condemned' between April 1 and October 31; PROHIBITED NON PRODUCTIVE=Classified waters that exist upstream in low-salinity areas where there

	typically is no resource. Waters are NOT sampled and therefore are classified by NSSP as "Prohibited".

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Maryland Department of Natural Resources 580 Taylor Avenue, Tawes State Office Building Annapolis, MD 21401 USA
Who also contributed to the data set?	Maryland Department of Natural Resources
To whom should users address questions about the data?	Kelly Greenhawk DP Programmer / Analyst Sarbanes Cooperative Oxford Laboratory, 904 South Morris Street Oxford, MD 21654 USA 410-226-0078 (voice) 410-226-0120 (FAX)
Who wrote the metadata?	Maryland Department of Natural Resources
Dates	Last modified: 29-Jun-2005
Metadata author	Maryland Department of Natural Resources Kelly Greenhawk DP Programmer / Analyst Sarbanes Cooperative Oxford Laboratory, 904 South Morris Street Oxford, MD 21654 USA 410-226-0078 (voice) 410-226-0120 (FAX) kgreenhawk@dnr.state.md.us
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-5. Meta-Data for "Baylor_grds"

Title	**Baylor_grds**
Abstract	Polygons digitized from Old Baylor Maps
How should this data set be cited?	Virginia Institute of Marine Science, Gloucester Point, VA
Online Links:	
Does the data set describe conditions during a particular time period?	
What is the general form of this data set?	arc info file

Data

FID	Internal feature number
Shape	Feature geometry
AREA	Area of feature in internal units squared.
PERIMETER	Perimeter of feature in internal units.
BAYLOR_GRDS#	Internal feature number
BAYLOR_GRDS-ID	User-defined feature number.
LEGCODE	Unknown
ACREAS	Unknown

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Virginia Institute of Marine Science Gloucester, VA
Who also contributed to the data set?	
To whom should users address questions about the data?	Virginia Institute of Marine Science Gloucester, VA

Who wrote the metadata?	U.S. Army Corps of Engineers
Dates	
Metadata author	U.S. Army Corps of Engineers Michelle Hamor 803 Front Street Norfolk, VA 23510 USA 757-441-7491 (voice) 757-441-7664 (fax) michelle.l.hamor@usace.army.mil
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-6. Meta-Data for “bottom”

Title	**bottom**
Abstract	Bottom Type within Chesapeake Bay
How should this data set be cited?	Virginia Institute of Marine Science Gloucester, VA
Online Links:	
Does the data set describe conditions during a particular time period?	
What is the general form of this data set?	Polygon shapefile

Data

FID	Internal feature number
Shape	Feature geometry
AREA	Unknown
PERIMETER	Unknown
BOTTYPE	Unknown
NOTES	Unknown
SOURCE	Unknown
Acres	Unknown

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Virginia Institute of Marine Science Gloucester, VA USA
Who also contributed to the data set?	
To whom should users address questions about the data?	

Who wrote the metadata?	U.S. Army Corps of Engineers 803 Front Street Norfolk, VA 23510 USA 757-441-7491 (voice) 757-441-7664 (fax) michelle.l.hamor@usace.army.mil
Dates	
Metadata author	U.S. Army Corps of Engineers 803 Front Street Norfolk, VA 23510 USA 757-441-7491 (voice) 757-441-7664 (fax) michelle.l.hamor@usace.army.mil
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-7. Meta-Data for "Yates_Baylor_utm"

Title	**Yates_Baylor_utm**
Abstract	Polygon delineation of Maryland oyster bottom as surveyed by C.C. Yates, circa 1906 plus those surveyed by Baylor in 1892-1893. To create tis compilation, the "baylor_grds" file was appended to the "Yatesbrs" file by using the "union" function in the Editor toolbox in ArcGIS version 9.3. All of the associated attributes are from the "Yatesbrs" file. For the attributes associated with the Baylor grounds survey, see the file "baylor_grds."
How should this data set be cited?	Maryland Department of Natural Resources, Fisheries Service, Sarbanes Cooperative Oxford Laboratory, 1911 and Virginia Institute of Marine Science, 1892-1893.
Online Links:	http://dnrweb.dnr.state.md.us/gis/data/index.html
Does the data set describe conditions during a particular time period?	01-Jan-1906 until 31-Dec-1911 for Maryland and 1892-1893 for Virginia.
What is the general form of this data set?	Polygon shapefile
Note	The Baylor layer was appended to the Yates layer so all of the attributes below are those for the Yates bars. For information on the Baylor layer, see the file entitled, "Baylor_grds."
	Data
FID	Internal feature number
Shape	Feature geometry
YATESNAME	Name given to oyster bar by Yates.
NUMCORNS	Number of corner coordinates published for oyster bar.
REFCODE	Reference code - Volume number and page number coordinates were taken from.
COUNTY	Two letter code for county within which oyster bar lies.

CENTROIDX	Longitude of centroid value, expressed in negative decimal degrees and calculated from MapInfo.
CENTROIDY	Latitude of centroid value, expressed in negative decimal degrees and calculated from MapInfo.
CALCDACRES	Size of oyster bar, in acres, calculated in MapInfo.

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Maryland Department of Natural Resources 580 Taylor Avenue, Tawes State Office Building Annapolis, MD 21401 USA Virginia Institute of Marine Science Gloucester, VA
Who also contributed to the data set?	Maryland Department of Natural Resources
To whom should users address questions about the data?	Kelly Greenhawk (Yates Bars, Maryland) DP Programmer / Analyst Sarbanes Cooperative Oxford Laboratory, 904 South Morris Street Oxford, MD 21654 USA 410-226-0078 (voice) 410-226-0120 (FAX) Marcia Berman (Baylor Bars, Virginia) Virginia Institute of Marine Science Gloucester Point, VA 23062 (804)684-7188 (voice) (804)684-7179 (fax) marcia@sweethall.wetlan.vims.edu
Who wrote the metadata?	Maryland Department of Natural Resources and Versar
Dates	Last modified: 20-April-2009
Metadata author	Maryland Department of Natural Resources Kelly Greenhawk DP Programmer / Analyst Sarbanes Cooperative Oxford Laboratory, 904 South Morris Street

	Oxford, MD 21654 USA 410-226-0078 (voice) 410-226-0120 (FAX) kgreenhawk@dnr.state.md.us Versar, Inc. 9200 Rumsey Road Columbia, MD 21045 410-964-9200 (voice) 410-964-5157 (fax) wslacum@versar.com
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-8. Meta-Data for “restoration_utm”

Title	**restoration_utm**
Abstract	Habitat restoration sites were compiled from lat/longs, town name locations, and site maps for the Habitat Resoration Project funded by the CBP Living Resources Subcommittee.t.
How should this data set be cited?	
Online Links:	
Does the data set describe conditions during a particular time period?	
What is the general form of this data set?	Arc Info File

Data

FID	Internal feature number
Shape	Feature geometry
AREA	Area of feature in internal units squared.
PERIMETER	Perimeter of feature in internal units.
RESTORATION#	Internal feature number.
RESTORATION-ID	User-defined feature number.
HRCODE	Unknown
PLNAME	Unknown
DELETE	Unknown
YEAR	Unknown

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Marcia Berman Virginia Institute of Marine Science, Center for Coastal Resources Management, Gloucester, VA 23062
Who also contributed to the data set?	
To whom should users address questions about the data?	Marcia Berman Director, Comprehensive Coastal Inventory Program

	Center for Coastal Resources Management Virginia Institute of Marine Science P.O. Box 1346 Gloucester Point, VA 23046 (804) 684-7188 (phone) (804)684-7179 (fax) marcia@sweethall.wetlan.vims.edu
Who wrote the metadata?	
Dates	
Metadata author	
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-9. Meta-Data for "Habitat_site"

Title	**Habitat_site**
Abstract	3D Oyster Reefs 4-20-06 - Moved Tangier Reefs 5R, 6R, 7R1, 7R2, and 7R3 to locations as depicted by surveys. See landform directory. MH
How should this data set be cited?	
Online Links:	
Does the data set describe conditions during a particular time period?	
What is the general form of this data set?	coverage

Data

FID	Internal feature number
Shape	Feature geometry
YEAR	Unknown
AGENCY	Unknown
SCALE	Unknown
Name	Unknown
Location	Unknown
Notes	Unknown

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	
Who also contributed to the data set?	
To whom should users address questions about the data?	U.S. Army Corps of Engineers Norfolk, VA 23661 (757) 441-7491 (voice) (757) 441-7664 (fax)

Who wrote the metadata?	U.S. Army Corps of Engineers
Dates	
Metadata author	Michelle Banton U.S. Army Corps of Engineers Norfolk, VA 23661 (757) 441-7491 (voice) (757) 441-7664 (fax) michelle.banton@usace.army.mil
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-10. Meta-Data for "oyster rock"

Title	**oyster_rock**
Abstract	Habitat restoration sites were compiled from lat/longs, town name locations, and site maps for the Habitat Resoration Project funded by the CBP Living Resources Subcommittee.t.
How should this data set be cited?	
Online Links:	
Does the data set describe conditions during a particular time period?	
What is the general form of this data set?	Arc info file

Data

FID	Internal feature number
Shape	Feature geometry
AREA	Area of feature in internal units squared.
PERIMETER	Perimeter of feature in internal units.
OYSTER_ROCK#	Internal feature number.
OYSTER_ROCK-ID	User-defined feature number.
TARGET	Unknown
ACRES	Unknown

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Marcia Berman Virginia Institute of Marine Science, Center for Coastal Resources Management, Gloucester, VA 23062
Who also contributed to the data set?	
To whom should users address questions about the data?	Marcia Berman Director, Comprehensive Coastal Inventory Program Center for Coastal Resources Management Virginia Institute of Marine Science

	P.O. Box 1346 Gloucester Point, VA 23046 (804) 684-7188 (phone) (804)684-7179 (fax) marcia@sweethall.wetlan.vims.edu
Who wrote the metadata?	U.S. Army Corps of Engineers
Dates	
Metadata author	U.S. Army Corps of Engineers, Norfolk District 903 Front Street Norfolk, VA 23510 757-441-7491 (voice) 757-441-7664 (fax) michelle.l.hamor@usace.army.mil
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-11. Meta-Data for "habitat_area_utm"

Title	**habitat_area_utm**
Abstract	Proposed restoration areas are developed in the office as a collaboration of the team based on existing data which may include bathymetry, bottom type, imagery, navigation channels, buoys and charts, and leased oyster grounds. Once in the field, the proposed areas are ground truthed and modified as necessary to meet certain requirements. When an area is removed based on new findings, it is clipped from the polygon and saved to capture areas that may not be ideal for restoration. Time and money is spent to locate ideal oyster restoration areas - it is important not to lose any information gained from field surveys or investigations.
How should this data set be cited?	
Online Links:	
Does the data set describe conditions during a particular time period?	
What is the general form of this data set?	Polygon shapefile

Data

FID	Internal feature number
Shape	Feature geometry
Siteid	Internal Feature Number
Sitename	Unknown
Type	Unknown
Dimension	Unknown
Owner	Unknown
prop_const	Unknown
constr_fy	Unknown

Area_Numbe	Unknown
cub_yd_she	Unknown
cub_yd_s_1	Unknown
Basin	Unknown
SHAPE_Leng	Unknown
SHAPE_Area	Area of feature in internal units squared
Status	Unknown
CX_Coordin	Unknown
CY_Coordin	Unknown
Acres	Unknown
Material	Unknown
Perimeter	Unknown
Area	Feature geometry
Permit_req	Unknown
Hectares	Unknown
Funding	Unknown
X	Unknown
Y	Unknown
x_decideg	Unknown
y_decideg	Unknown

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	
Who also contributed to the data set?	
To whom should users address questions about the data?	U.S. Army Corps of Engineers Norfolk, VA 23661 (757) 441-7491 (voice) (757) 441-7664 (fax)
Who wrote the metadata?	
Dates	
Metadata author	
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-12. Meta-Data for "Oys_targets2_utm"

Title	**Oys_targets2_utm**
Abstract	This project uses GIS modeling and best professional judgement to identify sites suitable for the construction of oyster reefs to support the oyster reef restoration program in Virginia's portion of the Chesapeake Bay. Criteria in Version 2 include: in addition to using the criteria for the first version of shell bottom or oyster rock, baylor public oyster ground, salinity > 9.999ppt and water depth between 1 and 6 meters. A GIS analysis was done using these data and results in this shapefile show the best potential sites for oyster reef restoration.
How should this data set be cited?	
Online Links:	
Does the data set describe conditions during a particular time period?	2006
What is the general form of this data set?	Polygon shapefile

Data

FID	Internal Feature Number
SHAPE	Feature Geometry
AREA	Area of feature in internal units squared
PERIMETER	Perimeter of feature in internal units
BOTTOM	Unknown
GOOD	Unknown
SALINITY	Unknown
CONDEMNED	Unknown
BAYLOR	Unknown
OYS_TARGET	Unknown
OYS_TARG_1	Unknown
BOTTYPE	Unknown
SEED	Unknown
SALINITY	Unknown

CONDEMNED BAYLOR	Unknown

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Comprehensive Coastal Inventory, Virginia Institute of Marine Science, Gloucester Point, Virginia
Who also contributed to the data set?	
To whom should users address questions about the data?	Sharon Killeen Virginia Institute of Marine Science P.O.Box 1346 Gloucester Point, Virginia 23062, USA 804-684-7534 (voice) 804-684-7179 (fax) sharon@vims.edu
Who wrote the metadata?	Sharon Killeen
Dates	
Metadata author	Virginia Institute of Marine Science P.O.Box 1346 Gloucester Point, Virginia 23062, USA 804-684-7534 (voice) 804-684-7179 (fax) sharon@vims.edu
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-13. Meta-Data for "condemed"

Title	**condemed**
Abstract	Condemned Oyster Areas
How should this data set be cited?	Virginia Institute of Marine Science, Gloucester Point, Virginia
Online Links:	
Does the data set describe conditions during a particular time period?	
What is the general form of this data set?	Arc Info File

Data

FID	Internal Feature Number
Shape	Feature Geometry
AREA	Area of feature in internal units squared
PERIMETER	Perimeter of feature in internal units.
CONDEMED#	Internal feature number.
CONDEMED-ID	User-defined feature number.

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Virginia Institute of Marine Science
Who also contributed to the data set?	VMRC
To whom should users address questions about the data?	Virginia Institute of Marine Science
Who wrote the metadata?	U.S. Army Corps of Engineers
Dates	
Metadata author	U.S. Army Corps of Engineers Michelle Hamor 803 Front Street Norfolk, VA 23510 USA 757-441-7491 (voice) 757-441-7664 (fax)
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-14. Meta-Data for "Bay_plantings_utm"

Title	**Bay_plantings_utm**
Abstract	Spatial file containing polygon information for oyster repletion activities conducted by Md. DNR between 1958 and 1999.
How should this data set be cited?	Maryland Department of Natural Resources, Sarbanes Cooperative Oxford Laboratory
Online Links:	
Does the data set describe conditions during a particular time period?	
What is the general form of this data set?	Polygon shapefile

Data

FID	Internal Feature Number
Shape	Feature Geometry
PLANT_NUMB	Incremental number assigned to plants as they were digitized.
YEAR	Two digit year planting was deployed
AREA_AC	Number of acres covered by plant, as recorded on mylars.
SHELL_TYPE	Type of material deployed as follows: "seed" = seed; "se&sh" = seed and shell; "dsh" = dredged shell; "fsh" = fresh shell; "baglessD" = bagless dredge; "subsh" = submerged shell; "poll" = pollutes
BUSHELS	Number of bushels of material deployed, taken from Shellfish Operations Oyster Propagation Activities summary report
CHART_NUMB	NOB chart number, from which planting was digitized
MAP_LETTER	Character code representing yearly range planting falls within as follows: "A" = 1960 - 1970; "B" = 1971 - 1975; "C" = 1976 - 1982; "D" = 1983 - 1987; "E" = 1988 - 1993; "F" = 1994 - 1999
COMMENTS	Additional information pertaining to planting, that did not fit into any other field, such as other agencies involved, whether planting is in a designated sanctuary, whether seed material is from a hatchery

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Maryland Department of Natural Resources, Sarbanes Cooperative Oxford Laboratory 904 South Morris Street

	Oxford, Maryland 21654 USA
Who also contributed to the data set?	
To whom should users address questions about the data?	Maryland Department of Natural Resources, Sarbanes Cooperative Oxford Laboratory 904 South Morris Street Oxford, Maryland 21654 USA
Who wrote the metadata?	Maryland Department of Natural Resources
Dates	02-04-2003
Metadata author	Maryland Department of Natural Resources Kelly Greenhawk Sarbanes Cooperative Oxford Laboratory 904 South Morris Street Oxford, Maryland 21654 USA 410-226-0078 (voice) 410-226-0120 (fax) kgreenhawk@dnr.state.md.us
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-15. Meta-Data for "dnrrepletion_utm"

Title	**dnrrepletion_utm**
Abstract	Polygon delineation of annual oyster repletion activities undertaken by the Maryland Department of Natural Resources, Shellfish Program.
How should this data set be cited?	Maryland Department of Natural Resources, Fisheries Service, Cooperative Oxford Laboratory, 09-Apr-2003
Online Links:	http://dnrweb.dnr.state.md.us/gis/data/index.html
Does the data set describe conditions during a particular time period?	10-Apr-2000 until publication date
What is the general form of this data set?	Polygon shapefile
	Data
FID	Internal feature number
Shape	Feature geometry
DATE_	Date of repletion activity; if seed planting, may be the date buoys were deployed
OPERATORS	From fieldsheet, names of staff operating vessel
NAME	From fieldsheet, code assigned to bar by Shellfish Program staff, usually taken from Maryland Oyster Bars publication (file mdoysbrs)
NOB	From fieldsheet, NOB number within which activity falls
ACCURACY	From fieldsheet, estimated accuracy of GPS
DESC_	From fieldsheet, description of repletion activity; usually bar name, current year and code for material deployed
ACRES	From fieldsheet, estimated number of acres covered by deployed material

DEPTH	From fieldsheet, depth range in feet at planting location
BOTTOM	From fieldsheet, bottom type(s) of are where material was deployed; codes are comma delimited and are as follows: SH = shell; M or MD mud; S = sand; CL = clay
COMMENTS	From fieldsheet, comments recorded by field staff (eg. funding agency) or comments from data producer (eg. incomplete coordinates on fieldsheet)
NUMCOORDS	Number of coordinates provided on fieldsheet
LAT1	From fieldsheet, latitude of first corner; expressed in degrees and decimal minutes to three places
LONG1	From fieldsheet, longitude of first corner; expressed in degrees and decimal minutes to three places
LAT2	From fieldsheet, latitude of second corner; expressed in degrees and decimal minutes to three places
LONG2	From fieldsheet, longitude of second corner; expressed in degrees and decimal minutes to three places
LAT3	From fieldsheet, latitude of third corner; expressed in degrees and decimal minutes to three places
LONG3	From fieldsheet, longitude of third corner; expressed in degrees and decimal minutes to three places
LAT4	From fieldsheet, latitude of fourth corner; expressed in degrees and decimal minutes to three places
LONG4	From fieldsheet, longitude of fourth corner; expressed in degrees and decimal minutes to three places

LAT5	From fieldsheet, latitude of center coordinate; expressed in degrees and decimal minutes to three places
LONG5	From fieldsheet, longitude of center coodinate; expressed in degrees and decimal minutes to three places
YEAR	Four digit year, derived from field DATE_
RECTYPE	Record type; "SHELL" for dredged shell or fresh shell planting; "SEED" for seed plant; OTHER for other types of material
ACCESS	Accession number; internal tracking number used by data producer; first two characters represent 2 digit year; Characters 3 through 5 are alphabetic and are a code for group responsible for planting activity ("DNR" denotes Md Department of Natural Resouces in this dataset); Characters 6 through 11 are the oyster bar code for the oyster bar within which the activity falls (from MDNR - Maryland Oyster Bar publication); Characters 12 through 14 denote type of material deployded (DSH = dredged shell; FSH = fresh shell; SSE = seed from state seed area; HSE = hatchery seed; characters 15-18 represent month and day of planting; the last character is intended to avoid duplicate accession / tracking numbers. Value will be the letter "A" if the activity on this bar was the only one of its kind that day, but will be assigned a "B", "C" , etc. for additional activities. Duplication will only occur if the same group plants the same material on different locations on the same bar during the same day.
TRIB	Tributary name within which activity falls, derived from barcode
BARNAME	Barname within which activity falls or intersects

BARCODE	Six character barcode, derived from MdOysBrs file
MATERIAL	Material code for type of material deployed; DSH = dredged shell; FSH = fresh shell; SSE = seed from state seed area; HSE = hatchery seed
MATSOURCE	From summary report, source of material deployed; Prior to 2002 code is a 2-4 character alphabetic code. Definitions for 2000 are as follows: BEA = Bald Eagle Addition #2; B = Bugby SSA; WCT = Wild Cherry Tree SSA; GM = Great Marsh; OC = Oyster Creek SSA; BC-N = Back Cove SSA; HSB = Horse Shoe Bend; GR = Gravelly Run; Definitions for 2001 are as follows: B = Bugby SSA; BN = Bugby North SSA; WCT = Wild Cherry Tree SSA; BC = Back Cove SSA (63 acres); Beginning in 2002, Shellfish staff used 6 character code from MdOysBrs file
BUSHELS	From summary report, number of bushels of material deployed; A negative 8 in this field denotes data that is missing at publication time, but will be updated in the near future.
X1	Calculated field, derived from Long1 (decimal degree equivalent) and used to generate polygon in MapInfo software
Y1	Calculated field, derived from Lat1 (decimal degree equivalent) and used to generate polygon in MapInfo software
X2	Calculated field, derived from Long2 (decimal degree equivalent) and used to generate polygon in MapInfo software
Y2	Calculated field, derived from Lat2 (decimal degree equivalent) and used to generate polygon in MapInfo software
X3	Calculated field, derived from Long3 (decimal degree equivalent) and used to generate polygon in MapInfo software

Y3	Calculated field, derived from Lat3 (decimal degree equivalent) and used to generate polygon in MapInfo software
X4	Calculated field, derived from Long4 (decimal degree equivalent) and used to generate polygon in MapInfo software
Y4	Calculated field, derived from Lat4 (decimal degree equivalent) and used to generate polygon in MapInfo software
X5	Calculated field, derived from Long5 (decimal degree equivalent) and used to generate polygon in MapInfo software
Y5	Calculated field, derived from Lat5 (decimal degree equivalent) and used to generate polygon in MapInfo software
PAGE	From summary report, page number where plant can be referenced
LOCDETAILS	From summary report, details regarding location of plant on oyster bar
CATEGORY	From summary report, activity purpose / category; Categories are as follows: "SEED TRANSPLANTED FOR NOB IMPROVEMENT BY DNR", "DSH FOR SEED OYSTER PRODUCTION BY DNR", "DSH FOR NOB IMPROVEMENT BY DNR", "DSH FOR CO SEED OYSTER PRODUCTION AND/OR GROWOUT, FSH FOR NOB IMPROVEMENT BY DNR; NOT LISTED (planting not found in summary report)

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Maryland Department of Natural Resources 580 Taylor Avenue, Tawes State Office Building Annapolis, MD 21401 USA
Who also contributed to the data set?	Maryland Department of Natural Resources

To whom should users address questions about the data?	Kelly Greenhawk DP Programmer / Analyst Sarbanes Cooperative Oxford Laboratory, 904 South Morris Street Oxford, MD 21654 USA 410-226-0078 (voice) 410-226-0120 (FAX)
Who wrote the metadata?	Maryland Department of Natural Resources
Dates	Last modified: 29-Jun-2005
Metadata author	Maryland Department of Natural Resources Kelly Greenhawk DP Programmer / Analyst Sarbanes Cooperative Oxford Laboratory, 904 South Morris Street Oxford, MD 21654 USA 410-226-0078 (voice) 410-226-0120 (FAX) kgreenhawk@dnr.state.md.us
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-16. Meta-Data for "MdSancRes_utm"

Title	**MdSancRes_utm**
Abstract	Polygon representation of oyster recovery activities undertaken in Maryland's oyster sanctuaries and reserves.
How should this data set be cited?	Kelly Greenhawk, MDNR, Fisheries Service
Online Links:	\\OX0057178\C$\Documents and Settings\kgreenhawk\My Documents\ArcData\Bndfile\Oysbound\mdsancres.shp
Does the data set describe conditions during a particular time period?	1997 until unknown
What is the general form of this data set?	Polygon shapefile
	Data
FID	Internal feature number
Shape	Feature geometry
RECTYPE	Type of record - SEED, SHELL or MULTI; object represents the boundaries of a seed planting activity, or deployment of shell or other material used as substrate for oysters
GROUP	Three character code for the name of the group which served as project leader for the activity; ANS = Academy of Natural Sciences; CBF = Chesapeake Bay Foundation; ORP = Oyster Recovery Partnership; DNR = Md. Department of Natural Resources; SRF = South River Federation; PRF = Potomac River Fisheries Commission; LCF = Living Classrooms Foundation; COE = Army Corps of Engineers
ORP	Oyster Recovery Partnership
CBF	Chesapeake Bay Foundation
DNR	Maryland Department of Natural Resources
COE	Army Corp of Engineers
ANS	Academy of Natural Science
LCF	Living Classroom Foundation

PRF	Potomac River Fisheries Commission
SRF	South River Federation
MRA	Magothy River Association
ACCESS	Internal DNR tracking / accession number to identify activity: characters 1-2 represent year activity took place; characters 3 through 5 represent project leader (see GROUP for more info); characters 6 through 11 represent barcode from MdOysBrs file/publication; characters12-14 represent type of material deployed (see MATERIAL fields for more info); characters 15-18 represent month and day of activity (MMDD); character 19 is used to avoid duplicate accession / tracking codes, when the same group deploys the same material more than once on the same bar on the same date. The letter "A" is used for the first planting, the letter "B" is used for the second planting, the letter "C" is used for the third planting, etc.
OTHGROUPS	Listing of other groups involved in activity
FUNDSOURCE	Funding source for activity
LOCATION	Location of activity, usually tributary name
BARNAME	Barname of oyster bar where activity took place, from form; barname will not always match barcode from MdOysbrs file since this field is reserved for information on the form
BOTTYPE	Bottom type at location; Codes are as follows: ND = no data provided; S = sand; SH = shell; M = mud; GR = gravel; ST = stone; BSH = broken shell; CL = clay
DEPTH	Depth or depth range in feet (minimum depth, followed by "-", followed by the maximum depth)
STARTDATE	Date or beginning date of deployment if a range of dates is provided on form; when material was deployed

ENDDATE	If a date range was provided, ending date of project. Field will be null if project was completed in one day or only start date was provided
SANCT	Logical field indicating whether activity took place in a sanctuary ("Y" or "N")
RESERVE	Logical field indicating whether activity took place in a reserve ("Y" or "N")
ORA	Logical field indicating whether activity took place in a designated Oyster Recovery Area
CLOSNAME	Name of sanctuary or reserve / name of closure followed by a dash, then an "S" if the closure is a sanctuary or an "R" if the closure is a reserve; "NONE" is used for projects that do not fall within a designated sanctuary or reserve, once entered into the GIS.
LOCNOTES	Notes on location of activity
MATERIAL1	Material deployed; DSH = dredged shell; FSH = fresh shell; HSE = hatchery seed; USE = seed from unknown source; MUL = multiple materials; BBO = buy back oysters; CUL = cultchless oysters; 1YC = one year old cultch; SOS = spat on shell; STO = stone; UNK = material unknown; RUB = rubble; SLG = slag; SHL = shell of unknown type; RFB = reef ball(s); SPT = spat; OG1 = oyster gardeners' 1 year old oysters; FNS = fines; OTH = other material; If code OTH is used, see field OTHER for description of material. See Value Definition Source for more information.
MATERIAL2	Material deployed if more than one material was deployed; DSH = dredged shell; FSH = fresh shell; HSE = hatchery seed; USE = seed from unknown source; MUL = multiple materials; BBO = buy back oysters; CUL = cultchless oysters; 1YC = one year old cultch; SOS = spat on shell; STO = stone; UNK = material unknown; RUB = rubble; SLG = slag; SHL = shell of unknown type; RFB = reef ball(s); SPT = spat; OG1 = oyster gardeners' 1 year old oysters; FNS = fines; OTH = other material.

MATERIAL3	Material deployed if more than two different materials were deployed; DSH = dredged shell; FSH = fresh shell; HSE = hatchery seed; USE = seed from unknown source; MUL = multiple materials; BBO = buy back oysters; CUL = cultchless oysters; 1YC = one year old cultch; SOS = spat on shell; STO = stone; UNK = material unknown; RUB = rubble; SLG = slag; SHL = shell of unknown type; RFB = reef ball(s); SPT = spat; OG1 = oyster gardeners' 1 year old oysters; FNS = fines; OTH = other material.
MATERIAL4	Material deployed, if more than 3 types of material were deployed; DSH = dredged shell; FSH = fresh shell; HSE = hatchery seed; USE = seed from unknown source; MUL = multiple materials; BBO = buy back oysters; CUL = cultchless oysters; 1YC = one year old cultch; SOS = spat on shell; STO = stone; UNK = material unknown; RUB = rubble; SLG = slag; SHL = shell of unknown type; RFB = reef ball(s); SPT = spat; OG1 = oyster gardeners' 1 year old oysters; FNS = fines; OTH = other material.
OTHER	Additional description of material in MATERIAL1
AVGSIZE	Average size of oysters, if seed was deployed, in centimeters. ND = no data provided
MATSOURCE	Material source, i.e. hatchery name or vendor
BSTUSED	Broodstock used, if applicable
TESTED	Was the material, if seed material, tested for disease ? ("Y" or "N")
DISEASE	Was disease present ? If the value of TESTED is "Y", field can be "Y", "N" or blank. A blank in this field denotes seed / oysters were tested but results of test were not indicated on form.
LAB_NAME	Name of lab performing disease diagnosis
DERMOPREV	Percent of sample testing positive for Dermo
MSXPREV	Percent of sample testing positive for MSX
CONTACT	Contact name for laboratory

CONTACTPH	Contact phone number for laboratory
OYS	Number of oysters deployed, if seed activity. Value will be a negative nine if number of oysters was not provided on form.
BU	Number of bushels of material deployed; Value will be a negative nine if number of bushels was not provided on form.
CUYDS	Number of cubic yards of material deployed; Value will be a negative nine if number of cubic yards was not provided on form.
CONFIG	Configuration of planting, if noted on form; flat, mound, etc.
ATTACH	Logical field reflecting whether an attachment describing configuration details was submitted with the form.
COMMENTS	Additional information pertaining to activity.
INCXY	Logical field. Is coordinate information provided on form incomplete ? ("Y" or "N")
NUMCOORDS	Number of corner coordinates provided on form
PRJORIGIN	Project origin; Field will contain "ND" for no data for activities where project origin was not reported on form.
PURP1	Project purpose (text field 1 of 2 due to ESRI text field limitations). Field will contain "ND" for no data for activities where project purpose was not reported on form.
PURP2	Project purpose (text field 2 of 2). Field will contain "ND" for no data for activities where project origin was not reported on form.
EXPRESULTS	Expected results. Field will contain "ND" for no data for activities where expected results were not reported on form.
DDY1	Decimal equivalent of corresponding LAT field
DDX1	Decimal equivalent of corresponding LONG field

DDY2	Decimal equivalent of corresponding LAT field
DDX2	Decimal equivalent of corresponding LONG field
DDY3	Decimal equivalent of corresponding LAT field
DDX3	Decimal equivalent of corresponding LONG field
DDY4	Decimal equivalent of corresponding LAT field
DDX4	Decimal equivalent of corresponding LONG field
DDY5	Decimal equivalent of corresponding LAT field
DDX5	Decimal equivalent of corresponding LONG field
DDY6	Decimal equivalent of corresponding LAT field
DDX6	Decimal equivalent of corresponding LONG field
OBJECTCOMM	Comments pertaining to spatial object location or shape, from database manager.
ACRES	Area of object in acres, calculated in GIS.
SQMETERS	Area of object in square meters, calculated in GIS.
LAT1	Latitude value of first corner of planted area, recorded from GPS. Values are expressed in degrees and decimal minutes.
LONG1	Longitude value of first corner of planted area, recorded from GPS. Values are expressed in degrees and decimal minutes.
LAT2	Latitude value of second corner of planted area, recorded from GPS. Values are expressed in degrees and decimal minutes.
LONG2	Longitude value of second corner of planted area, recorded from GPS. Values are expressed in degrees and decimal minutes.
LAT3	Latitude value of third corner of planted area, recorded from GPS. Values are expressed in degrees and decimal minutes.

LONG3	Longitude value of third corner of planted area, recorded from GPS. Values are expressed in degrees and decimal minutes.
LAT4	Latitude value of fourth corner of planted area, recorded from GPS. Values are expressed in degrees and decimal minutes.
LONG4	Longitude value of fourth corner of planted area, recorded from GPS. Values are expressed in degrees and decimal minutes.
LAT5	Latitude value of fifth corner of planted area, recorded from GPS. Values are expressed in degrees and decimal minutes.
LONG5	Longitude value of fifth corner of planted area, recorded from GPS. Values are expressed in degrees and decimal minutes.
LAT6	Latitude value of sixth corner of planted area, recorded from GPS. Values are expressed in degrees and decimal minutes.
LONG6	Longitude value of sixth corner of planted area, recorded from GPS. Values are expressed in degrees and decimal minutes.
PRJPREP	Description of preparations undertaken to ready site for deployment.
CENTROIDX	X value of centroid coordinate, expressed in meters. Field is calculated in GIS and used to center polygon objects for records where only one coordinate is provided.
CENTROIDY	Y value of centroid coordinate, expressed in meters. Field is calculated in GIS and used to center polygon objects for records where only one coordinate is provided.

TONS	Amount of material deployed, expressed in tons. Value will be a negative nine if number of tons was not provided on form.

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Maryland Department of Natural Resources 580 Taylor Avenue, Tawes State Office Building Annapolis, MD 21401 USA
Who also contributed to the data set?	Maryland Department of Natural Resources, Fisheries Service, Shellfish Program
To whom should users address questions about the data?	Eric Campbell Biologist 580 Taylor Avenue, Tawes State Office Building Annapolis, MD 21401 USA 410-260-8344 (voice) 410-260-8279 (FAX)
Who wrote the metadata?	Maryland Department of Natural Resources
Dates	Last modified: 29-Jun-2005
Metadata author	Maryland Department of Natural Resources, Fisheries Service, Shellfish Program Eric Campbell Biologist 580 Taylor Avenue, Tawes State Office Building Annapolis, MD 21401 USA 410-260-8344 (voice) 410-260-8279 (FAX) kgreenhawk@dnr.state.md.us
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-17. Meta-Data for "MD_lease_bars_utm"

Title	**MD_lease_bars_utm**
Abstract	"The Natural Oyster Bar/lease lines shown are for oyster management purposes only. For the official boundary(ies) consult the current official Natural Oyster Bar Chart." The oyster bars/leases in this product are part of the conversion of the present mylar based Natural Oyster Bar Charts to digital format. They are based on bars that were delineated by the Bay Bottom Survey from 1975-1985, and amendments, Potomac River Oyster Survey of 1928, and amendments, and the Potomac River Bottom Survey of 1994, and amendments. They may differ from the bars shown on the current official mylar based Natural Oyster Bar Charts. Leases are based on the conversion of the coordinates from the original lease documents. They are based on surveys dating from 1912 to the present. Coordinates based on early surveys were converted by NADCON to NAD 83-91 values. Surveys performed after 1995 were done by GPS in the same coordinates. It is the responsibility of the licensee to verify that this data is current. This office does not automatically notify licensees of changes/updates to this data. Some leases have corner points that fall on the shoreline. In these instances this file may exhibit lines that cross the shoreline, or that connect from point to point over the water. In these cases the true extent of the lease should be verified from the lease document. Any requests for all or part of this data must be referred to this office. The data is copyrighted by the State of Maryland, Department of Natural Resources. The data is available only in DXF format, with coordinates in NAD 1983 (1991 adjustment) Maryland Zone 1900 State Plane coordinate Meters.

	The dataset was provided by Louis Wright (MDNR, Natural Resources Police) as a CAD line file. It was converted to a polyline shapefile and then to a polygon shapefile using tools in ArcGIS.
How should this data set be cited?	Maryland Department of Natural Resources,
Online Links:	
Does the data set describe conditions during a particular time period?	11/24/04
What is the general form of this data set?	Polygon shapefile

Data

FID	Internal Feature Number
Shape	Feature Geometry
OBJECTID	Internal feature number.
CODE	Concatenation of three values from associated dbf file, composed of 2 letter county code, followed by a three digit lease number, followed by a dash, then followed by the lease area in acres (acreages in this field are from the lease agreement, and may differ from acreage calculated in a GIS
CALCDACRES	Lease area expressed in acres, calculated in MapInfo
BOUNDLEN	Combined length of all sides, expressed in meters.
CENTX	X value of center of lease, expressed in meters.
CENTY	Y value of center of lease, expressed in meters.
ID	Internal id number.
LONGITUDE	Longitude value of polygon's centerpoint, expressed in decimal degrees, WG84
LATITUTE	Latitude value of polygon's centerpoint, expressed in decimal degrees, WG84
VERIFIED	Logical field, indicating whether lease object was found on corresponding paper chart and visually verified
EDITS	Type of edit operation applied to polygon object; "S" denotes object was edited by snapping nodes to the adjacent shoreline; "M" denotes miscellaneous modifications were applied to the polygon; "C" denotes object / polygon was created manually through visual inspection of the lease object on the chart.
X	Unknown

Y	Unknown
NOAA	Unknown
OPE_basin	Unknown
Shape_Leng	Unknown
Shape_Area	Area of feature in internal units squared.

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Louis Wright Maryland Department of Natural Resources Natural Resources Police Matapeake, Maryland 21654 USA
Who also contributed to the data set?	
To whom should users address questions about the data?	Maryland Department of Natural Resources, Natural Resources Police Matapeake, Maryland 21654 USA
Who wrote the metadata?	Maryland Department of Natural Resources
Dates	January 2005
	Maryland Department of Natural Resources
	Louis Wright
	Versar, Inc. 410-964-9200
Metadata author	
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-18. Meta-Data for "Privateleases"

Title	**Privateleases**
Abstract	This polygon coverage delineates general survey boundaries of private oyster ground leases in Virginia. The coverage was generated from data provided by the Virginia Marine Resources Commission; the state agency responsible for regulating private oyster ground leases in Virginia. Data was originally received in AutoCad. Considerable manipulation was required to make the conversion. While private lease boundaries are legally defined, this coverage does not meet legal survey standards.
How should this data set be cited?	Comprehensive Coastal Inventory, Virginia Institute of Marine Science and Virginia Marine Resources Commission, 2002.
Online Links:	
Does the data set describe conditions during a particular time period?	2002
What is the general form of this data set?	Arc Info File

Data

PRILEASE83.PAT

Column	Item Name	Width	Output Type	N.Dec	Alternate Type
1	AREA	4	12	F	3
5	PERIMETER	4	12	F	4
9	PRILEASE83#	4	5	B	-
13	PRILEASE83-ID	4	5	B	-
17	LEASE	8	8	C	-

PRILEASE83.AAT

Column	Item Name	Width	Output Type	N.Dec	Alternate Type
1	FNODE#	4	5	B	-
5	TNODE#	4	5	B	-
9	LPOLY#	4	5	B	-
13	RPOLY#	4	5	B	-
17	LENGTH	4	12	F	3
21	PRILEASE83#	4	5	B	-
25	PRILEASE83-ID	4	5	B	-
29	ENTITY	14	14	C	-

43	HANDLE	16	16	C	-
59	LAYER	32	32	C	-
91	ELEVATION	8	19	F	5
99	THICKNESS	8	19	F	5
107	COLOR	4	6	B	-
111	LINETYPE	32	32	C	-
143	LINEWIDTH	8	19	F	5
151	STYLE	32	32	C	-
183	TEXT	254	254	C	-

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Virginia Institute of Marine Science (VIMS) P.O. Box 1346 Gloucester Point, VA 23062 USA
Who also contributed to the data set?	Maryland Department of Natural Resources
To whom should users address questions about the data?	Marcia Berman Director Comprehensive Coastal Inventory Program Virginia Institute of Marine Science (VIMS), P.O. Box 1346 Gloucester Point, VA 23062 USA 804-684-7188 (voice) 804-684-7179 (FAX)
Who wrote the metadata?	Virginia Institute of Marine Science (VIMS)
Dates	Last modified: 03-Nov-2004
Metadata author	Virginia Institute of Marine Science (VIMS) Tamia Rudnicky GIS Programmer/Analyst Virginia Institute of Marine Science (VIMS), P.O. Box 1346 Gloucester Point, VA 23062 USA 804-684-7181 (voice) 804-684-7179 (FAX) tamia@vims.edu
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-19. Meta-Data for "Bathy"

Title	**Bathy**
Abstract	This dataset contains bathymetric one meter low water contours for the mainstem Chesapeake Bay. The contours were generated by ArcInfo using surveys from the National Oceanic and Atmospheric Administration (NOAA) Hydrographic Survey Data CD-ROM. The one meter low water contours were generated by interpolating the Hydrographic surveys (~3.5 million soundings) and generating contours.
How should this data set be cited?	Chesapeake Bay Program
Online Links:	http://www.ngdc.noaa.gov/ngdc.html
Does the data set describe conditions during a particular time period?	
What is the general form of this data set?	Raster

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	NOAA National Geophysical Data Center 325 Broadway Boulder, CO 80305 USA
Who also contributed to the data set?	Chesapeake Bay Program
To whom should users address questions about the data?	410 Severn Avenue, Suite 109 Annapolis, MD 21403 USA 800-YOUR-BAY (voice) 410-267-5777 (FAX)
Who wrote the metadata?	Chesapeake Bay Program
Metadata author	Chesapeake Bay Program 410 Severn Avenue, Suite 109 Annapolis, MD 21403 USA 800-YOUR-BAY (voice) 410-267-5777 (FAX)
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-20. Meta-Data for "historic_spat_set2_utm"

Title	**historic_spat_set2_utm**
Abstract	This data set depicts historic oyster spat set in the Maryland portion of the Chesapeake Bay from 1939 through 2008. These data are collected annually by the Maryland Department of Natural Resources (MDDNR) during the annual fall oyster dredge survey.
How should this data set be cited?	Maryland Department of Natural Resources, Fisheries Service, Sarbanes Cooperative Oxford Laboratory, Oxford, MD.
Online Links:	http://dnrweb.dnr.state.md.us/gis/data/index.html
Does the data set describe conditions during a particular time period?	1939-2008
What is the general form of this data set?	Point shapefile
	Data
OBJECTID	Internal feature number
Shape	Feature geometry
ID	
CultchID	Unique identifying number for cultch areas described by Greenhawk 2005.
Long_	centroid of longitude for oyster bar where sampling occurred expressed in decimal degrees
Lat	centroid of latitude for oyster bar where sampling occurred expressed in decimal degrees
Region	Region where sampled oyster bar occurs
BarCode	Yates bar code
BarName	Yates bar name
Alt_Bar	Alternate bar name
Yr1939	Spat set sampled in 1939
Yr1940	Spat set sampled in 1940
Yr1941	Spat set sampled in 1941
Yr1942	Spat set sampled in 1942
Yr1943	Spat set sampled in 1943
Yr1944	Spat set sampled in 1944
Yr1945	Spat set sampled in 1945
Yr1946	Spat set sampled in 1946
Yr1947	Spat set sampled in 1947
Yr1948	Spat set sampled in 1948

Yr1949	Spat set sampled in 1949
Yr1950	Spat set sampled in 1950
Yr1951	Spat set sampled in 1951
Yr1952	Spat set sampled in 1952
Yr1953	Spat set sampled in 1953
Yr1954	Spat set sampled in 1954
Yr1955	Spat set sampled in 1955
Yr1956	Spat set sampled in 1956
Yr1957	Spat set sampled in 1957
Yr1958	Spat set sampled in 1958
Yr1959	Spat set sampled in 1959
Yr1960	Spat set sampled in 1960
Yr1961	Spat set sampled in 1961
Yr1962	Spat set sampled in 1962
Yr1963	Spat set sampled in 1963
Yr1964	Spat set sampled in 1964
Yr1965	Spat set sampled in 1965
Yr1966	Spat set sampled in 1966
Yr1967	Spat set sampled in 1967
Yr1968	Spat set sampled in 1968
Yr1969	Spat set sampled in 1969
Yr1970	Spat set sampled in 1970
Yr1971	Spat set sampled in 1971
Yr1972	Spat set sampled in 1972
Yr1973	Spat set sampled in 1973
Yr1974	Spat set sampled in 1974
Yr1975	Spat set sampled in 1975
Yr1976	Spat set sampled in 1976
Yr1977	Spat set sampled in 1977
Yr1978	Spat set sampled in 1978
Yr1979	Spat set sampled in 1979
Yr1980	Spat set sampled in 1980
Yr1981	Spat set sampled in 1981
Yr1982	Spat set sampled in 1982
Yr1983	Spat set sampled in 1983
Yr1984	Spat set sampled in 1984
Yr1985	Spat set sampled in 1985
Yr1986	Spat set sampled in 1986
Yr1987	Spat set sampled in 1987
Yr1988	Spat set sampled in 1988
Yr1989	Spat set sampled in 1989

Yr1990	Spat set sampled in 1990
Yr1991	Spat set sampled in 1991
Yr1992	Spat set sampled in 1992
Yr1993	Spat set sampled in 1993
Yr1994	Spat set sampled in 1994
Yr1995	Spat set sampled in 1995
Yr1996	Spat set sampled in 1996
Yr1997	Spat set sampled in 1997
Yr1998	Spat set sampled in 1998
Yr1999	Spat set sampled in 1999
Yr2000	Spat set sampled in 2000
Yr2001	Spat set sampled in 2001
Yr2002	Spat set sampled in 2002
Yr2003	Spat set sampled in 2003
Yr2004	Spat set sampled in 2004
Yr2005	Spat set sampled in 2005
Yr2006	Spat set sampled in 2006
Yr2007	Spat set sampled in 2007
Yr2008	Spat set sampled in 2008

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Maryland Department of Natural Resources 580 Taylor Avenue, Tawes State Office Building Annapolis, MD 21401 USA
Who also contributed to the data set?	Maryland Department of Natural Resources
To whom should users address questions about the data?	Kelly Greenhawk DP Programmer / Analyst Sarbanes Cooperative Oxford Laboratory, 904 South Morris Street Oxford, MD 21654 USA 410-226-0078 (voice) 410-226-0120 (FAX)
Who wrote the metadata?	Versar, Inc., Columbia, MD 21045
Dates	Last Modified: March 27, 2009
Metadata author	Versar, Inc. 9200 Rumsey Road

	Columbia, MD 21045 Phone: 410-964-9200 Fax:410-964-5156
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-21. Meta-Data for "SAV2007"

Title	**SAV2007**
Abstract	The 2007 Chesapeake Bay SAV Coverage was mapped from 1:24,000 black and white aerial photography to access water quality in the Bay. Each area of SAV was interpreted from the rectified photography and classified into one of four density classes by the percentage of cover. The SAV beds were entered into an ArcInfo GIS coverage using the quality control procedures documented below.
How should this data set be cited?	Virginia Institute of Marine Science, 2008
Online Links:	http://web.vims.edu/bio/sav/gis_data.html
Does the data set describe conditions during a particular time period?	May 23, 2007 to October 21, 2007
What is the general form of this data set?	Polygon shapefile
Data	
SAV bed	A GT-polygon representing a portion of an SAV bed or an area completely surrounded by SAV that does not contain SAV.
Area	Area of the GT-polygon
Perimeter	Perimeter of the GT-polygon
Beds07#	Internal GT-polygon number
Beds07-id	User GT-polygon number
BedID	Two-letter SAV bed identifier
Density	SAV bed density classification. A ZERO VALUE IN THIS FIELD SIGNIFIES A LAND AREA OR ANY OTHER NON-SAV AREA THAT IS COMPLETELY SURROUNDED BY SAV. THESE POLYGONS SHOULD BE EXCLUDED FROM SAV AREA COMPUTATIONS. Values range from 0-4. 0= No SAV; 1= 0-10% cover (very sparse); 2= 10-40% cover (sparse); 3= 40-70% cover (moderate); 4= 70-100% cover (dense).
QuadID	Identification number of USGS quads that contains the SAV bed. Values range from 1-235.

1= Conowingo Dam, MD.-PA; 2= Aberdeen, MD; 3= Havre de Grace, MD; 4= North East, MD; 5= Elkton, MD-DE; 6= White Marsh, MD; 7= Edgewood, MD; 8= Perryman, MD; 9= Spesutie, MD; 10= Earleville, MD; 11= Cecilton, MD; 12= Baltimore East, MD; 13= Middle River, MD; 14= Gunpowder Neck, MD; 15= Hanesville, MD; 16= Betterton, MD; 17= Galena, MD; 18= Curtis Bay, MD; 19= Sparrows Point, MD; 20= Swan Point, MD; 21= Rock Hall, MD; 22= Chestertown, MD; 23= Round Bay, MD; 24= Gibson Island, MD; 25= Love Point, MD; 26= Langford Creek, MD; 27= Centreville, MD; 28= Washington West, MD-DC-VA; 29= Washington East, DC-MD; 30= South River, MD; 31= Annapolis, MD; 32= Kent Island, MD; 33= Queenstown, MD; 34= Alexandria, VA-DC-MD; 35= Deale, MD; 36= Claiborne, MD; 37= St. Michaels, MD; 38= Easton, MD; 39= Fort Belvoir, VA-MD; 40= Mt. Vernon, VA-MD; 41= Lower Marlboro, MD; 42= North Beach, MD; 43= Tilghman, MD; 44= Oxford, MD; 45= Trappe, MD; 46= Preston, MD; 47= Quantico, VA-MD; 48= Indian Head, MD- VA; 49= Benedict, MD; 50= Prince Frederick, MD; 51= Hudson, MD; 52= Church Creek, MD; 53= Cambridge, MD; 54= East New Market, MD; 55= Widewater, VA-MD; 56= Nanjemoy, MD; 57= Mathias Point, MD-VA; 58= Popes Creek, MD; 59= Mechanicsville, MD; 60= Broomes Island, MD; 61= Cove Point, MD; 62= Taylors Island, MD; 63= Golden Hill, MD; 64= Passapatanzy, MD-VA; 65= King George, VA-MD; 66= Dahlgren, VA-MD; 67= Colonial Beach North, VA-MD; 68= Rock Point, MD; 69= Leonardtown, MD; 70= Hollywood, MD; 71= Solomons Island, MD; 72= Barren Island, MD; 73= Honga, MD; 74= Wingate, MD; 75= Nanticoke, MD; 76= Colonial Beach South, VA-MD; 77= Stratford Hall, VA-MD; 78= St. Clements Island, VA-MD; 79= Piney Point, MD-VA; 80= St. Mary's City, MD; 81= Point No Point, MD; 82= Richland Point, MD; 83= Bloodsworth Island, MD; 84= Deal Island, MD; 85= Monie, MD; 86= Champlain, VA;

87= Machodoc, VA; 88= Kinsale, VA-MD; 89= St. George Island, MD-VA; 90= Point Lookout, MD; 91= Kedges Straits, MD; 92= Terrapin Sand Point, MD; 93= Marion, MD; 94= Mount Landing, VA; 95= Tappahannock, VA; 96= Lottsburg, VA; 97= Heathsville, VA-MD; 98= Burgess, VA-MD; 99= Ewell, MD-VA; 100= Great Fox Island, MD-VA; 101= Crisfield, MD-VA; 102= Saxis, VA-MD; 103= Dunnsville, VA; 104= Morattico, VA; 105= Lively, VA; 106= Reedville, VA; 107= Tangier Island, VA; 108= Chesconessex, VA; 109= Parksley, VA; 110= Urbanna, VA; 111= Irvington, VA; 112= Fleets Bay, VA; 113= Nandua Creek, VA; 114= Pungoteague, VA; 115= West Point, VA; 116= Saluda, VA; 117= Wilton, VA; 118= Deltaville, VA; 119= Jamesville, VA; 120= Toano, VA; 121= Gressitt, VA; 122= Ware Neck, VA; 123= Mathews, VA; 124= Franktown, VA; 125= Westover, VA; 126= Charles City, VA; 127= Brandon, VA; 128= Norge, VA; 129= Williamsburg, VA; 130= Clay Bank, VA; 131= Achilles, VA; 132= New Point Comfort, VA; 133= Cape Charles, VA; 134= Cheriton, VA; 135= Savedge, VA; 136= Claremont, VA; 137= Surry, VA; 138= Hog Island, VA; 139= Yorktown, VA; 140= Poquoson West, VA; 141= Poquoson East, VA; 142= Elliotts Creek, VA; 143= Townsend, VA; 144= Bacons Castle, VA; 145= Mulberry Island, VA; 146= Newport News North, VA; 147= Hampton, VA; 148= Benns Church, VA; 149= Newport News South, VA; 150= Norfolk North, VA; 151= Little Creek, VA; 152= Cape Henry, VA; 153= Chuckatuck, VA; 154= Bowers Hill, VA; 155= Norfolk South, VA; 156= Kempsville, VA; 157= Princess Anne, VA; 158= Wye Mills, MD; 159= Bristol, MD; 160= Fowling Creek, MD; 161= Port Tobacco, MD; 162= Charlotte Hall, MD; 163= Mardela Springs, MD; 164= Wetipquin, MD; 165= Selbyville, MD; 166= Assawoman Bay, MD; 167= Berlin, MD; 168= Ocean City, MD; 169= Public Landing, MD; 170= Tingles Island, Md; 171= Girdle Tree, MD-VA; 172= Boxiron, MD-VA; 173=

	Whittington Point, MD-VA; 174= Chincoteague West, VA; 175= Chincoteague East, VA; 176= Anacostia, DC-MD; 177= East of New Point, VA; 178= Bethel Beach, VA; 179= Goose Island, VA; 180= Horseshoe Point, MD; 181= Bowie, MD; 182= Smith Point, VA-MD; 183= East of Reedville, VA; 184= Cobb Island, VA; 185= Suffolk, VA; 186= Fisherman's Island, VA; 187= Exmore, VA; 188= Kingston, MD; 189= Eden, MD; 190= Rhodesdale, MD; 191= Sharptown, MD; 192= Hobbs, MD; 193= Church Hill, MD; 194= Lancaster, VA; 195= Gloucester, VA; 196= Princess Anne, MD; 197= Haynesville, VA; 198= Hallwood, VA-MD; 199= Millington, MD; 200= Rollins Fork, VA; 201= Loretto, VA; 202= Pocomoke City, MD-VA; 203= Diputanta North, VA; 204= Hopewell, VA; 205= Chester, VA; 206= Drewrys Bluff, VA; 207= Dutch Gap, VA; 208= Roxbury, VA; 209= Providence Forge, VA; 210= Walkers, VA; 211= Richmond, VA; 212= Ship Shoal Inlet, VA; 213= Great Machipongo Inlet, VA; 214= Nassawadox, VA; 215= Quinbly Inlet, VA; 216= Wachapreague, VA; 217= Accomax, VA; 218= Metompkin Inlet, VA; 219= Bloxom, VA; 220= Wallops Island, VA; 221= Deep Creek, VA; 222= Fentress, VA; 223= Pleasant Ridge, VA; 224= Creeds, VA; 225= King William, VA; 226= King & Queen Courthouse, VA; 227= Truhart, VA; 228= Tunstall, VA; 229= New Kent, VA; 230= Manquin, VA; 231= Port Royal, VA; 232= Wachapreague East, VA; 233= Aylett, VA; 234= Snow Hill, MD; 235= Montross, VA.
CBPSEG	Chesapeake Bay Program segment which contains the SAV bed
STATE	U.S. State which contains the SAV bed (currently blank)
Zone	Bay zone which contains the the SAV bed
Surveyed	Indicates whether the polygon was covered by the annual survey.

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Virginia Institute of Marine Science Virginia Institute of Marine Science Gloucester Point, Virginia 23062 USA

Who also contributed to the data set?	Maryland Department of Natural Resources
To whom should users address questions about the data?	SAV Data Administrator Virginia Institute of Marine Science Gloucester Point, Virginia 23062 USA 804-684-7088 (voice)
Who wrote the metadata?	Virginia Institute of Marine Science
Dates	Last modified: 21-Oct-2007
Metadata author	Virginia Institute of Marine Science SAV Data Administrator Virginia Institute of Marine Science Gloucester Point, Virginia 23062 USA 804-684-7088 (voice) savadmin@vims.edu
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-22. Meta-Data for "pots_phase1_utm"

Title	**pots_phase1_utm**
Abstract	Unknown
How should this data set be cited?	Unknown
Online Links:	
Does the data set describe conditions during a particular time period?	Unknown
What is the general form of this data set?	Polygon shapefile
Data	
FID	Internal feature number
SHAPE	Feature geometry
PERIMETER	Unknown
POTS_PHA_1	Unknown
BOTCON_	Unknown
BOTSAL_	Unknown
BOTSAL_ID	Unknown
BOTSEED_	Unknown
BOTSEED_ID	Unknown
BOTTYPE1_I	Unknown
BOTTYPE	Unknown
BOTTOM	Unknown
SEEDC_	Unknown
SEEDC_ID	Unknown
SALINITY83	Unknown
SALINITY84	Unknown
SHORECN07	Unknown
SHORECN071	Unknown
SHOREISLCN	Unknown
SHOREISL_1	Unknown
SALINITY	Unknown
CONDEMNED8	Unknown
CONDEMNED9	Unknown
CONDEMNED	Unknown
NEWBAYLOR_	Unknown
NEWBAYLOR1	Unknown

BAYLOR	Unknown
GOOD	Unknown

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Unknown
Who also contributed to the data set?	Unknown
To whom should users address questions about the data?	Virginia Institute of Marine Science, Gloucester Point, VA
Who wrote the metadata?	Unknown
Dates	Unknown
	Unknown
Metadata author	
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-23. Meta-Data for "Baylor83_utm"

Title	**Baylor83_utm**
Abstract	Unknown
How should this data set be cited?	Unknown
Online Links:	
Does the data set describe conditions during a particular time period?	Unknown
What is the general form of this data set?	Polygon shapefile

Data

FID	Unknown
SHAPE	Unknown
AREA	Unknown
PERIMETER	Unknown
BAYLOR83_	Unknown
BAYLOR83_1	Unknown
LEGCODE	Unknown

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Unknown
Who also contributed to the data set?	Unknown
To whom should users address questions about the data?	Virginia Institute of Marine Science, Gloucester Point, VA
Who wrote the metadata?	Unknown
Dates	
Metadata author	Unknown
	Unknown

Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-24. Meta-Data for "botall83"

Title	**botall83**
Abstract	Unknown
How should this data set be cited?	Unknown
Online Links:	
Does the data set describe conditions during a particular time period?	Unknown
What is the general form of this data set?	Polygon shapefile
Data	
FID	Internal feature number
SHAPE	Feature geometry
AREA	Unknown
PERIMETER	Unknown
BOTALL83_	Unknown
BOTALL83_1	Unknown
BOTTOM	Unknown
Who produced the data set?	
Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Unknown
Who also contributed to the data set?	Unknown
To whom should users address questions about the data?	Sharon Killeen Virginia Institute of Marine Science P.O.Box 1346 Gloucester Point, Virginia 23062, USA 804-684-7534 (voice) 804-684-7179 (fax) sharon@vims.edu
Who wrote the metadata?	Unknown
Dates	Unknown
	Unknown

Metadata author	
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

Attachment 2-B: Compiled Data: Salinity, Dissolved Oxygen, and Phytoplankton

By Versar

CHESAPEAKE BAY NATIVE OYSTER RESTORATION MASTER PLAN

SUMMARY OF SALINITY, DISSOLVED OXYGEN, & PHYTOPLANKTON DATA LAYERS

PREPARED FOR:

U.S. Army Cops of Engineers
10 South Howard St.
Baltimore, MD 21201

PREPARED BY:

Methratta, E. T., Slacum, Jr., H. W., Dew-Baxter, J.
Versar, Inc.
Ecological Sciences & Applications Division
Applied Ecosystem Assessment Group
9200 Rumsey Road
Columbia, MD 21045

OVERVIEW

A total of 24 GIS rasters were generated to depict the two most important water quality parameters identified by the USACE Native Oyster Restoration Master Plan (NORMP) team for the American oyster *Crassostrea virginica*: salinity and dissolved oxygen (DO). For dissolved oxygen, separate surface and bottom rasters were generated to depict the mean for the summer season (June-August) during 2 recent wet (2003-2004), dry (2001-2002), and average rainfall years (2005-2006). Rasters for three measures of variability, the standard error, the 25th percentile, and the 75th percentile were created for both surface and bottom DO by combining data from all rainfall year types. For salinity, separate surface and bottom rasters were generated to depict the mean for the growing season (April-October) during each of 2 recent wet (2003-2004), dry (2001-2002), and average rainfall years (2005-2006). Rasters for three measures of variability, the standard error, the 25th percentile, and the 75th percentile were created for both surface and bottom salinity by combining data from all rainfall year types.

Point data were gathered from the Maryland Department of Natural Resources, the Maryland Department of the Environment, Alliance for Chesapeake Bay, Virginia Department of Health/Division of Shellfish Sanitation, and the Chesapeake Bay Program The relevant bottom depth for the salinity and DO bottom layers was considered to be ≤7m. Data from fixed stations whose depth was ≤7m and vertical profile samples that sampled within the 7m depth contour were included in the interpolations. For surface layers, all data identified as surface data by the data sources were included in the interpolations. Interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used and interpolations were made using up to 10 of the nearest points. The output grid cell size is 1 km X 1 km. Areas of the Bay with bottom depths ≤7m were clipped out of the interpolated raster in order to obtain rasters that include only the areas relevant for oyster restoration. All rasters are projected with NAD 1983 UTM Zone 18.

In addition to the salinity and DO rasters, a point shapefile was created that contains data for the distribution and abundance of phytoplankton in Chesapeake Bay. These data were obtained from the Chesapeake Bay Program data hub and from the Maryland Department of Natural Resources and projected as a point shapefile using NAD 1983 UTM Zone 18. Together, these data sources span the years of 1980 to 2009. These data are also stored in a searchable Access database that contains two tables. One table contains the names and geographic locations of the sampling stations ("phytoplankton stations") and the second table contains the data for each of the stations ("phytoplankton data"). Data for individual stations can be queried out of the phytoplankton data table using the station name from the phytoplankton station table.

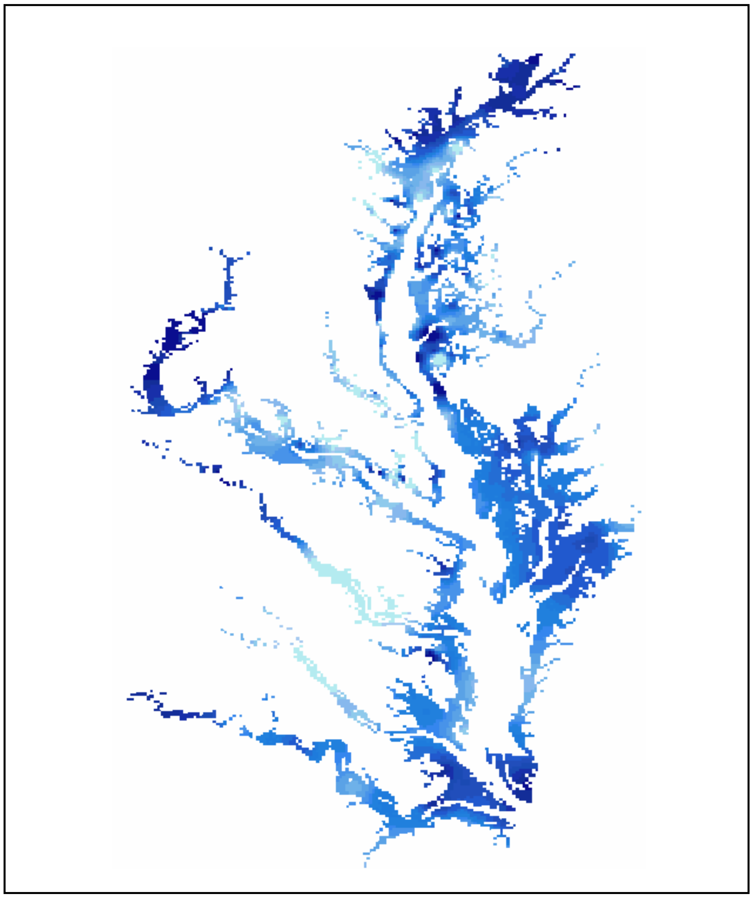
In the following summary report, the file name, a brief summary, and a thumbnail photo are provided for each water quality raster and for the phytoplankton shapefile. Appendix A provides complete metadata for all rasters. Appendix B contains tables that indicate the sources of data and the sample sizes upon which each of the interpolations is based. Accompanying this summary report is a geodatabase containing all GIS files and tables and an Access database containing the phytoplankton data.

SUMMARY TABLE

Files	GIS Format
1. Mean Bottom Dissolved Oxygen, Summer, Wet Year	Raster
2. Mean Bottom Dissolved Oxygen, Summer, Dry Year	Raster
3. Mean Bottom Dissolved Oxygen, Summer, Average Rainfall Year	Raster
4. Mean Surface Dissolved Oxygen, Summer, Wet Year	Raster
5. Mean Surface Dissolved Oxygen, Summer, Dry Year	Raster
6. Mean Surface Dissolved Oxygen, Summer, Average Rainfall Year	Raster
7. Mean Bottom Salinity, Growing Season, Wet Year	Raster
8. Mean Bottom Salinity, Growing Season, Dry Year	Raster
9. Mean Bottom Salinity, Growing Season, Average Rainfall Year	Raster
10. Mean Surface Salinity, Growing Season, Wet Year	Raster
11. Mean Surface Salinity, Growing Season, Dry Year	Raster
12. Mean Surface Salinity, Growing Season, Average Rainfall Year	Raster
13. Standard Error, Bottom Dissolved Oxygen, Summer, All Rainfall Years	Raster
14. 5th Percentile, Bottom Dissolved Oxygen, Summer, All Rainfall Years	Raster
15. 75th Percentile, Bottom Dissolved Oxygen, Summer, All Rainfall Years	Raster
16. Standard Error, Surface Dissolved Oxygen, Summer, All Rainfall Years	Raster
17. 25th Percentile, Surface Dissolved Oxygen, Summer, All Rainfall Years	Raster
18. 75th Percentile, Surface Dissolved Oxygen, Summer, All Rainfall Years	Raster
19. Standard Error, Bottom Salinity, Growing Season, All Rainfall Years	Raster
20. 25th Percentile, Bottom Salinity, Growing Season, All Rainfall Years	Raster
21. 75th Percentile, Bottom Salinity, Growing Season, All Rainfall Years	Raster
22. Standard Error, Surface Salinity, Growing Season, All Rainfall Years	Raster
23. 25th Percentile, Surface Salinity, Growing Season, All Rainfall Years	Raster
24. 75th Percentile, Surface Salinity, Growing Season, All Rainfall Years	Raster
25. Phytoplankton Abundance and Distribution	Point Shapefile, Access Database
Appendices	
Appendix A: Metadata summary	
Appendix B: Data sources and sample sizes	

Mean Bottom Dissolved Oxygen, Summer, Wet Year

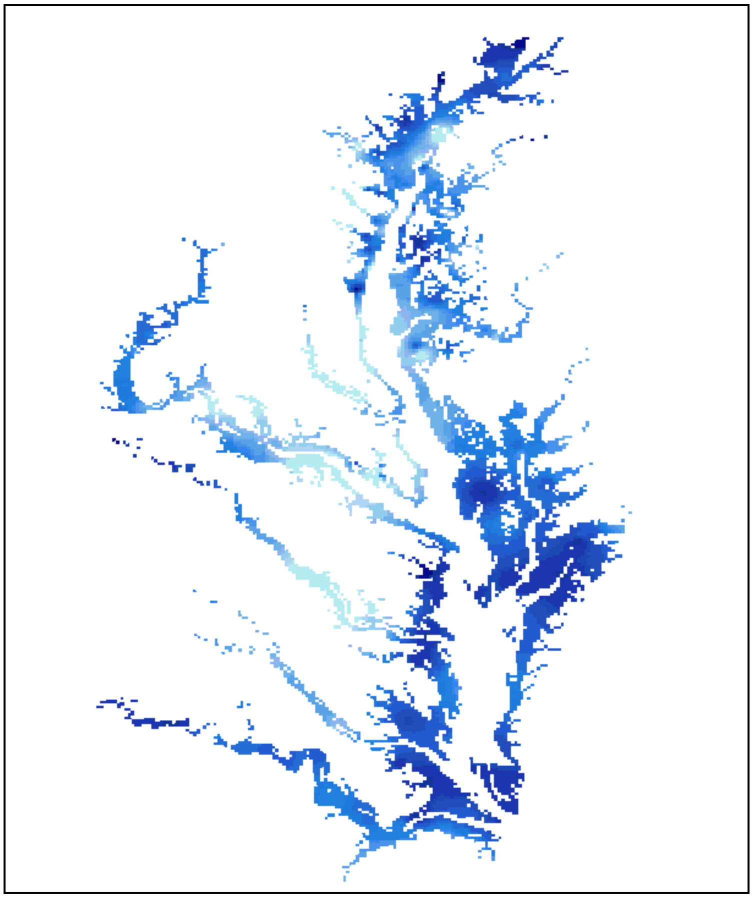
1. File Name: bdo_su_wet_mean
Metadata Summary: Appendix A-1



This raster depicts mean bottom dissolved oxygen for the summer (June-August) of two recent wet years (2003-2004) at bottom depths ≤7m in Chesapeake Bay. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of the Environment, and Chesapeake Bay Program. Fixed stations whose bottom depth was ≤7m and vertical profile stations that collected data within the 7m depth contour were included. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.

Mean Bottom Dissolved Oxygen, Summer, Dry Year

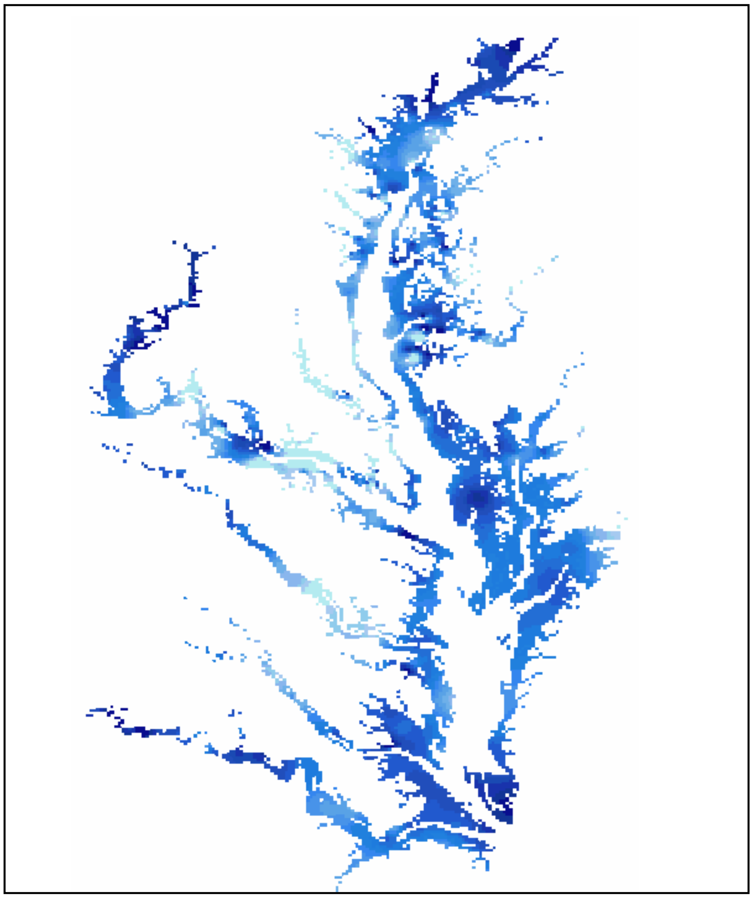
2. File Name: bdo_su_dry_mean
Metadata Summary: Appendix A-2



This raster depicts mean bottom dissolved oxygen for the summer (June-August) of two recent dry years (2001-2002) at bottom depths ≤7m in Chesapeake Bay. This raster was generated using data from Maryland Department of the Environment and Chesapeake Bay Program. Fixed stations whose bottom depth was ≤7m and vertical profile stations that collected data within the 7m depth contour were included. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation.A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.

Mean Bottom Dissolved Oxygen, Summer, Average Rainfall Year

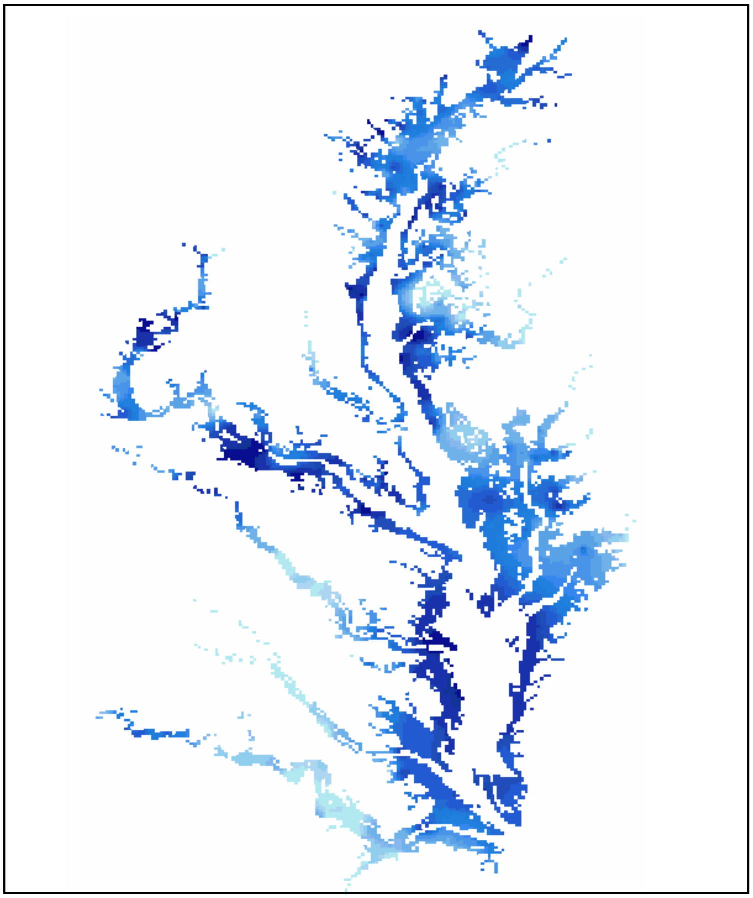
3. File Name: bdo_su_ave_mean
Metadata Summary: Appendix A-3



This raster depicts mean bottom dissolved oxygen for the summer (June-August) of two recent average rainfall years (2005-2006) at bottom depths ≤7m in Chesapeake Bay. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of the Environment, and Chesapeake Bay Program. Fixed stations whose bottom depth was ≤7m and vertical profile stations that collected data within the 7m depth contour were included. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.

Mean Surface Dissolved Oxygen, Summer, Wet Year

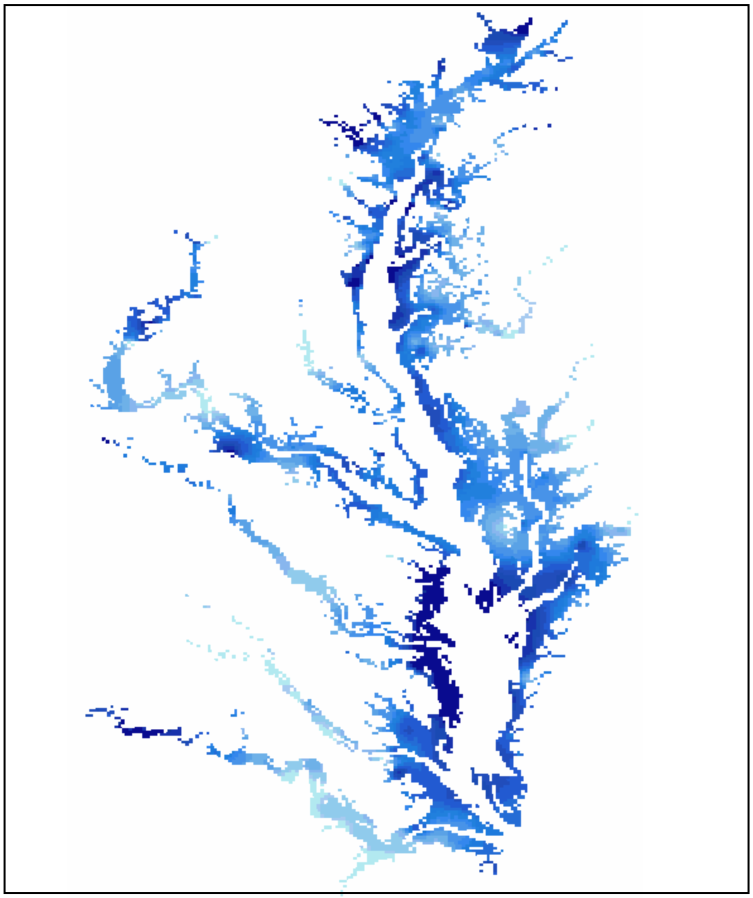
4. File Name: sdo_su_wet_mean
Metadata Summary: Appendix A-4



This raster depicts mean surface dissolved oxygen for the summer (June-August) of two recent wet years (2003-2004) in Chesapeake Bay. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of the Environment, Alliance for the Chesapeake Bay, and Chesapeake Bay Program. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.

Mean Surface Dissolved Oxygen, Summer, Dry Year

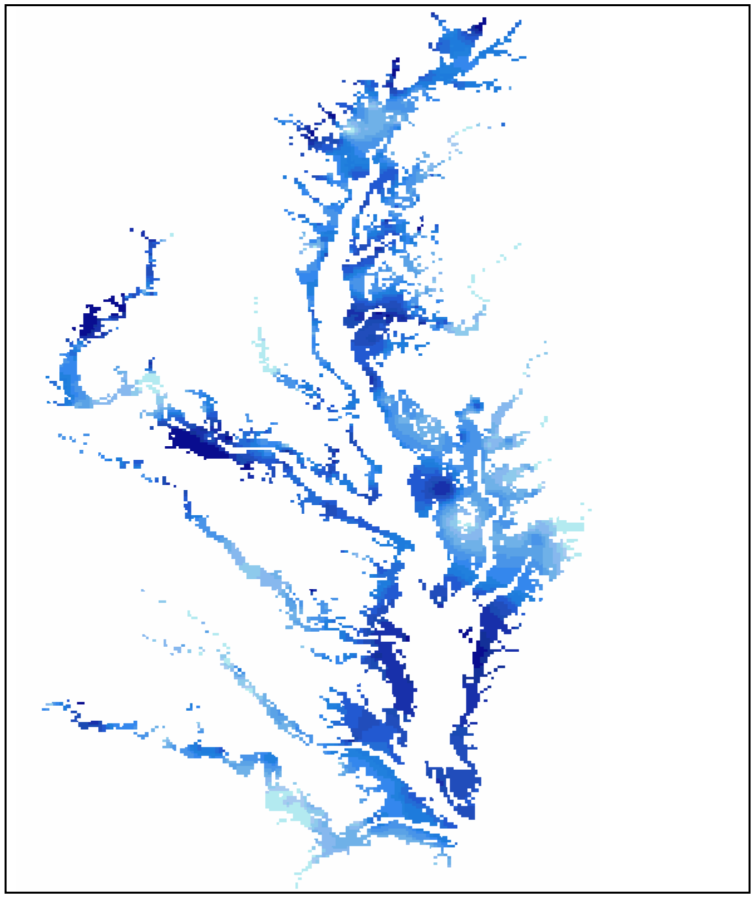
5. File Name: sdo_su_dry_mean
Metadata Summary: Appendix A-5



This raster depicts mean surface dissolved oxygen for the summer of (June-August) of two recent dry years (2001-2002) in Chesapeake Bay. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of the Environment, Alliance for the Chesapeake Bay, and Chesapeake Bay Program. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation.A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.

Mean Surface Dissolved Oxygen, Summer, Average Rainfall Year

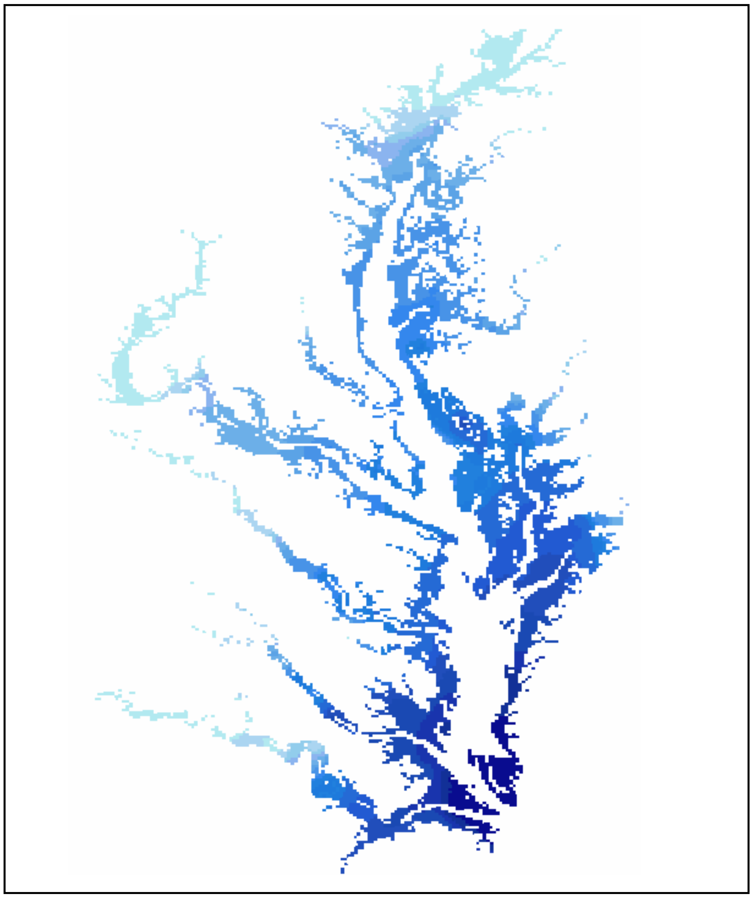
6. File Name: sdo_su_ave_mean
Metadata Summary: Appendix A-6



This raster depicts mean surface dissolved oxygen for the summer (June-August) of two recent average years (2005-2006) in Chesapeake Bay. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of the Environment, Alliance for the Chesapeake Bay, and Chesapeake Bay Program. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.

Mean Bottom Salinity, Growing Season, Wet Year

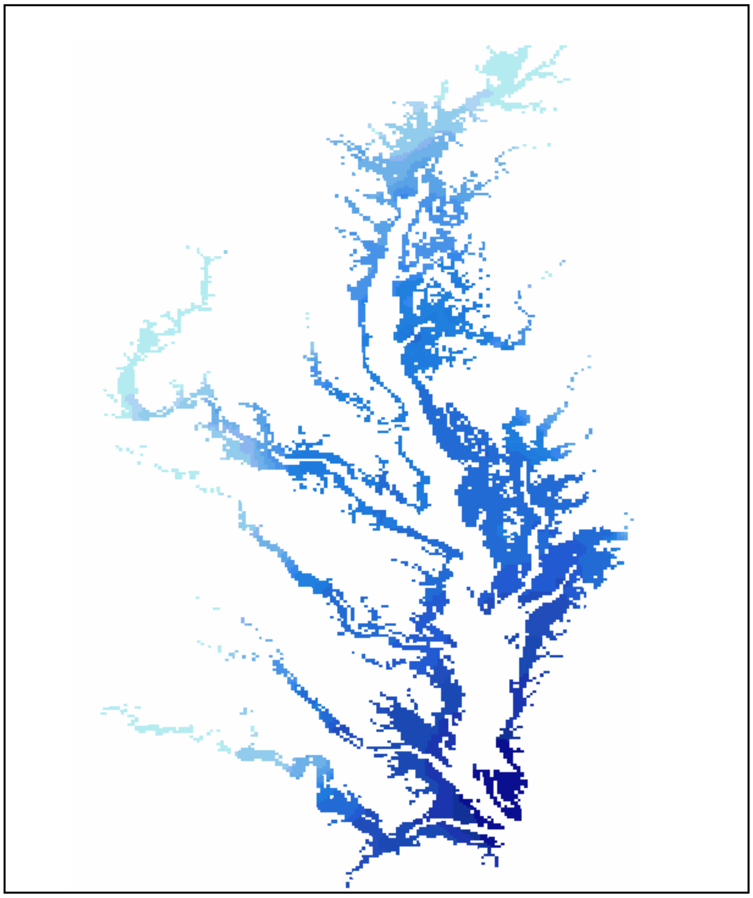
7. File Name: bsal_gr_wet_mean
Metadata Summary: Appendix A-7



This raster depicts mean bottom salinity during the growing season of the American oyster (*Crassostrea virginica*) (April-October) occurring during two recent wet years (2003-2004) at bottom depths ≤7m in Chesapeake Bay. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of Environment, and Chesapeake Bay Program. Fixed stations whose bottom depth was ≤7m and vertical profile stations that collected data within the 7m depth contour were included. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.

Mean Bottom Salinity, Growing Season, Dry Year

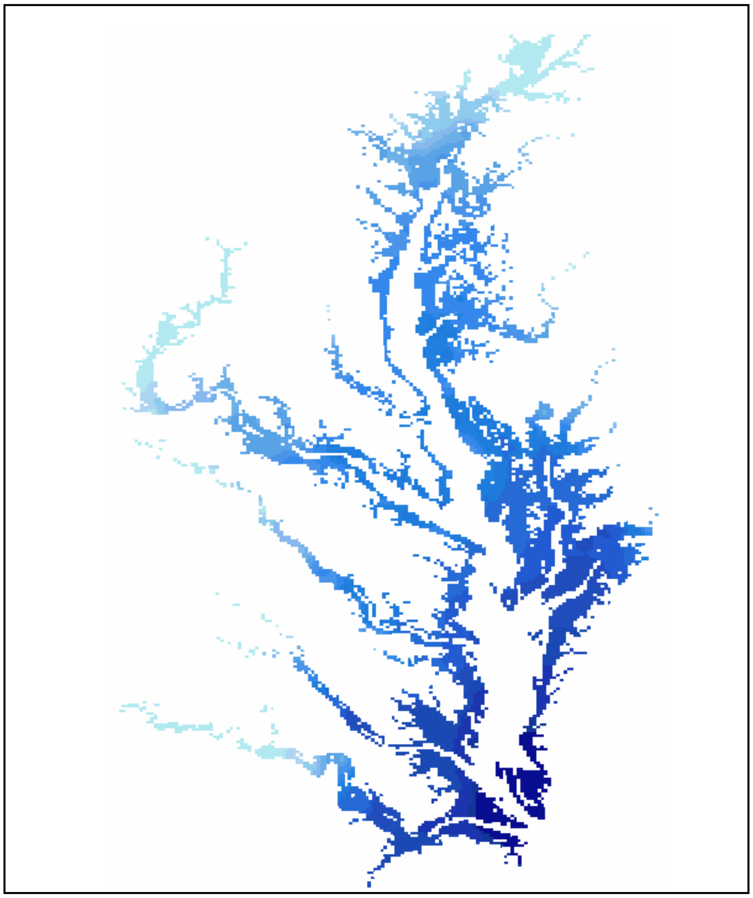
8. File Name: bsal_gr_dry_mean
Metadata Summary: Appendix A-8



This raster depicts mean bottom salinity during the growing season of the American oyster (*Crassostrea virginica*) (April-October) occurring during two recent dry years (2001-2002) at bottom depths ≤7m in Chesapeake Bay. This raster was generated using data from Maryland Department of Environment, and Chesapeake Bay Program. Fixed stations whose bottom depth was ≤7m and vertical profile stations that collected data within the 7m depth contour were included. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.

Mean Bottom Salinity, Growing Season, Average Year

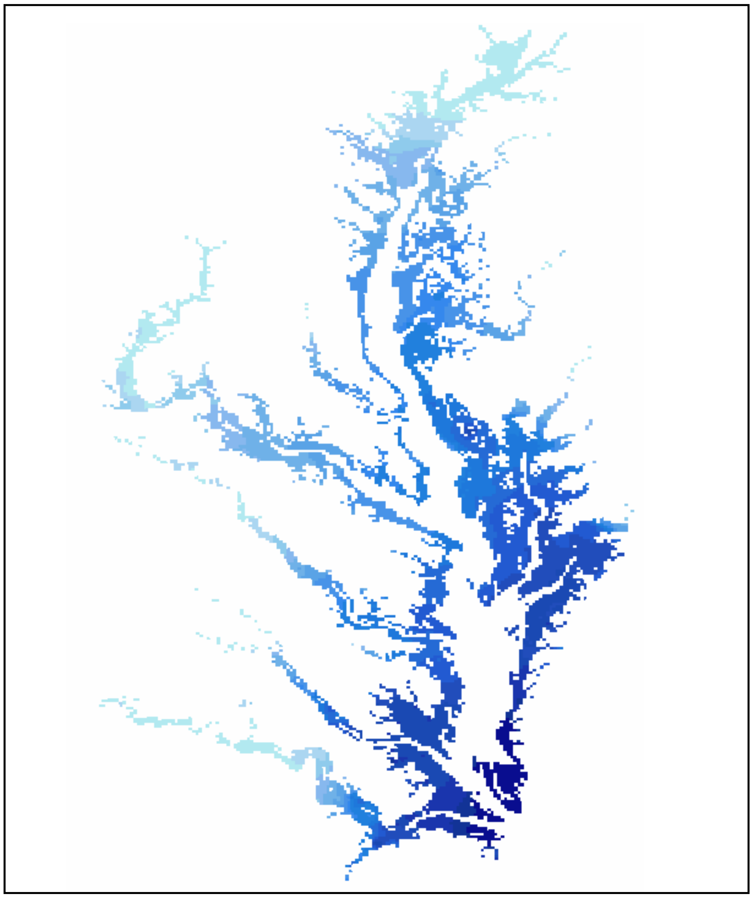
9. File Name: bsal_gr_ave_mean
Metadata Summary: Appendix A-9



This raster depicts mean bottom salinity during the growing season of the American oyster (*Crassostrea virginica*) (April-October) occurring during two recent average years (2005-2006) at bottom depths ≤7m in Chesapeake Bay. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of Environment, and Chesapeake Bay Program. Fixed stations whose bottom depth was ≤7m and vertical profile stations that collected data within the 7m depth contour were included. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.

Mean Surface Salinity, Growing Season, Wet Year

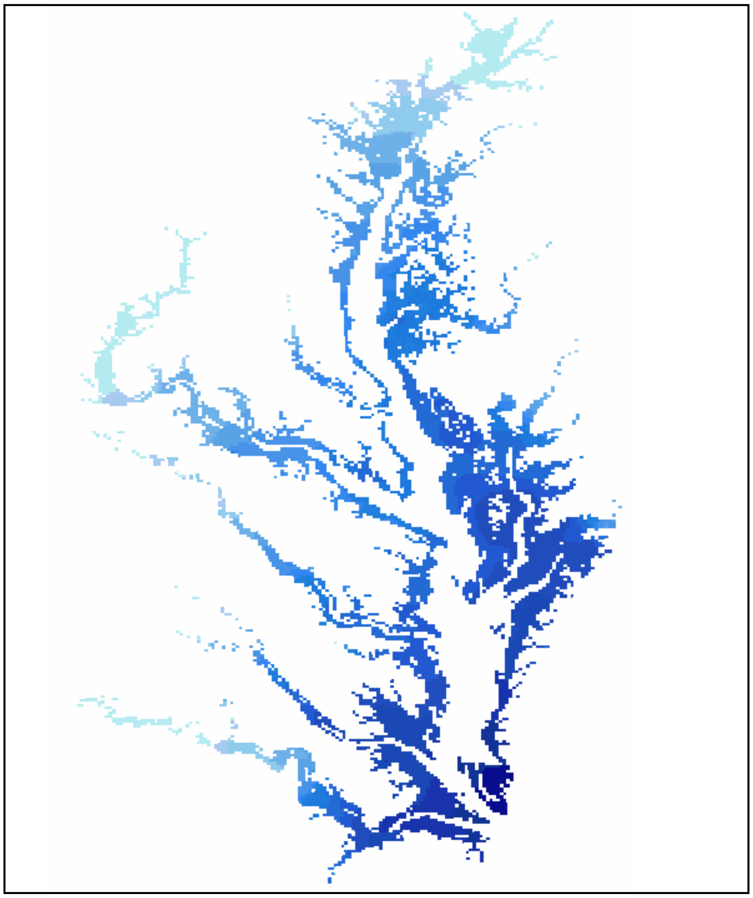
10. File Name: ssal_gr_wet_mean
Metadata Summary: Appendix A-10



This raster depicts mean surface salinity during the growing season of the American oyster (*Crassostrea virginica*) (April-October) occurring during two recent wet years (2003-2004) in Chesapeake Bay. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of Environment, Virginia Department of Health Division of Shellfish Sanitation, Alliance for the Chesapeake Bay, and Chesapeake Bay Program. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.

Mean Surface Salinity, Growing Season, Dry Year

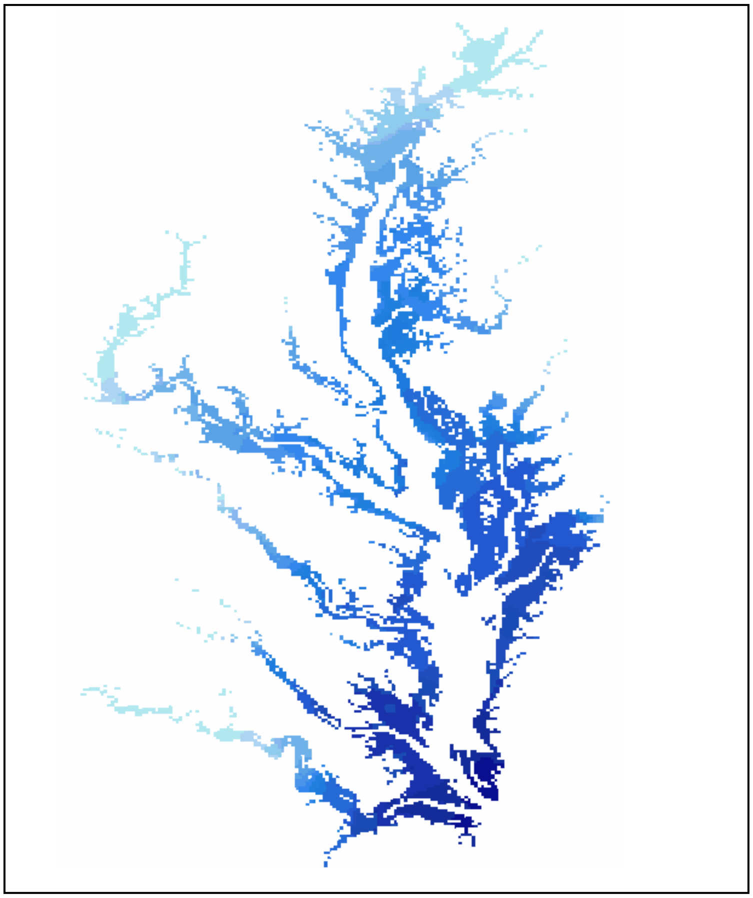
11. File Name: ssal_gr_dry_mean
Metadata Summary: Appendix A-11



This raster depicts mean surface salinity during the growing season of the American oyster (*Crassostrea virginica*) (April-October) occurring during two recent dry years (2001-2002) in Chesapeake Bay. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of Environment, Virginia Department of Health Division of Shellfish Sanitation, Alliance for the Chesapeake Bay, and Chesapeake Bay Program. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.

Mean Surface Salinity, Growing Season, Average Rainfall Year

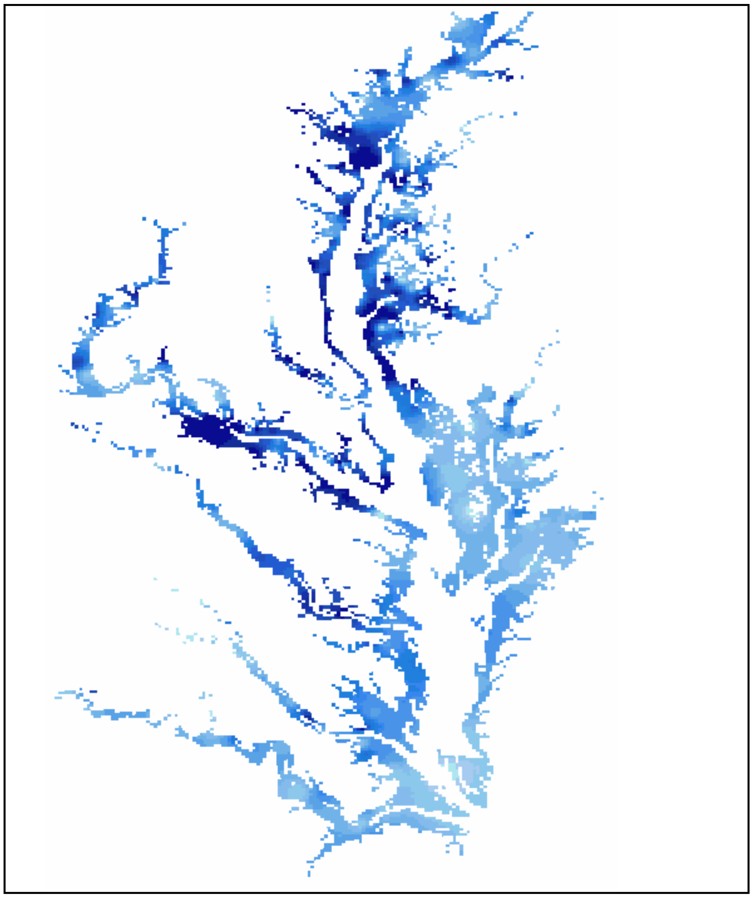
12. File Name: ssal_gr_ave_mean
Metadata Summary: Appendix A-12



This raster depicts mean surface salinity during the growing season of the American oyster (*Crassostrea virginica*) (April-October) occurring during two recent average years (2005-2006) in Chesapeake Bay. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of Environment, Virginia Department of Health Division of Shellfish Sanitation, Alliance for the Chesapeake Bay, and Chesapeake Bay Program. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.

Standard Error, Bottom Dissolved Oxygen, Summer, All Rainfall Year Types

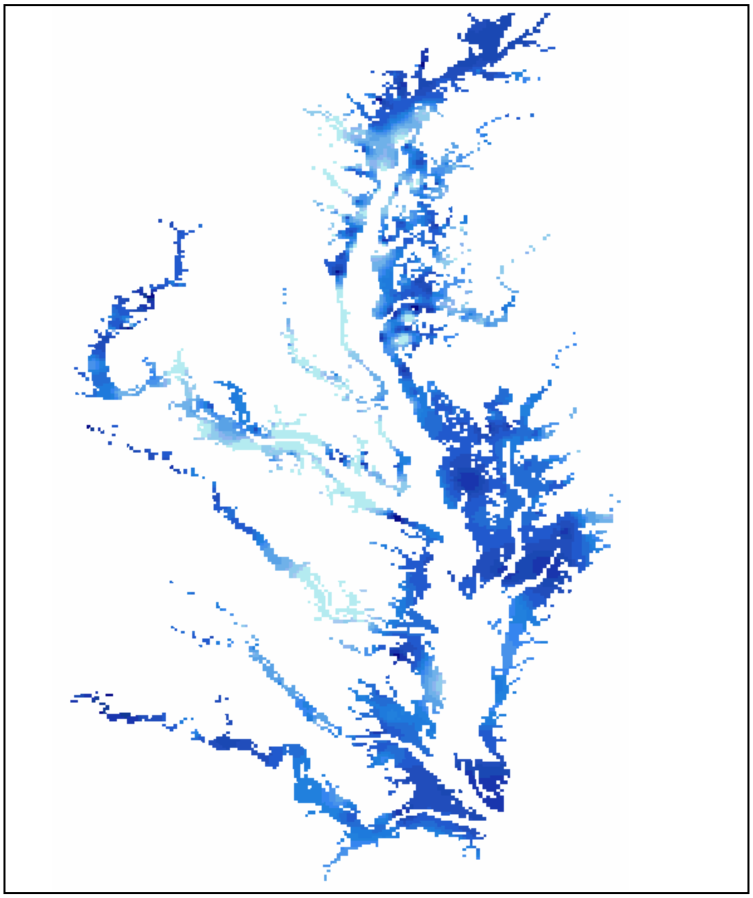
13. File Name: bdo_su_all_SE
Metadata Summary: Appendix A-13



This raster depicts standard error of the mean bottom dissolved oxygen for summer (June-August) during the years 2001-2006 at bottom depths ≤7m in Chesapeake Bay. This span of time contains 2 wet, 2 dry, and 2 average rainfall years. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of the Environment, and Chesapeake Bay Program. Fixed stations whose bottom depth was ≤7m and vertical profile stations that collected data within the 7m depth contour were included. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.

25th Percentile, Bottom Dissolved Oxygen, Summer, All Rainfall Year Types

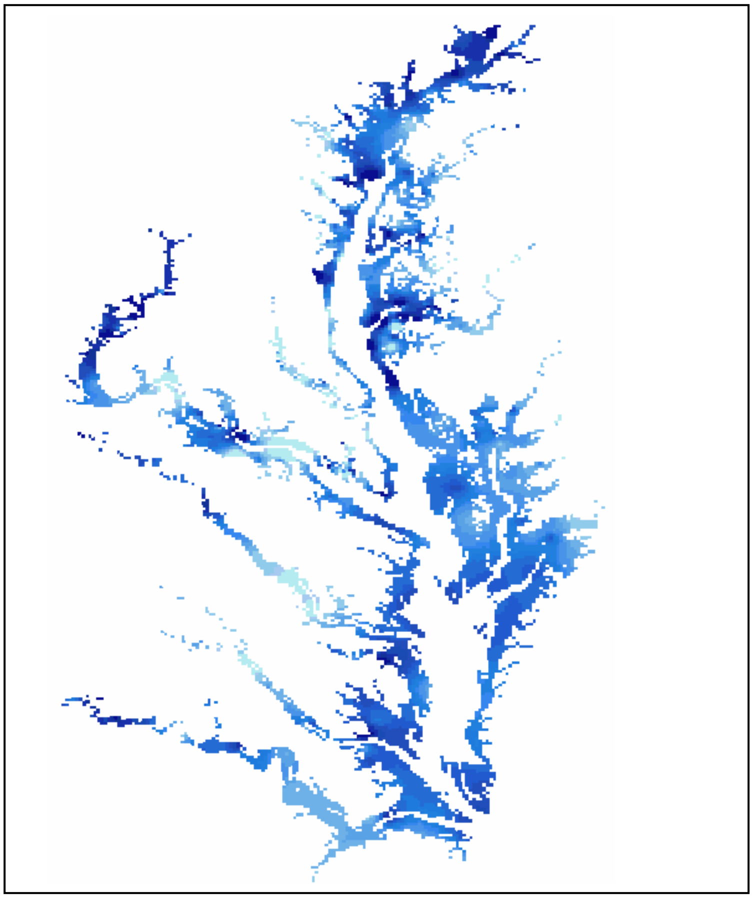
14. File Name: bdo_su_all_Q1
Metadata Summary: Appendix A-14



This raster depicts the 25th percentile of bottom dissolved oxygen for summer (June-August) during the years 2001-2006 at bottom depths ≤7m in Chesapeake Bay. This span of time contains 2 wet, 2 dry, and 2 average rainfall years. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of the Environment, and Chesapeake Bay Program. Fixed stations whose bottom depth was ≤7m and vertical profile stations that collected data within the 7m depth contour were included. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.

75th Percentile of Bottom Dissolved Oxygen, Summer, All Rainfall Year Types

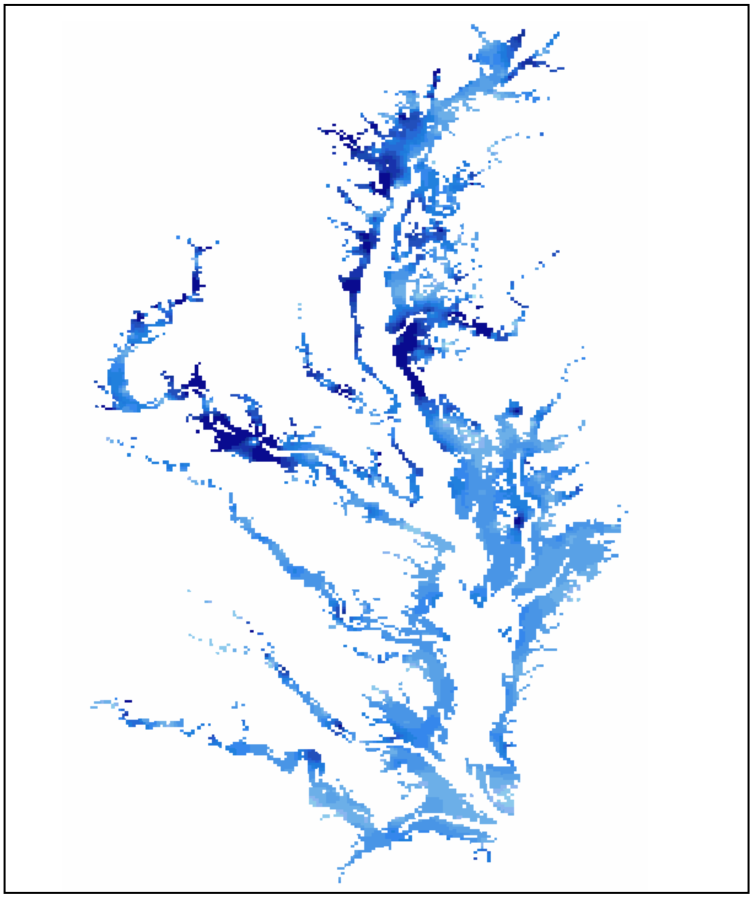
15. File Name: bdo_su_all_Q3
Metadata Summary: Appendix A-15



This raster depicts the 75th percentile of bottom dissolved oxygen for summer (June-August) during the years 2001-2006 at bottom depths ≤7m in Chesapeake Bay. This span of time contains 2 wet, 2 dry, and 2 average rainfall years. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of the Environment, and Chesapeake Bay Program. Fixed stations whose bottom depth was ≤7m and vertical profile stations that collected data within the 7m depth contour were included. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.

Standard Error, Surface Dissolved Oxygen, Summer, All Rainfall Year Types

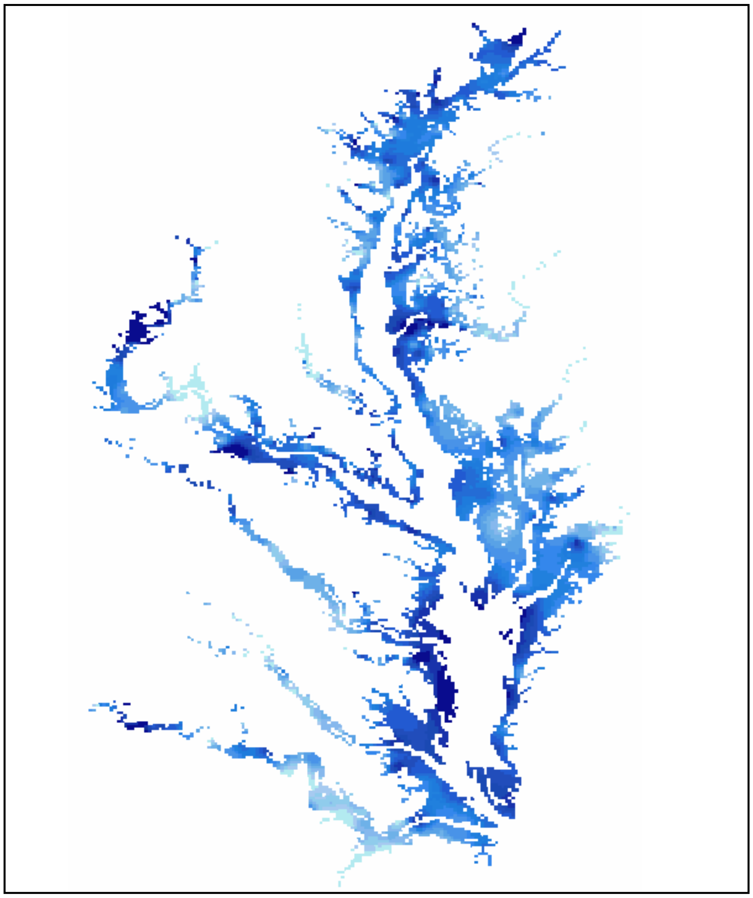
16. File Name: sdo_su_all_SE
Metadata Summary: Appendix A-16



This raster depicts the standard error of the mean surface dissolved oxygen for summer (June-August) during the years 2001-2006 in Chesapeake Bay. This span of time contains 2 wet, 2 dry, and 2 average rainfall years. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of Environment, Alliance for the Chesapeake Bay, and Chesapeake Bay Program. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.

25th Percentile, Surface Dissolved Oxygen, Summer, All Rainfall Year Types

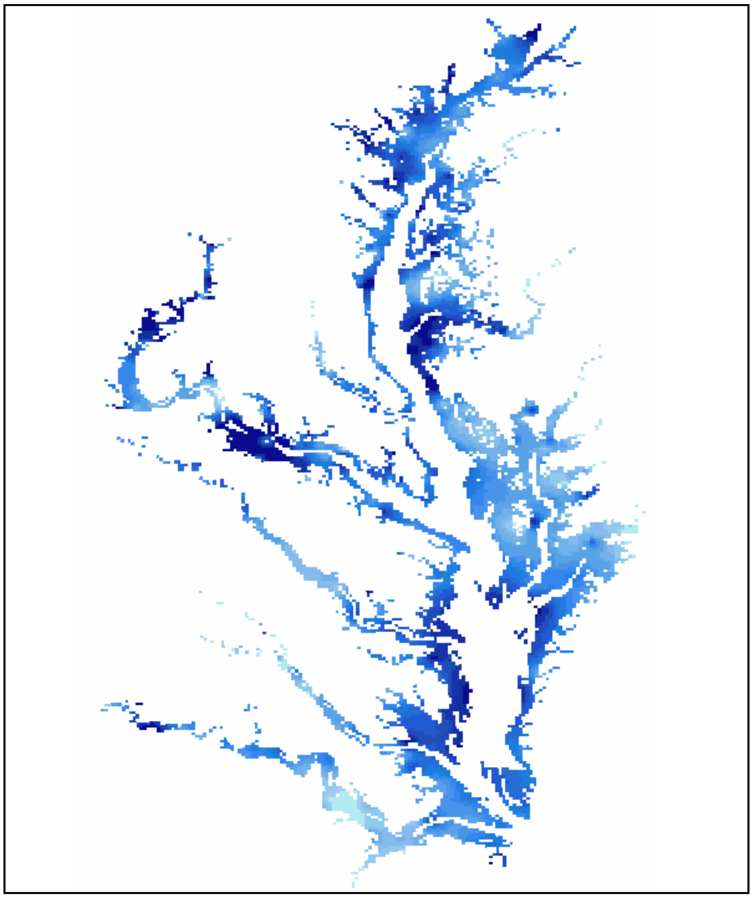
17. File Name: sdo_su_all_Q1
Metadata Summary: Appendix A-17



This raster depicts the 25th percentile of surface dissolved oxygen for summer (June-August) occurring during the years 2001-2006 in Chesapeake Bay. This span of time contains 2 wet, 2 dry, and 2 average rainfall years. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of Environment, Alliance for the Chesapeake Bay, and Chesapeake Bay Program. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.

75th Percentile, Surface Dissolved Oxygen, Summer, All Rainfall Year Types

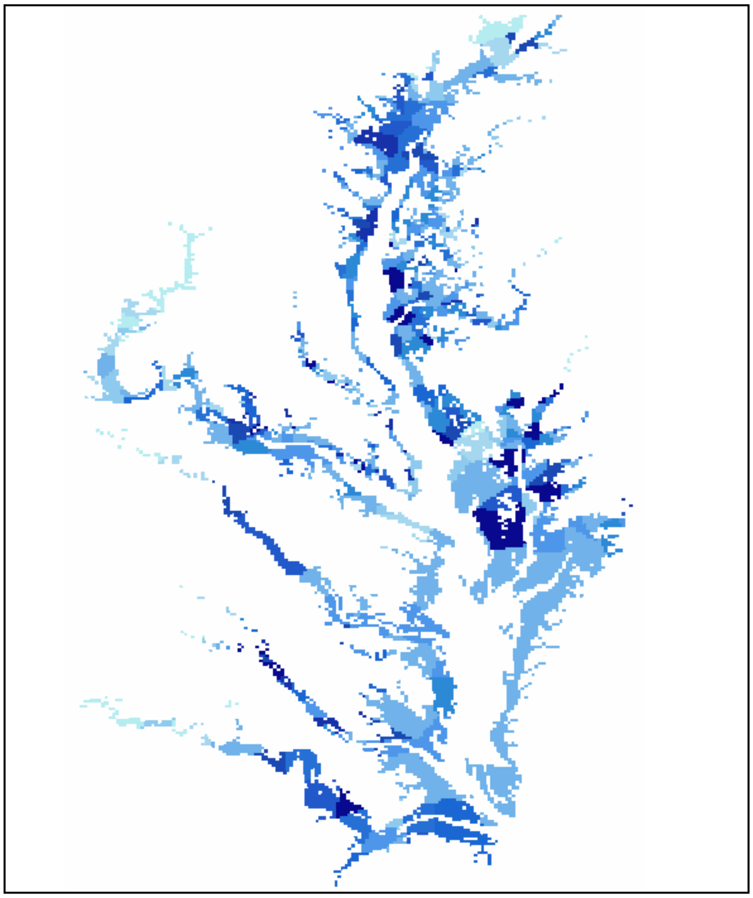
18. File Name: sdo_su_all_Q3
Metadata Summary: Appendix A-18



This raster depicts the 75th percentile of surface dissolved oxygen for summer (June-August) occurring during the years 2001-2006 in Chesapeake Bay. This span of time contains 2 wet, 2 dry, and 2 average rainfall years. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of Environment, Alliance for the Chesapeake Bay, and Chesapeake Bay Program. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.

Standard Error, Bottom Salinity, Growing Season, All Rainfall Year Types

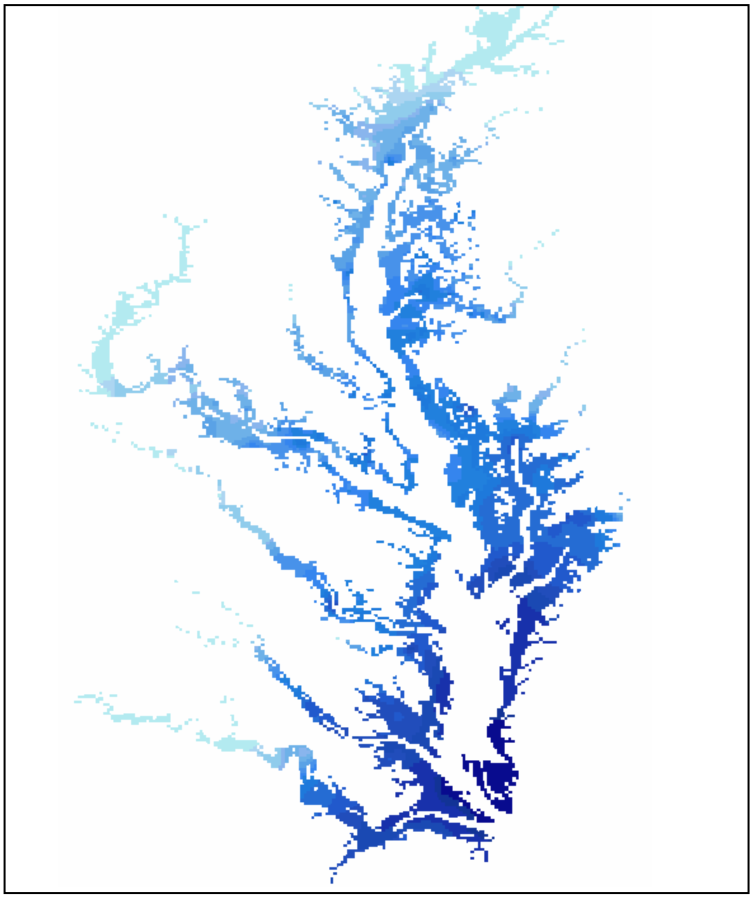
19. File Name: bsal_gr_all_SE
Metadata Summary: Appendix A-19



This raster depicts the standard error of the mean bottom salinity during the growing season of the American oyster (*Crassostrea virginica*) (April-October) occurring during the years 2001-2006 at bottom depths ≤7m in Chesapeake Bay. This span of time contains 2 wet, 2 dry, and 2 average rainfall years. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of the Environment, and Chesapeake Bay Program. Fixed stations whose bottom depth was ≤7m and vertical profile stations that collected data within the 7m depth contour were included. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.

25th Percentile, Bottom Salinity, Growing Season, All Rainfall Year Types

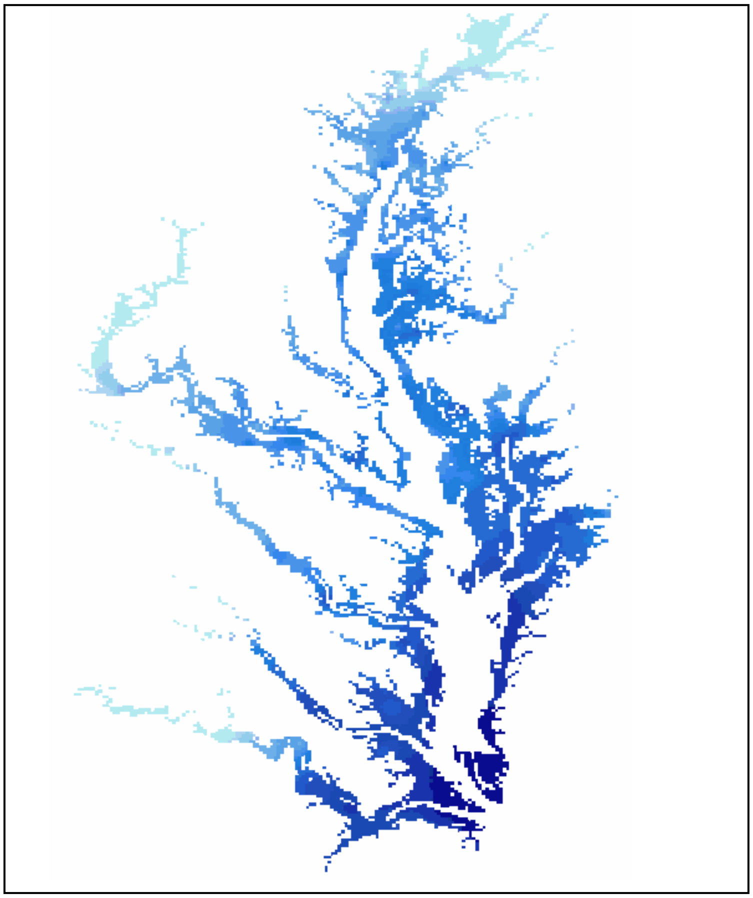
20. File Name: bsal_gr_all_Q1
Metadata Summary: Appendix A-20



This raster depicts the 25th percentile of bottom salinity during the growing season of the American oyster (*Crassostrea virginica*) (April-October) during the years 2001-2006 at bottom depths ≤7m in Chesapeake Bay. This span of time contains 2 wet, 2 dry, and 2 average rainfall years. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of the Environment, and Chesapeake Bay Program. Fixed stations whose bottom depth was ≤7m and vertical profile stations that collected data within the 7m depth contour were included. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.

75th Percentile, Bottom Salinity, Growing Season, All Rainfall Year Types

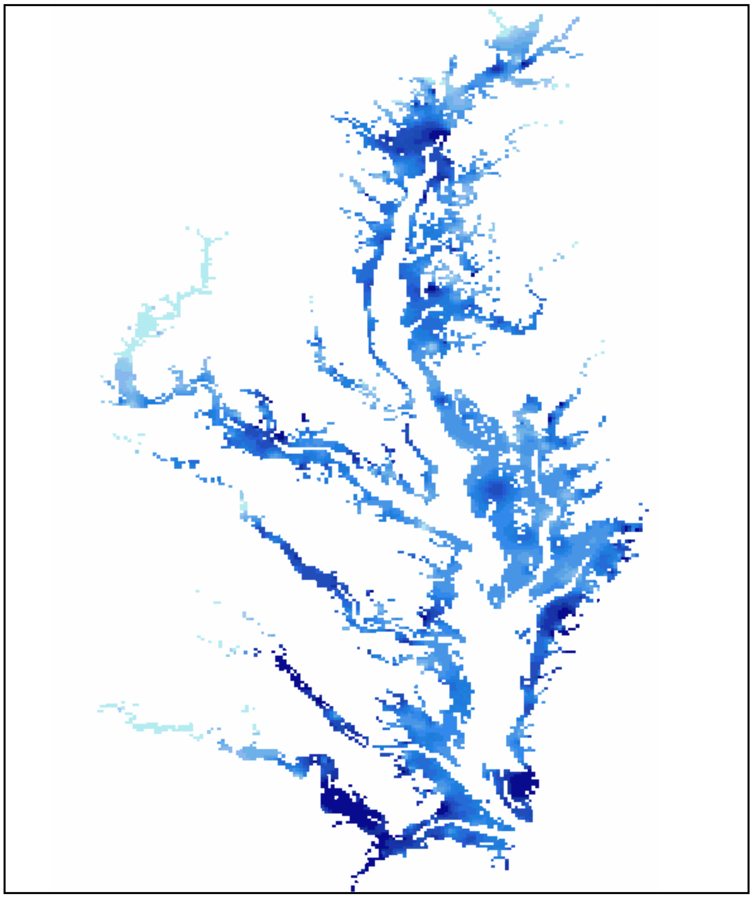
21. File Name: bsal_gr_all_Q3
Metadata Summary: Appendix A-21



This raster depicts the 75th percentile of bottom salinity during the growing season of the American oyster (*Crassostrea virginica*) (April-October) during the years 2001-2006 at bottom depths ≤7m in Chesapeake Bay. This span of time contains 2 wet, 2 dry, and 2 average rainfall years. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of the Environment, and Chesapeake Bay Program. Fixed stations whose bottom depth was ≤7m and vertical profile stations that collected data within the 7m depth contour were included. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.

Standard Error, Surface Salinity, Growing Season, All Rainfall Year Types

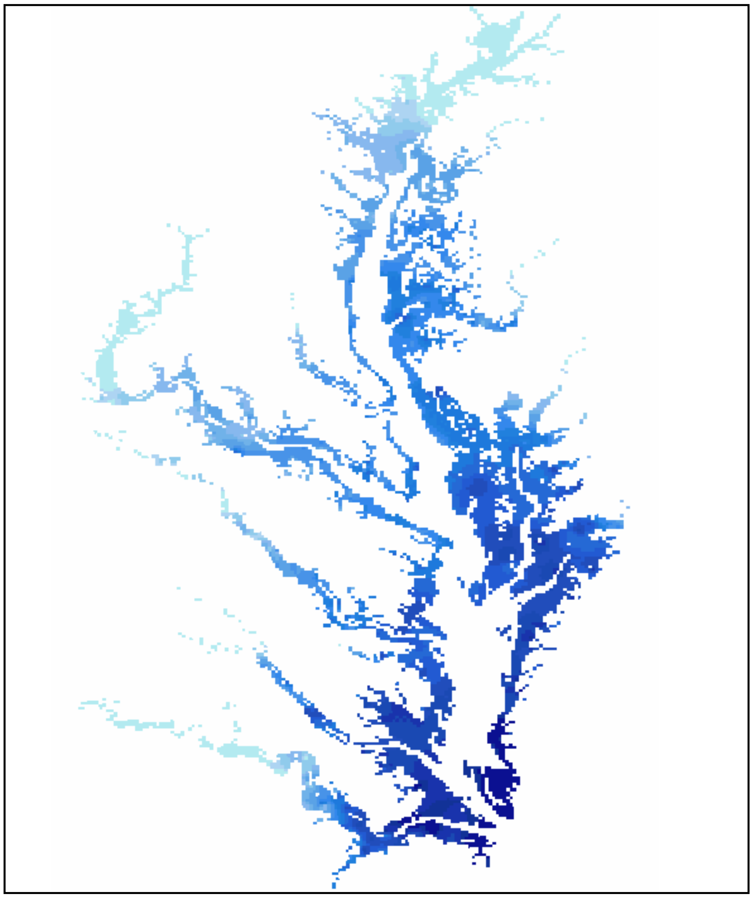
22. File Name: ssal_gr_all_SE
Metadata Summary: Appendix A-22



This raster depicts standard error of the mean surface salinity during the growing season of the American oyster (*Crassostrea virginica*) (April- October) occurring during the years 2001-2006 in Chesapeake Bay. This span of time contains 2 wet, 2 dry, and 2 average rainfall years. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of Environment, Virginia Department of Health Division of Shellfish Sanitation, Alliance for the Chesapeake Bay, and Chesapeake Bay Program. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.

25th Percentile, Surface Salinity, Growing Season, All Rainfall Year Types

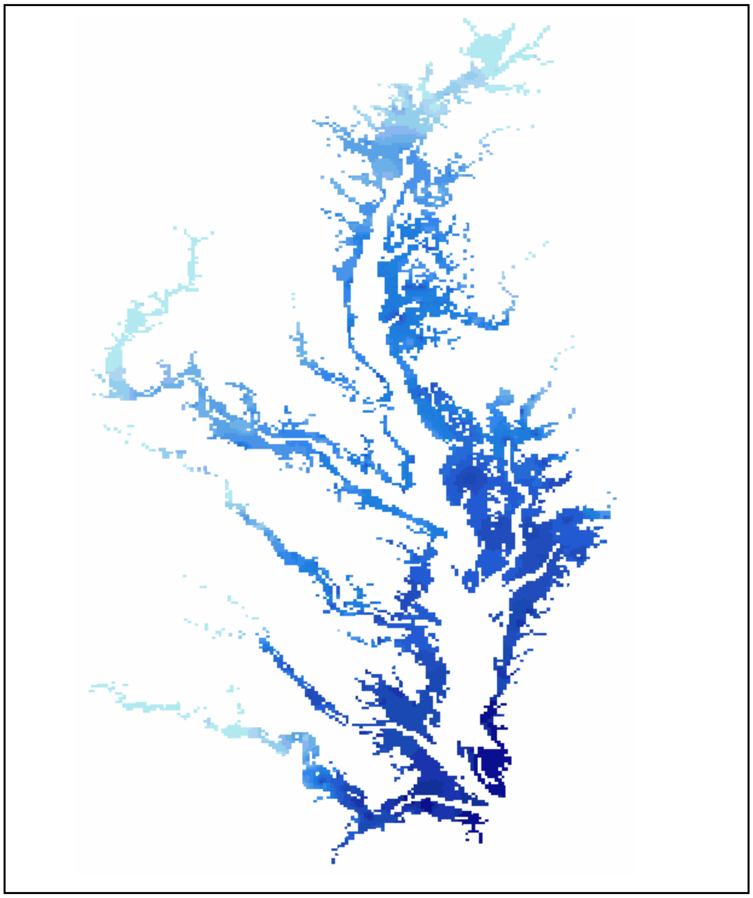
23. File Name: ssal_gr_all_Q1
Metadata Summary: Appendix A-23



This raster depicts the 25th percentile of surface salinity during the growing season of the American oyster (*Crassostrea virginica*) (April-October) occurring during the years 2001-2006 in Chesapeake Bay. This span of time contains 2 wet, 2 dry, and 2 average rainfall years. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of Environment, Virginia Department of Health Division of Shellfish Sanitation, Alliance for the Chesapeake Bay, and Chesapeake Bay Program. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.

75th Percentile, Surface Salinity, Growing Season, All Rainfall Year Types

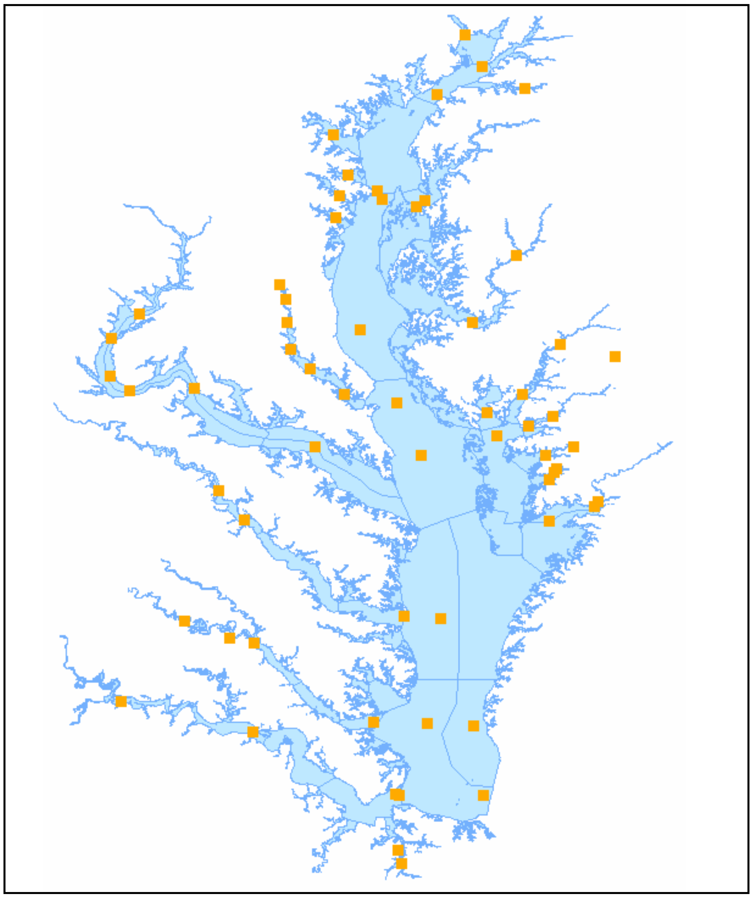
24. File Name: ssal_gr_all_Q3
Metadata Summary: Appendix A-24



This raster depicts the 75th percentile of surface salinity during the growing season of the American oyster (*Crassostrea virginica*) (April-October) occurring during the years 2001-2006 in Chesapeake Bay. This span of time contains 2 wet, 2 dry, and 2 average rainfall years. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of Environment, Virginia Department of Health Division of Shellfish Sanitation, Alliance for the Chesapeake Bay, and Chesapeake Bay Program. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.

Phytoplankton Abundance and Distribution

24. File Name: Phytoplankton_utm
Metadata Summary: Appendix A-25



This dataset contains information on the distribution and abundance of phytoplankton in the Chesapeake Bay. Data were downloaded from the Chesapeake Bay Program data hub; Old Dominion University and Morgan State University collected these data. Additional data in this dataset were provided by the Maryland Department of Natural Resources. Together, these data cover the time period of 1980-2009. These data are stored in a searchable Access database that contains two tables. One table contains the names and geographic locations of the sampling stations ("phytoplankton_stations") and the second table contains the data for each of the stations ("phytoplankton data"). Data for individual stations can be queried out of the data table using the station name from the station table.

References

Shepard, D. 1968. A two-dimensional interpolation function for irregularly-spaced data, Proc. 23rd National Conference ACM, ACM, 517-524.

APPENDIX A

METADATA SUMMARY

A-1. Meta-Data for "bdo_su_wet_mean"

Title	**Mean Bottom Dissolved Oxygen, Summer, Wet Year**
Abstract	This raster depicts mean bottom dissolved oxygen for the summer (June-August) occurring during two recent wet years (2003-2004) at bottom depths ≤7m in Chesapeake Bay. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of Environment, and Chesapeake Bay Program. Fixed stations whose bottom depth was ≤7m and vertical profile stations that collected data within the 7m depth contour were included. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.
How should this data set be cited?	Versar 2009
Online Links:	www.versar.com
Does the data set describe conditions during a particular time period?	Summer (June-August) 2003-2004
What is the general form of this data set?	Raster

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Maryland Department of Natural Resources (MDNR), Eyes on the Bay , Tawes State Office Building, 580 Taylor Avenue, D2, Annapolis MD, 21401 Maryland Department of Environment (MDE), Department of Shellfish Health, Montgomery Park, 1800 Washington Blvd., Baltimore, MD 21230 Chesapeake Bay Program (CBP), Water

	Quality Database, 410 Severn Avenue, Suite 109, Annapolis, MD 21403
Who also contributed to the data set?	Versar, Inc.
To whom should users address questions about the data?	Versar, Inc. 9200 Rumsey Road, Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Who wrote the metadata? Metadata author	Versar, Inc. 9200 Rumsey Road Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-2. Meta-Data for "bdo_su_dry_mean"

Title	**Mean Bottom Dissolved Oxygen, Summer, Dry Year**
Abstract	This raster depicts mean bottom dissolved oxygen for the summer (June-August) of two recent dry years (2001-2002) at bottom depths ≤7m in Chesapeake Bay. This raster was generated using data from Maryland Department of Environment and Chesapeake Bay Program. Fixed stations whose bottom depth was ≤7m and vertical profile stations that collected data within the 7m depth contour were included. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.
How should this data set be cited?	Versar 2009
Online Links:	www.versar.com
Does the data set describe conditions during a particular time period?	Summer (June-August) 2001-2002
What is the general form of this data set?	Raster

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Maryland Department of Environment (MDE), Department of Shellfish Health, Montgomery Park, 1800 Washington Blvd., Baltimore, MD 21230 Chesapeake Bay Program (CBP), Water Quality Database, 410 Severn Avenue, Suite 109, Annapolis, MD 21403
Who also contributed to the data set?	Versar, Inc.
To whom should users address questions	Versar, Inc.

about the data?	9200 Rumsey Road, Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Who wrote the metadata? Metadata author	Versar, Inc. 9200 Rumsey Road Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-3. Meta-Data for "bdo_su_ave_mean"

Title	**Mean Bottom Dissolved Oxygen, Summer, Average Rainfall Year**
Abstract	This raster depicts mean bottom dissolved oxygen for the summer (June-August) of two recent average years (2005-2006) at bottom depths ≤7m in Chesapeake Bay. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of Environment, and Chesapeake Bay Program. Fixed stations whose bottom depth was ≤7m and vertical profile stations that collected data within the 7m depth contour were included. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.
How should this data set be cited?	Versar 2009
Online Links:	www.versar.com
Does the data set describe conditions during a particular time period?	Summer (June-August) 2005-2006
What is the general form of this data set?	Raster

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Maryland Department of Natural Resources (MDNR), Eyes on the Bay , Tawes State Office Building, 580 Taylor Avenue, D2, Annapolis MD, 21401 Maryland Department of Environment (MDE), Department of Shellfish Health, Montgomery Park, 1800 Washington Blvd., Baltimore, MD 21230 Chesapeake Bay Program (CBP), Water Quality Database, 410 Severn Avenue, Suite

	109, Annapolis, MD 21403
Who also contributed to the data set?	Versar, Inc.
To whom should users address questions about the data?	Versar, Inc. 9200 Rumsey Road, Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Who wrote the metadata? Metadata author	Versar, Inc. 9200 Rumsey Road Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-4. Meta-Data for "sdo_su_wet_mean"

Title	**Mean Surface Dissolved Oxygen, Summer, Wet Year**
Abstract	This raster depicts mean surface dissolved oxygen for the summer (June-August) of two recent wet years (2003-2004) in Chesapeake Bay. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of Environment, Alliance for the Chesapeake Bay, and Chesapeake Bay Program. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.
How should this data set be cited?	Versar 2009
Online Links:	www.versar.com
Does the data set describe conditions during a particular time period?	Summer (June-August) 2003-2004
What is the general form of this data set?	Raster

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Maryland Department of Natural Resources (MDNR), Eyes on the Bay , Tawes State Office Building, 580 Taylor Avenue, D2, Annapolis MD, 21401 Maryland Department of Environment (MDE), Department of Shellfish Health, Montgomery Park, 1800 Washington Blvd., Baltimore, MD 21230 Alliance for the Chesapeake Bay ,6600 York Road Suite 100, Baltimore, Maryland 21212 Chesapeake Bay Program (CBP), Water

	Quality Database, 410 Severn Avenue, Suite 109, Annapolis, MD 21403
Who also contributed to the data set?	Versar, Inc.
To whom should users address questions about the data?	Versar, Inc. 9200 Rumsey Road, Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Who wrote the metadata? Metadata author	Versar, Inc. 9200 Rumsey Road Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-5. Meta-Data for "sdo_su_dry_mean"

Title	**Mean Surface Dissolved Oxygen, Summer, Dry Year**
Abstract	This raster depicts mean surface dissolved oxygen for the summer (June-August) of two recent dry years (2001-2002) in Chesapeake Bay. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of Environment, Alliance for the Chesapeake Bay, and Chesapeake Bay Program. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.
How should this data set be cited?	Versar 2009
Online Links:	www.versar.com
Does the data set describe conditions during a particular time period?	Summer (June-August) 2001-2002
What is the general form of this data set?	Raster
Who produced the data set?	
Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Maryland Department of Natural Resources (MDNR), Eyes on the Bay , Tawes State Office Building, 580 Taylor Avenue, D2, Annapolis MD, 21401 Maryland Department of Environment (MDE), Department of Shellfish Health, Montgomery Park, 1800 Washington Blvd., Baltimore, MD 21230 Alliance for the Chesapeake Bay ,6600 York Road Suite 100, Baltimore, Maryland 21212 Chesapeake Bay Program (CBP), Water

	Quality Database, 410 Severn Avenue, Suite 109, Annapolis, MD 21403
Who also contributed to the data set?	Versar, Inc.
To whom should users address questions about the data?	Versar, Inc. 9200 Rumsey Road, Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Who wrote the metadata? Metadata author	Versar, Inc. 9200 Rumsey Road Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-6. Meta-Data for "sdo_su_ave_mean"

Title	**Mean Surface Dissolved Oxygen, Summer, Average Rainfall Year**
Abstract	This raster depicts mean surface dissolved oxygen for the summer (June-August) of two recent average rainfall years (2005-2006) in Chesapeake Bay. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of Environment, Alliance for the Chesapeake Bay, and Chesapeake Bay Program. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.
How should this data set be cited?	Versar 2009
Online Links:	www.versar.com
Does the data set describe conditions during a particular time period?	Summer (June-August) 2005-2006
What is the general form of this data set?	Raster

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Maryland Department of Natural Resources (MDNR), Eyes on the Bay , Tawes State Office Building, 580 Taylor Avenue, D2, Annapolis MD, 21401 Maryland Department of Environment (MDE), Department of Shellfish Health, Montgomery Park, 1800 Washington Blvd., Baltimore, MD 21230 Alliance for the Chesapeake Bay ,6600 York Road Suite 100, Baltimore, Maryland 21212 Chesapeake Bay Program (CBP), Water

	Quality Database, 410 Severn Avenue, Suite 109, Annapolis, MD 21403
Who also contributed to the data set?	Versar, Inc.
To whom should users address questions about the data?	Versar, Inc. 9200 Rumsey Road, Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Who wrote the metadata? Metadata author	Versar, Inc. 9200 Rumsey Road Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-7. Meta-Data for "bsal_gr_wet_mean"

Title	**Mean Bottom Salinity, Growing Season, Wet Year**
Abstract	This raster depicts mean bottom salinity during growing season of the American oyster (*Crassostrea virginica*) (April to October) occurring during two recent wet years (2003-2004) at bottom depths ≤7m in Chesapeake Bay. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of Environment, and Chesapeake Bay Program. Fixed stations whose bottom depth was ≤7m and vertical profile stations that collected data within the 7m depth contour were included. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.
How should this data set be cited?	Versar 2009
Online Links:	www.versar.com
Does the data set describe conditions during a particular time period?	Growing Season (April-October) 2003-2004
What is the general form of this data set?	Raster

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Maryland Department of Natural Resources (MDNR), Eyes on the Bay , Tawes State Office Building, 580 Taylor Avenue, D2, Annapolis MD, 21401 Maryland Department of Environment (MDE), Department of Shellfish Health, Montgomery Park, 1800 Washington Blvd., Baltimore, MD 21230

	Chesapeake Bay Program (CBP), Water Quality Database, 410 Severn Avenue, Suite 109, Annapolis, MD 21403
Who also contributed to the data set?	Versar, Inc.
To whom should users address questions about the data?	Versar, Inc. 9200 Rumsey Road, Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Who wrote the metadata?	Versar, Inc.
Metadata author	9200 Rumsey Road Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-8. Meta-Data for "bsal_gr_dry_mean"

Title	**Mean Bottom Salinity, Growing Season, Dry Year**
Abstract	This raster depicts mean bottom salinity during the growing season of the American oyster (*Crassostrea virginica*) (April to October) during two recent dry years (2001-2002) at bottom depths ≤7m in Chesapeake Bay. This raster was generated using data from Maryland Department of Environment, and Chesapeake Bay Program. Fixed stations whose bottom depth was ≤7m and vertical profile stations that collected data within the 7m depth contour were included. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.
How should this data set be cited?	Versar 2009
Online Links:	www.versar.com
Does the data set describe conditions during a particular time period?	Growing Season (April-October) 2001-2002
What is the general form of this data set?	Raster

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Maryland Department of Environment (MDE), Department of Shellfish Health, Montgomery Park, 1800 Washington Blvd., Baltimore, MD 21230 Chesapeake Bay Program (CBP), Water Quality Database, 410 Severn Avenue, Suite 109, Annapolis, MD 21403
Who also contributed to the data set?	Versar, Inc.

To whom should users address questions about the data?	Versar, Inc. 9200 Rumsey Road, Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Who wrote the metadata? Metadata author	Versar, Inc. 9200 Rumsey Road Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-9. Meta-Data for "bsal_gr_ave_mean"

Title	**Mean Bottom Salinity, Growing Season, Average Year**
Abstract	This raster depicts mean bottom salinity during the growing season of the American oyster (*Crassostrea virginica*) (April to October) occurring during two recent average years (2005-2006) at bottom depths ≤7m in Chesapeake Bay. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of Environment, and Chesapeake Bay Program. Fixed stations whose bottom depth was ≤7m and vertical profile stations that collected data within the 7m depth contour were included. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.
How should this data set be cited?	Versar 2009
Online Links:	www.versar.com
Does the data set describe conditions during a particular time period?	Growing Season (April-October) 2005-2006
What is the general form of this data set?	Raster

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Maryland Department of Natural Resources (MDNR), Eyes on the Bay , Tawes State Office Building, 580 Taylor Avenue, D2, Annapolis MD, 21401 Maryland Department of Environment (MDE), Department of Shellfish Health, Montgomery Park, 1800 Washington Blvd., Baltimore, MD 21230

	Chesapeake Bay Program (CBP), Water Quality Database, 410 Severn Avenue, Suite 109, Annapolis, MD 21403
Who also contributed to the data set?	Versar, Inc.
To whom should users address questions about the data?	Versar, Inc. 9200 Rumsey Road, Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Who wrote the metadata? Metadata author	Versar, Inc. 9200 Rumsey Road Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-10. Meta-Data for "ssal_gr_wet_mean"

Title	**Mean Surface Salinity, Growing Season, Wet Year**
Abstract	This raster depicts mean surface salinity for the growing season of the American oyster (*Crassostrea virginica*) (April to October) occurring during two recent wet years (2003-2004) in Chesapeake Bay. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of Environment, Virginia Department of Health Division of Shellfish Sanitation, Alliance for the Chesapeake Bay, and Chesapeake Bay Program. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.
How should this data set be cited?	Versar 2009
Online Links:	www.versar.com
Does the data set describe conditions during a particular time period?	Growing Season (April-October) 2001-2002
What is the general form of this data set?	Raster

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Maryland Department of Natural Resources (MDNR), Eyes on the Bay , Tawes State Office Building, 580 Taylor Avenue, D2, Annapolis MD, 21401 Maryland Department of Environment (MDE), Department of Shellfish Health, Montgomery Park, 1800 Washington Blvd., Baltimore, MD 21230 Virginia Department of Health (VDH),

	Division of Shellfish Sanitation, Madison Building, 109 Governor Street, 6th Floor Richmond, Virginia 23219
	Alliance for the Chesapeake Bay ,6600 York Road Suite 100, Baltimore, Maryland 21212
	Chesapeake Bay Program (CBP), Water Quality Database, 410 Severn Avenue, Suite 109, Annapolis, MD 21403
Who also contributed to the data set?	Versar, Inc.
To whom should users address questions about the data?	Versar, Inc. 9200 Rumsey Road, Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Who wrote the metadata? Metadata author	Versar, Inc. 9200 Rumsey Road Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-11. Meta-Data for "ssal_gr_dry_mean"

Title	**Mean Surface Salinity, Growing Season, Dry Year**
Abstract	This raster depicts mean surface salinity for the growing season of the American oyster (*Crassostrea virginica*) (April to October) occurring during two recent dry years (2001-2002) in Chesapeake Bay. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of Environment, Virginia Department of Health Division of Shellfish Sanitation, Alliance for the Chesapeake Bay, and Chesapeake Bay Program. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.
How should this data set be cited?	Versar 2009
Online Links:	www.versar.com
Does the data set describe conditions during a particular time period?	Growing Season (April-October) 2001-2002
What is the general form of this data set?	Raster

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Maryland Department of Natural Resources (MDNR), Eyes on the Bay , Tawes State Office Building, 580 Taylor Avenue, D2, Annapolis MD, 21401 Maryland Department of Environment (MDE), Department of Shellfish Health, Montgomery Park, 1800 Washington Blvd., Baltimore, MD 21230 Virginia Department of Health (VDH),

	Division of Shellfish Sanitation, Madison Building, 109 Governor Street, 6th Floor Richmond, Virginia 23219
	Alliance for the Chesapeake Bay ,6600 York Road Suite 100, Baltimore, Maryland 21212
	Chesapeake Bay Program (CBP), Water Quality Database, 410 Severn Avenue, Suite 109, Annapolis, MD 21403
Who also contributed to the data set?	Versar, Inc.
To whom should users address questions about the data?	Versar, Inc. 9200 Rumsey Road, Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Who wrote the metadata? Metadata author	Versar, Inc. 9200 Rumsey Road Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-12. Meta-Data for "ssal_gr_ave_mean"

Title	**Mean Surface Salinity, Growing Season, Average Year**
Abstract	This raster depicts mean surface salinity for the growing season of the American oyster (*Crassostrea virginica*) (April to October) occurring during two recent average years (2005-2006) in Chesapeake Bay. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of Environment, Virginia Department of Health Division of Shellfish Sanitation, Alliance for the Chesapeake Bay, and Chesapeake Bay Program. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.
How should this data set be cited?	Versar 2009
Online Links:	www.versar.com
Does the data set describe conditions during a particular time period?	Growing Season (April-October) 2005-2006
What is the general form of this data set?	Raster

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Maryland Department of Natural Resources (MDNR), Eyes on the Bay , Tawes State Office Building, 580 Taylor Avenue, D2, Annapolis MD, 21401 Maryland Department of Environment (MDE), Department of Shellfish Health, Montgomery Park, 1800 Washington Blvd., Baltimore, MD 21230 Virginia Department of Health (VDH),

	Division of Shellfish Sanitation, Madison Building, 109 Governor Street, 6th Floor Richmond, Virginia 23219 Alliance for the Chesapeake Bay ,6600 York Road Suite 100, Baltimore, Maryland 21212 Chesapeake Bay Program (CBP), Water Quality Database, 410 Severn Avenue, Suite 109, Annapolis, MD 21403
Who also contributed to the data set?	Versar, Inc.
To whom should users address questions about the data?	Versar, Inc. 9200 Rumsey Road, Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Who wrote the metadata? Metadata author	Versar, Inc. 9200 Rumsey Road Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-13. Meta-Data for "bdo_su_all_SE"

Title	**Standard Error, Bottom Dissolved Oxygen, Summer, All Rainfall Year Types**
Abstract	This raster depicts the standard error of the mean bottom dissolved oxygen level for the summer (June-August) occurring during 2001-2006 at bottom depths ≤7m in Chesapeake Bay. This span of time contains 2 wet years, 2 dry years, and 2 average rainfall years. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of Environment, and Chesapeake Bay Program. Fixed stations whose bottom depth was ≤7m and vertical profile stations that collected data within the 7m depth contour were included. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.
How should this data set be cited?	Versar 2009
Online Links:	www.versar.com
Does the data set describe conditions during a particular time period?	Summer (June-August) 2001-2006
What is the general form of this data set?	Raster

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Maryland Department of Natural Resources (MDNR), Eyes on the Bay , Tawes State Office Building, 580 Taylor Avenue, D2, Annapolis MD, 21401 Maryland Department of Environment (MDE), Department of Shellfish Health, Montgomery Park, 1800 Washington Blvd., Baltimore, MD 21230

	Chesapeake Bay Program (CBP), Water Quality Database, 410 Severn Avenue, Suite 109, Annapolis, MD 21403
Who also contributed to the data set?	Versar, Inc.
To whom should users address questions about the data?	Versar, Inc. 9200 Rumsey Road, Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Who wrote the metadata? Metadata author	Versar, Inc. 9200 Rumsey Road Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-14. Meta-Data for "bdo_su_all_Q1"

Title	**25th Percentile, Bottom Dissolved Oxygen, Summer, All Rainfall Year Types**
Abstract	This raster depicts the 25th percentile of bottom dissolved oxygen for summer (June-August) occurring during years 2001-2006 at bottom depths ≤7m in Chesapeake Bay. This span of time contains 2 wet years, 2 dry years, and 2 average rainfall years. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of Environment, and Chesapeake Bay Program. Fixed stations whose bottom depth was ≤7m and vertical profile stations that collected data within the 7m depth contour were included. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.
How should this data set be cited?	Versar 2009
Online Links:	www.versar.com
Does the data set describe conditions during a particular time period?	Summer (June-August) 2001-2006
What is the general form of this data set?	Raster

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Maryland Department of Natural Resources (MDNR), Eyes on the Bay , Tawes State Office Building, 580 Taylor Avenue, D2, Annapolis MD, 21401 Maryland Department of Environment (MDE), Department of Shellfish Health, Montgomery Park, 1800 Washington Blvd., Baltimore, MD 21230

	Chesapeake Bay Program (CBP), Water Quality Database, 410 Severn Avenue, Suite 109, Annapolis, MD 21403
Who also contributed to the data set?	Versar, Inc.
To whom should users address questions about the data?	Versar, Inc. 9200 Rumsey Road, Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Who wrote the metadata? Metadata author	Versar, Inc. 9200 Rumsey Road Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-15. Meta-Data for "bdo_su_all_Q3"

Title	**75th Percentile, Bottom Dissolved Oxygen, Summer, All Rainfall Year Types**
Abstract	This raster depicts the 75th percentile of bottom dissolved oxygen for the summer (June-August) occurring during the years 2001-2006 at bottom depths ≤7m in Chesapeake Bay. This span of time contains 2 wet years, 2 dry years, and 2 average rainfall years. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of Environment, and Chesapeake Bay Program. Fixed stations whose bottom depth was ≤7m and vertical profile stations that collected data within the 7m depth contour were included. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.
How should this data set be cited?	Versar 2009
Online Links:	www.versar.com
Does the data set describe conditions during a particular time period?	Summer (June-August) 2001-2006
What is the general form of this data set?	Raster

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Maryland Department of Natural Resources (MDNR), Eyes on the Bay , Tawes State Office Building, 580 Taylor Avenue, D2, Annapolis MD, 21401 Maryland Department of Environment (MDE), Department of Shellfish Health, Montgomery Park, 1800 Washington Blvd., Baltimore, MD 21230

	Chesapeake Bay Program (CBP), Water Quality Database, 410 Severn Avenue, Suite 109, Annapolis, MD 21403
Who also contributed to the data set?	Versar, Inc.
To whom should users address questions about the data?	Versar, Inc. 9200 Rumsey Road, Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Who wrote the metadata? Metadata author	Versar, Inc. 9200 Rumsey Road Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-16. Meta-Data for "bdo_su_all_SE"

Title	**Standard Error, Surface Dissolved Oxygen, Summer, All Rainfall Year Types**
Abstract	This raster depicts the standard error of the mean surface dissolved oxygen for the summers (June-August) occurring during the years 2001-2006 in Chesapeake Bay. This span of time contains 2 wet years, 2 dry years, and 2 average rainfall years. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of Environment, Alliance for the Chesapeake Bay, and Chesapeake Bay Program. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.
How should this data set be cited?	Versar 2009
Online Links:	www.versar.com
Does the data set describe conditions during a particular time period?	Summer (June-August) 2001-2006
What is the general form of this data set?	Raster

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Maryland Department of Natural Resources (MDNR), Eyes on the Bay , Tawes State Office Building, 580 Taylor Avenue, D2, Annapolis MD, 21401 Maryland Department of Environment (MDE), Department of Shellfish Health, Montgomery Park, 1800 Washington Blvd., Baltimore, MD 21230 Alliance for the Chesapeake Bay ,6600 York Road Suite 100, Baltimore, Maryland 21212

	Chesapeake Bay Program (CBP), Water Quality Database, 410 Severn Avenue, Suite 109, Annapolis, MD 21403
Who also contributed to the data set?	Versar, Inc.
To whom should users address questions about the data?	Versar, Inc. 9200 Rumsey Road, Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Who wrote the metadata?	Versar, Inc.
Metadata author	9200 Rumsey Road Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-17. Meta-Data for "sdo_su_all_Q1"

Title	**25th Percentile, Surface Dissolved Oxygen, Summer, All Rainfall Year Types**
Abstract	This raster depicts the 25th percentile for surface dissolved oxygen for the summer (June-August) of the years 2001-2006 in Chesapeake Bay. This span of time contains 2 wet years, 2 dry years, and 2 average rainfall years. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of Environment, Alliance for the Chesapeake Bay, and Chesapeake Bay Program. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.
How should this data set be cited?	Versar 2009
Online Links:	www.versar.com
Does the data set describe conditions during a particular time period?	Summer (June-August) 2001-2006
What is the general form of this data set?	Raster

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Maryland Department of Natural Resources (MDNR), Eyes on the Bay , Tawes State Office Building, 580 Taylor Avenue, D2, Annapolis MD, 21401 Maryland Department of Environment (MDE), Department of Shellfish Health, Montgomery Park, 1800 Washington Blvd., Baltimore, MD 21230 Alliance for the Chesapeake Bay ,6600 York Road Suite 100, Baltimore, Maryland 21212

	Chesapeake Bay Program (CBP), Water Quality Database, 410 Severn Avenue, Suite 109, Annapolis, MD 21403
Who also contributed to the data set?	Versar, Inc.
To whom should users address questions about the data?	Versar, Inc. 9200 Rumsey Road, Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Who wrote the metadata? Metadata author	Versar, Inc. 9200 Rumsey Road Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-18. Meta-Data for "sdo_su_all_Q3"

Title	**75th Percentile, Surface Dissolved Oxygen, Summer, All Rainfall Year Types**
Abstract	This raster depicts the 75th percentile for surface dissolved oxygen for the summer (June-August) of the years 2001-2006 in Chesapeake Bay. This span of time contains 2 wet years, 2 dry years, and 2 average rainfall years. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of Environment, Alliance for the Chesapeake Bay, and Chesapeake Bay Program. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.
How should this data set be cited?	Versar 2009
Online Links:	www.versar.com
Does the data set describe conditions during a particular time period?	Summer (June-August) 2001-2006
What is the general form of this data set?	Raster

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Maryland Department of Natural Resources (MDNR), Eyes on the Bay , Tawes State Office Building, 580 Taylor Avenue, D2, Annapolis MD, 21401 Maryland Department of Environment (MDE), Department of Shellfish Health, Montgomery Park, 1800 Washington Blvd., Baltimore, MD 21230 Alliance for the Chesapeake Bay ,6600 York Road Suite 100, Baltimore, Maryland 21212

	Chesapeake Bay Program (CBP), Water Quality Database, 410 Severn Avenue, Suite 109, Annapolis, MD 21403
Who also contributed to the data set?	Versar, Inc.
To whom should users address questions about the data?	Versar, Inc. 9200 Rumsey Road, Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Who wrote the metadata? Metadata author	Versar, Inc. 9200 Rumsey Road Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-19. Meta-Data for “sdo_su_all_SE”

Title	**Standard Error, Bottom Salinity, Growing Season, All Rainfall Year Types**
Abstract	This raster depicts the standard error of the mean for bottom salinity occurring during the growing season of the American oyster (*Crassostrea virginica*) (April to October) for the years 2001-2006 at bottom depths ≤7m in Chesapeake Bay. This span of time contains 2 wet years, 2 dry years, and 2 average rainfall years. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of Environment, and Chesapeake Bay Program. Fixed stations whose bottom depth was ≤7m and vertical profile stations that collected data within the 7m depth contour were included. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.
How should this data set be cited?	Versar 2009
Online Links:	www.versar.com
Does the data set describe conditions during a particular time period?	Summer (June-August) 2001-2006
What is the general form of this data set?	Raster

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Maryland Department of Natural Resources (MDNR), Eyes on the Bay , Tawes State Office Building, 580 Taylor Avenue, D2, Annapolis MD, 21401 Maryland Department of Environment (MDE), Department of Shellfish Health, Montgomery Park, 1800 Washington Blvd., Baltimore, MD

	21230
	Chesapeake Bay Program (CBP), Water Quality Database, 410 Severn Avenue, Suite 109, Annapolis, MD 21403
Who also contributed to the data set?	Versar, Inc.
To whom should users address questions about the data?	Versar, Inc. 9200 Rumsey Road, Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Who wrote the metadata? Metadata author	Versar, Inc. 9200 Rumsey Road Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-20. Meta-Data for "bsal_gr_all_Q1"

Title	**25th Percentile, Bottom Salinity, Growing Season, All Rainfall Year Types**
Abstract	This raster depicts the 25th percentile of bottom salinity for the growing season of the American oyster (*Crassostrea virginica*) (April to October) occurring during years 2001-2006 at bottom depths ≤7m in Chesapeake Bay. This span of time contains 2 wet years, 2 dry years, and 2 average rainfall years. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of Environment, and Chesapeake Bay Program. Fixed stations whose bottom depth was ≤7m and vertical profile stations that collected data within the 7m depth contour were included. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.
How should this data set be cited?	Versar 2009
Online Links:	www.versar.com
Does the data set describe conditions during a particular time period?	Summer (June-August) 2001-2006
What is the general form of this data set?	Raster

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Maryland Department of Natural Resources (MDNR), Eyes on the Bay , Tawes State Office Building, 580 Taylor Avenue, D2, Annapolis MD, 21401 Maryland Department of Environment (MDE), Department of Shellfish Health, Montgomery Park, 1800 Washington Blvd., Baltimore, MD 21230

	Chesapeake Bay Program (CBP), Water Quality Database, 410 Severn Avenue, Suite 109, Annapolis, MD 21403
Who also contributed to the data set?	Versar, Inc.
To whom should users address questions about the data?	Versar, Inc. 9200 Rumsey Road, Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Who wrote the metadata? Metadata author	Versar, Inc. 9200 Rumsey Road Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-21. Meta-Data for "bsal_gr_all_Q3"

Title	**75th Percentile, Bottom Salinity, Growing Season, All Rainfall Year Types**
Abstract	This raster depicts the 75th percentile of bottom salinity for the growing season of the American oyster (*Crassostrea virginica*) (April to October) occurring during the years 2001-2006 at bottom depths ≤7m in Chesapeake Bay. This span of time contains 2 wet years, 2 dry years, and 2 average rainfall years. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of Environment, and Chesapeake Bay Program. Fixed stations whose bottom depth was ≤7m and vertical profile stations that collected data within the 7m depth contour were included. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.
How should this data set be cited?	Versar 2009
Online Links:	www.versar.com
Does the data set describe conditions during a particular time period?	Summer (June-August) 2001-2006
What is the general form of this data set?	Raster

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Maryland Department of Natural Resources (MDNR), Eyes on the Bay , Tawes State Office Building, 580 Taylor Avenue, D2, Annapolis MD, 21401 Maryland Department of Environment (MDE), Department of Shellfish Health, Montgomery Park, 1800 Washington Blvd., Baltimore, MD 21230

	Chesapeake Bay Program (CBP), Water Quality Database, 410 Severn Avenue, Suite 109, Annapolis, MD 21403
Who also contributed to the data set?	Versar, Inc.
To whom should users address questions about the data?	Versar, Inc. 9200 Rumsey Road, Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Who wrote the metadata? Metadata author	Versar, Inc. 9200 Rumsey Road Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-22. Meta-Data for "ssal_gr_all_SE"

Title	**Standard Error, Surface Salinity, Growing Season, All Rainfall Year Types**
Abstract	This raster depicts the standard error of the mean for surface salinity for the growing season of the American oyster (*Crassostrea virginica*) (April to October) occurring during the years 2001-2006 in Chesapeake Bay. This span of time contains 2 wet years, 2 dry years, and 2 average rainfall years. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of Environment, Virginia Department of Health Division of Shellfish Sanitation, Alliance for the Chesapeake Bay, and Chesapeake Bay Program. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.
How should this data set be cited?	Versar 2009
Online Links:	www.versar.com
Does the data set describe conditions during a particular time period?	Summer (June-August) 2001-2006
What is the general form of this data set?	Raster

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Maryland Department of Natural Resources (MDNR), Eyes on the Bay , Tawes State Office Building, 580 Taylor Avenue, D2, Annapolis MD, 21401 Maryland Department of Environment (MDE), Department of Shellfish Health, Montgomery Park, 1800 Washington Blvd., Baltimore, MD 21230

	Virginia Department of Health (VDH), Division of Shellfish Sanitation, Madison Building, 109 Governor Street, 6th Floor Richmond, Virginia 23219 Alliance for the Chesapeake Bay ,6600 York Road Suite 100, Baltimore, Maryland 21212 Chesapeake Bay Program (CBP), Water Quality Database, 410 Severn Avenue, Suite 109, Annapolis, MD 21403
Who also contributed to the data set?	Versar, Inc.
To whom should users address questions about the data?	Versar, Inc. 9200 Rumsey Road, Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Who wrote the metadata? Metadata author	Versar, Inc. 9200 Rumsey Road Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-23. Meta-Data for "ssal_gr_all_Q1"

Title	**25th Percentile, Surface Salinity, Growing Season, All Rainfall Year Types**
Abstract	This raster depicts the 25th percentile of surface salinity for the growing season of the American oyster (*Crassostrea virginica*) (April to October) occurring during years 2001-2006 in Chesapeake Bay. This span of time contains 2 wet years, 2 dry years, and 2 average rainfall years. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of Environment, Virginia Department of Health Division of Shellfish Sanitation, Alliance for the Chesapeake Bay, and Chesapeake Bay Program. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.
How should this data set be cited?	Versar 2009
Online Links:	www.versar.com
Does the data set describe conditions during a particular time period?	Summer (June-August) 2001-2006
What is the general form of this data set?	Raster

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Maryland Department of Natural Resources (MDNR), Eyes on the Bay , Tawes State Office Building, 580 Taylor Avenue, D2, Annapolis MD, 21401 Maryland Department of Environment (MDE), Department of Shellfish Health, Montgomery Park, 1800 Washington Blvd., Baltimore, MD 21230

	Virginia Department of Health (VDH), Division of Shellfish Sanitation, Madison Building, 109 Governor Street, 6th Floor Richmond, Virginia 23219 Alliance for the Chesapeake Bay ,6600 York Road Suite 100, Baltimore, Maryland 21212 Chesapeake Bay Program (CBP), Water Quality Database, 410 Severn Avenue, Suite 109, Annapolis, MD 21403
Who also contributed to the data set?	Versar, Inc.
To whom should users address questions about the data?	Versar, Inc. 9200 Rumsey Road, Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Who wrote the metadata? Metadata author	Versar, Inc. 9200 Rumsey Road Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-24. Meta-Data for "ssal_gr_all_Q3"

Title	**75th Quartile, Surface Salinity, Growing Season, All Rainfall Year Types**
Abstract	This raster depicts the 75th percentile of surface salinity for the growing season of the American oyster (*Crassostrea virginica*) (April to October) occurring during the years 2001-2006 in Chesapeake Bay. This span of time contains 2 wet years, 2 dry years, and 2 average rainfall years. This raster was generated using data from Maryland Department of Natural Resources, Maryland Department of Environment, Virginia Department of Health Division of Shellfish Sanitation, Alliance for the Chesapeake Bay, and Chesapeake Bay Program. Using these point data sources, interpolations were carried out using Inverse-Distance Weighting (IDW) in ArcGIS version 9.3. The power of the interpolation was set to 2. Higher values of power allot less influence to points further away on the surface being interpolated (Shepard 1968). By using power equal to 2, values included in the interpolation were multiplied by the inverse of their squared distance from the point being interpolated, thereby reducing their overall weight in the interpolation. A variable search radius was used with up to 10 of the nearest points used to make the interpolation. The output grid cell size is 1 km X 1 km.
How should this data set be cited?	Versar 2009
Online Links:	www.versar.com
Does the data set describe conditions during a particular time period?	Summer (June-August) 2001-2006
What is the general form of this data set?	Raster

Who produced the data set?

Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Maryland Department of Natural Resources (MDNR), Eyes on the Bay , Tawes State Office Building, 580 Taylor Avenue, D2, Annapolis MD, 21401 Maryland Department of Environment (MDE), Department of Shellfish Health, Montgomery Park, 1800 Washington Blvd., Baltimore, MD 21230

	Virginia Department of Health (VDH), Division of Shellfish Sanitation, Madison Building, 109 Governor Street, 6th Floor Richmond, Virginia 23219 Alliance for the Chesapeake Bay ,6600 York Road Suite 100, Baltimore, Maryland 21212 Chesapeake Bay Program (CBP), Water Quality Database, 410 Severn Avenue, Suite 109, Annapolis, MD 21403
Who also contributed to the data set?	Versar, Inc.
To whom should users address questions about the data?	Versar, Inc. 9200 Rumsey Road, Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Who wrote the metadata? Metadata author	Versar, Inc. 9200 Rumsey Road Columbia, MD Phone: 410-964-9200 Fax: 410-964-5156
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

A-25. Meta-Data for "Phytoplankon_utm"

Title	**Distribution and Abundance of Phytoplankton**
Abstract	This dataset contains information on the distribution and abundance of phytoplankton in the Chesapeake Bay. Data were downloaded from the Chesapeake Bay Program data hub; Old Dominion University and Morgan State University collected these data during the years of 1980-2008. Additional data in this dataset were provided by the Maryland Department of Natural Resources. These data are stored in a searchable Access database that contains two tables. One table contains the names and geographic locations of the sampling stations ("phytoplankton stations") and the second table contains the data for each of the stations ("phytoplankton data"). Data for individual stations can be queried out of the data table using the station name from the station table.
How should this data set be cited?	Versar, Inc. 2009
Online Links:	Chesapeake Bay Program Data Hub: http://www.chesapeakebay.net/dataandtools.aspx Maryland Department of Natural Resources http://www.dnr.state.md.us/
Does the data set describe conditions during a particular time period?	1980-2009
What is the general form of this data set?	Shapefile

Data

FID	unique whole numbers that are automatically generated by ArcGIS.
Shape	Feature geometry. All features are points in this shapefile.
STATION	Name of the station where the data were collected.
LATITUDE	The latitude of the sampling station in decimal degrees.
LONGITUDE	The longitude of the sampling station in decimal degrees.
LL_DATUM	GIS projection.
BASIN	Water body in which the sampling station is located.
SUBBASIN	Sub-water body in which the sampling station is located.
OLDSTATION	Old station name for MDDNR data.
LAT	Latitude of sampling station in Degrees (1st two digits), Minutes (3rd and 4th digits), Seconds (last two digits)
LONG	Longitude of sampling station in Degrees (1st two digits), Minutes (3rd and 4th digits), Seconds (last two digits)

Who produced the data set?	Versar, Inc. 9200 Rumsey Road Columbia, MD 21045
Who are the originators of the data set? (may include formal authors, digital compilers, and editors)	Maryland Department of Natural Resources Tawes State Office Building, 580 Taylor Avenue, D2, Annapolis MD, 21401 Chesapeake Bay Program (CBP), Water Quality Database, 410 Severn Avenue, Suite 109, Annapolis, MD 21403
Who also contributed to the data set?	Versar, Inc. 9200 Rumsey Road Columbia, MD 21045
To whom should users address questions about the data?	H. Ward Slacum Environmental Scientist 9200 Rumsey Road Ste. 100 Columbia, Maryland 21045 USA 410-964-9200 (voice) 410-964-5156 (FAX)
Who wrote the metadata?	Versar, Inc.
Metadata author	Versar, Inc. c/o Elizabeth Methratta. Senior Scientist 9200 Rumsey Road Ste. 100 Columbia, Maryland 21045 USA 410-964-9200 (voice) 410-964-5156 (FAX) wslacum@versar.com
Metadata standard	FGDC Content Standards for Digital Geospatial Metadata (FGDC-STD-001-1998)

APPENDIX B

DATA SOURCES AND SAMPLE SIZES

Source	Flow	Bottom DO		Surface DO		Bottom Salinity		Surface Salinity	
		Num. of Stations	Num. of Samples	Num. of Stations	Num. of Samples	Num. of Stations	Num. of Samples	Num. of Stations	Num. of Samples
Alliance for CB Citizen Mon.	Ave	0	0	48	897	0	0	32	742
Alliance for CB Citizen Mon.	Dry	0	0	61	1,443	0	0	45	1,227
Alliance for CB Citizen Mon.	Wet	0	0	59	1,273	0	0	42	950
CBP	Ave	0	2,431	547	3,862	0	5,240	429	7,335
CBP	Dry	6	1,336	288	2,156	4	2,910	234	4,065
CBP	Wet	9	1,874	443	3,151	8	3,935	372	6,150
MDDNR Cont. Mon.	Ave	29	3,505	29	3,302	29	8,466	29	7,947
MDDNR Cont. Mon.	Dry	0	0	7	790	0	0	7	1,641
MDDNR Cont. Mon.	Wet	15	1,898	24	2,881	15	4,141	24	6,429
MDE	Ave	210	1,060	57	1,297	231	2,389	69	2,975
MDE	Dry	120	628	61	926	155	1,320	64	1,883
MDE	Wet	178	1,022	64	1,435	175	2,070	87	2,962
VDH Shellfish	Ave	0	0	0	0	0	0	309	3,481
VDH Shellfish	Dry	0	0	0	0	0	0	300	3,787
VDH Shellfish	Wet	0	0	0	0	0	0	360	3,523

Table B-1. The number of sampling stations (Num. of Stations) and number of samples (Num. of Samples) taken from each data source to construct the rasters for the **mean** of each parameter during each rainfall (Flow) year type. The number of samples is greater than the number of sampling stations because most sampling stations provided more than one sample. Data sources: Alliance for Chesapeake Bay Citizen Monitoring, Chesapeake Bay Program (CBP), Maryland Department of Natural Resources Continuous Monitoring (MDNR Cont. Mon.), Maryland Department of the Environment (MDE), Virginia Department of Health/Division of Shellfish Sanitation (VDH Shellfish).

Flow	Bottom DO Num. of Stations	Bottom DO Num. of Samples	Surface DO Num. of Stations	Surface DO Num. of Samples	Bottom Salinity Num. of Stations	Bottom Salinity Num. of Samples	Surface Salinity Num. of Stations	Surface Salinity Num. of Samples
Ave	239	6,996	681	9,358	260	16,095	868	22,480
Dry	126	1,964	417	5,315	159	4,230	650	12,603
Wet	202	4,794	590	8,740	198	10,146	885	20,014

Table B-2. The total number of sampling stations and number of samples used to construct the rasters for the **mean** of each parameter during each rainfall (Flow) year type. The number of samples is greater than the number of sampling stations because most sampling stations provided more than one sample. The information in this table represents a summation of station counts and sample counts across data sources listed in Table B-1.

Source	Bottom DO		Surface DO		Bottom Salinity		Surface Salinity	
	Num. of Stations	Num. of Samples	Num. of Stations	Num. of Samples	Num. of Stations	Num. of Samples	Num. of Stations	Num. of Samples
Alliance for CB Citizen Mon.	0	0	168	3,613	0	0	119	2,919
CBP	15	5,641	1,278	9,169	12	12,085	1,035	17,550
MDDNR Cont. Mon.	44	5,403	60	6,973	44	12,607	60	16,017
MDE	508	2,710	182	3,658	561	5,779	220	7,820
VDH Shellfish	0	0	0	0	0	0	969	10,791

Table B-3. The number of sampling stations and number of samples taken from each data source to construct the rasters for the **variability** (standard error, 25th percentile, 75th percentile) of each parameter during each rainfall (Flow) year type. The number of samples is greater than the number of sampling stations because most sampling stations provided more than one sample. Data sources: Alliance for Chesapeake Bay Citizen Monitoring, Chesapeake Bay Program (CBP), Maryland Department of Natural Resources Continuous Monitoring (MDNR Cont. Mon.), Maryland Department of the Environment (MDE), Virginia Department of Health/Division of Shellfish Sanitation (VDH Shellfish).

C-3: GIS ANALYSIS

Native Oyster Restoration Master Plan
GIS Analysis Methodology: Tri Suitability Evaluation

The GIS analysis evaluation used was a sequence of steps or functions used as part of a GIS analysis (the binary, ranking, rating, and weighted rating analysis evaluations where grids are multiplied, added, averaged and weighted averaged, but there are many, many more approaches possible).

GIS analysis evaluations provide:
• A simplified, manageable view of reality
• They capture spatial relationships of objects
• They capture attributes of an object
• This type of evaluation can help you understand, describe, or predict how things work in the real world
• They can also help us understand our level of knowledge about the real world
• Types: representation & process (suitability, distance, surface, hydrologic and more)

The Native Oyster Restoration Master Plan GIS Analysis began with these existing base raster datasets:

Mean Surface Salinity, growing season wet	-	ssal_gr_wet_mean
Mean Surface Salinity, growing season dry	-	ssal_gr_dry_mean
Mean Surface Salinity, growing season average	-	ssal_gr_avg_mean
Mean Bottom Salinity, growing season wet	-	bsal_gr_wet_mean
Mean Bottom Salinity, growing season dry	-	bsal_gr_dry_mean
Mean Bottom Salinity, growing season average	-	bsal_gr_avg_mean
Bottom DO-mean summer- Wet years	-	bdo_su_wet_mean
Bottom DO-mean summer- Dry years	-	bdo_su_dry_mean
Bottom DO-mean summer- average years	-	bdo_su_ave_mean

Maps of each of these datasets are available in Appendix C-4 (Figures C-4A to F, and J-I).

Figure C-3A depicts the GIS evaluation that was completed. The following text describes the steps that were carried out to complete the evaluation.

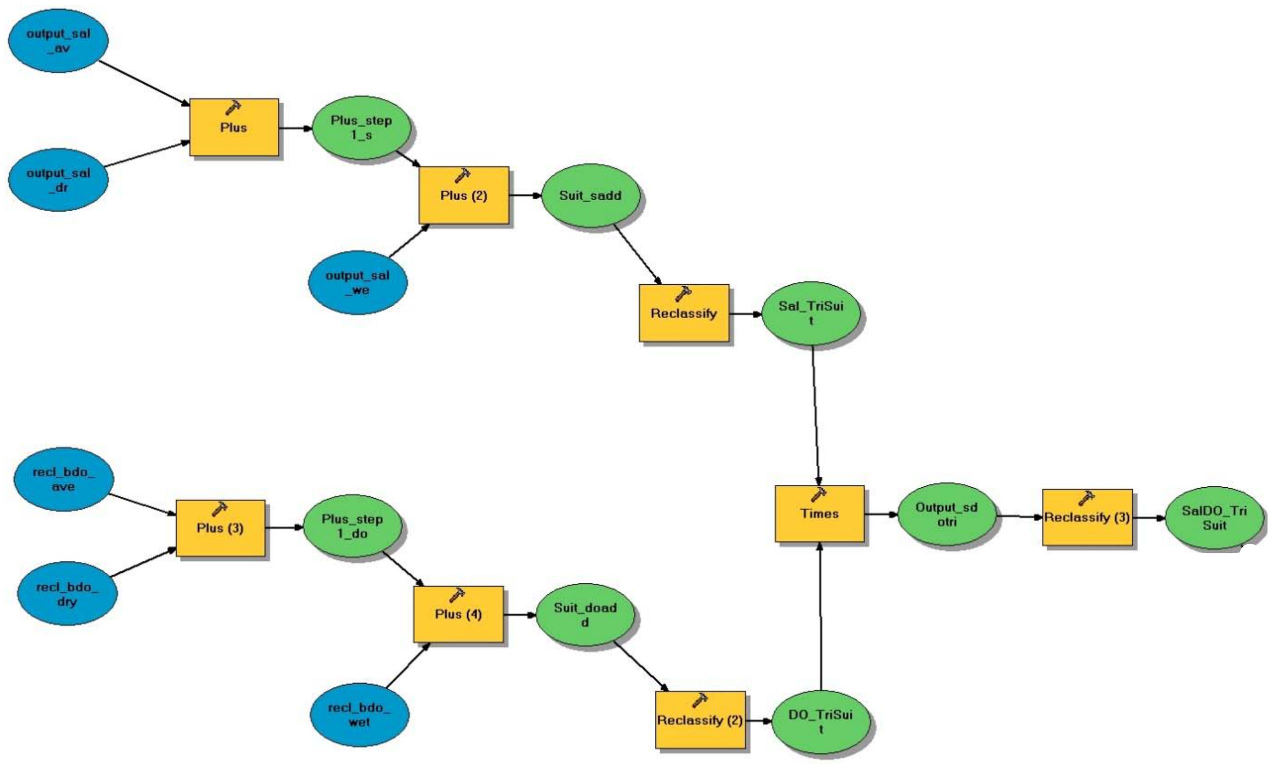


Figure C-3A: GIS Trisuitability Evaluation

Step 1 Each of these base datasets went through the **Reclassify** analysis tool which changes the values in a raster from their Old Values to New Values.

	Old Values	New Values
Unsuitable DO or salinity	0 - 4.999999	0
Suitable DO or salinity	5 - 50	1
	No Data	No Data

Once these base datasets were reclassified, the output file created these new rasters:
recl_ssal_ave
recl_ssal_dry
recl_ssal_wet
recl_bsal_ave
recl_bsal_dry
recl_bsal_wet
recl_bdo_ave
recl_bdo_dry
recl_bdo_wet

Step 2 The study team wanted to include both bottom and surface salinity to evaluate whether an area was good for both larval (surface) and mature (bottom) oysters. With the above new raster datasets created by the **Reclassify** tool, the next step was to **Times** (multiplies the values of two rasters on a cell by cell basis) the Surface and Bottom Salinity rasters. Cells that have suitable surface and bottom salinity have a value of '1' after multiplication. Those that do not meet one or both criteria have a value of '0'.

recl_ssal_ave	X	recl_bsal_ave	=	output_sal_av
recl_ssal_dry	X	recl_bsal_dry	=	output_sal_dr
recl_ssal_wet	X	recl_bsal_wet	=	output_sal_we

Step 3 The next two steps combined the data for all hydrologic conditions in order to determine if an area was suitable under all hydrologic years, suitable in only some years, or not suitable regardless of hydrologic conditions. Involvement of raster datasets created by Steps 1 and 2 were used in the **Plus** analysis tool to add the values of two rasters on a cell by cell basis within the analysis window. Cells that had suitable conditions in all hydrologic years resulted in a value '3' (1+1+1); those that had suitable conditions in some years had a value of '2' (1+1+0, 0+1+1, or 1+0+1) or '1' (1+0+0, 0+1+0, or 0+0+1); and those that were unsuitable regardless of hydrologic year resulted in a value of '0' (0+0+0).

output_sal_av	+	output_sal_dr	=	Plus_step1_s
recl_bdo_ave	+	recl_bdo_dry	=	Plus_step1_do

Step 4 The **Plus** analysis tool was used again for the raster datasets below.

output_sal_we	+	Plus_step1_s	=	Suit_sadd
recl_bdo_wet	+	Plus_step1_do	=	Suit_doadd

Step 5 The **Reclassify** tool was used again on the raster datasets (both Suit_sadd and Suit_doadd) created in Step 4.

	Old Values	New Values
Currently not suitable	0	0
Sometimes suitable	1	1
Sometimes suitable	2	1
Always suitable	3	2
	No Data	No Data

Once these raster datasets were reclassified, the output file created these new rasters:

Sal_Trisuit (Figure 5-7)
DO_Trisuit (Figure 5-8)

Step 6 This step overlayed the salinity and DO data layers to identify areas that were suitable for both salinity and DO. With the above new raster datasets created by the **Reclassify** tool, we again used the **Times** tool (multiplies the values of two rasters on a cell by cell basis) on the Sal_Trisuit and DO_Trisuit rasters. Cells that had suitable conditions for both salinity and DO resulted in a value '4' (2x2); those that were sometimes suitable had a value of '1' (1x1) or '2' (2x1 or 1x2); and those that were unsuitable resulted in a value of '0' (0x0, 0x1, 1x0, 0x2, or 2x0).

Sal_Trisuit X DO_Trisuit = output_sdotri

Step 7 Again the **Reclassify** tool was involved in changing the values in a raster from their Old Values to New Values.

output_sdotri

	Old Values	New Values
Currently not suitable	0	0
Sometimes suitable	1	1
Sometimes suitable	2	1
Always Suitable	4	2
	No Data	No Data

Once this raster layer was reclassified, the output file created this new raster:

SalDO_TriSuit (Figure C-3B)

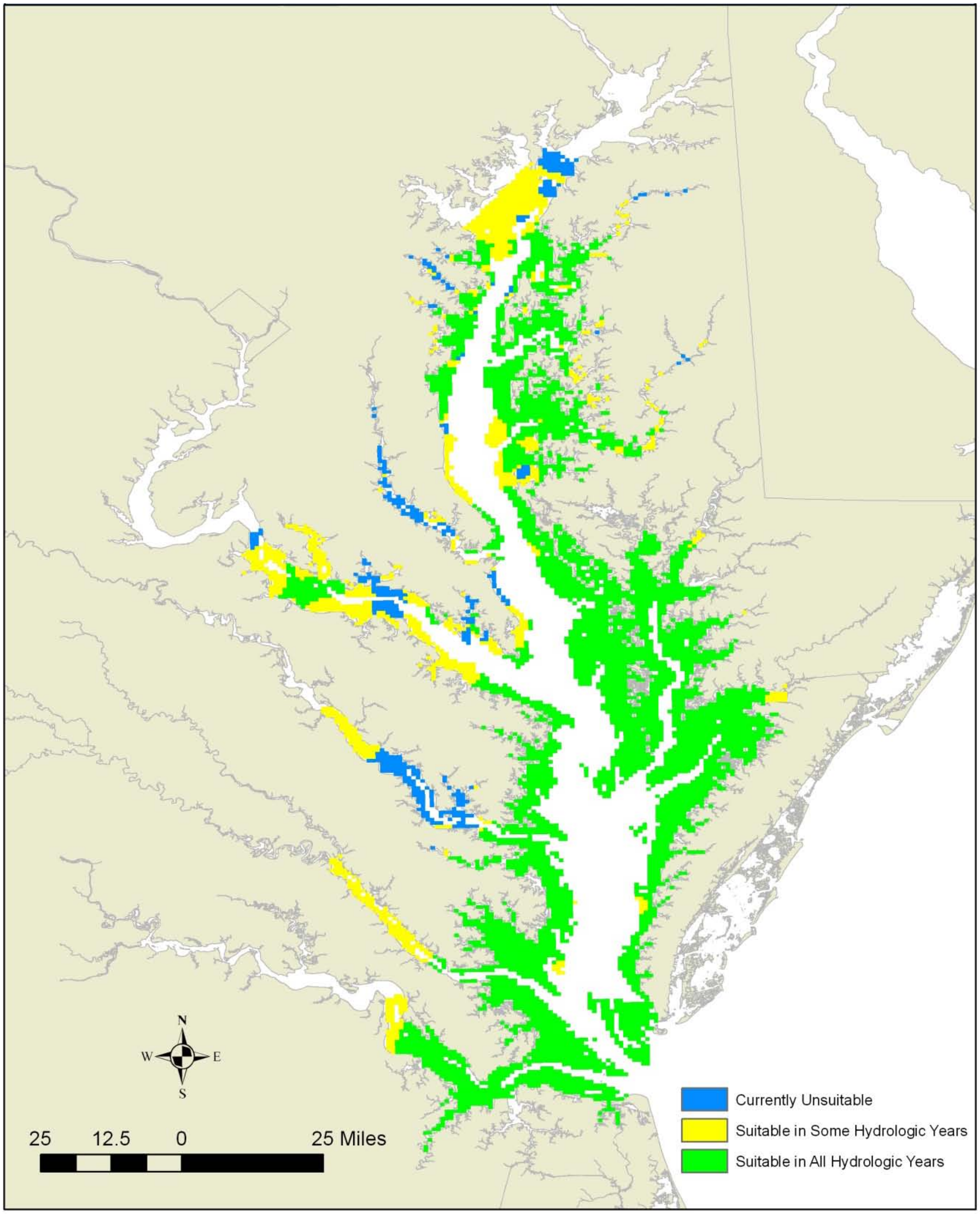


Figure C-3B: Saldo_trisuit

Step 8 Involved two steps, A & B. The first was to **Reclassify** the baselayer water depth file:

8A Chesapeake_Bay (water depth)

Old Values	New Values
-52 - -20	0
-20 - 0	1
0 - 2	0
No Data	No Data

Once this raster layer was reclassified, the output file created this new raster:

recl_baydepth (Figure 5-9)

8B This step screened the areas that are suitable for salinity and DO for water depth. The **Times** tool (multiplies the values of two rasters on a cell by cell basis) was used on the SalDO_TriSuit and recl_baydepth rasters.

SalDO_TriSuit X recl_baydepth = SDO_D_TriSuit (Figure 5-12)

Step 9 This file **SDO_D_TriSuit** was joined with the DSS boundaries (**DSS_sdo_d_trisuit**) to provide a summation of 'always suitable', 'sometimes suitable', and 'currently not suitable' acreages by DSS. Table 5.5 provides a summary of suitable and unsuitable acreages by DSS.

Step 10 In order to identify the 'always suitable', 'sometimes suitable', and 'currently not suitable' acreages within the boundaries of the Yates bars and Baylor grounds, **DSS_sdo_d_trisuit** was clipped by **yates_baylor_utm**. (**DSS_sdo_d_trisuit_YB**) (Figure 5-13).

Step 11 The sdo_d_trisuit data was also analyzed to provide the 'always suitable', 'sometimes suitable', and 'currently not suitable' acreages within the boundaries of designated oyster sanctuaries. **DSS_sdo_d_trisuit** was clipped by **Sanctuaries_Dec2010**. (**DSS_sdo_d_trisuit_Sanc**)

Step 12 The final step was to identify the 'always suitable', 'sometimes suitable', and 'currently not suitable' acreages within the boundaries of the Yates bars and Baylor grounds and within the designated oyster sanctuaries. **DSS_sdo_d_trisuit** was clipped by the **yates_baylor_utm** and then clipped by **Sanctuaries_Dec2010.** (**DSS_sdo_d_trisuit_YB_Sanc**) (Figure 5-14)

Evaluation of the impact of using 5 mg/L for the DO criteria rather than 2 mg/L.

Similar GIS analyses as described above were performed using 2 mg/L for the DO criteria to understand the impacts to the results from setting the criteria at 5 mg/L. The results are provided in Figure C-4P.

C-4: MISCELLANEOUS MAPS AND TABLES

This appendix contains maps depicting data used in the GIS methodology at intermediate steps as well as analyses performed to consider surface DO and setting the DO criteria at 2 mg/L. Suitability results are presented for individual hydrologic year. The locations of the water quality stations are provided as well as information on the Virginia Oyster Atlas.

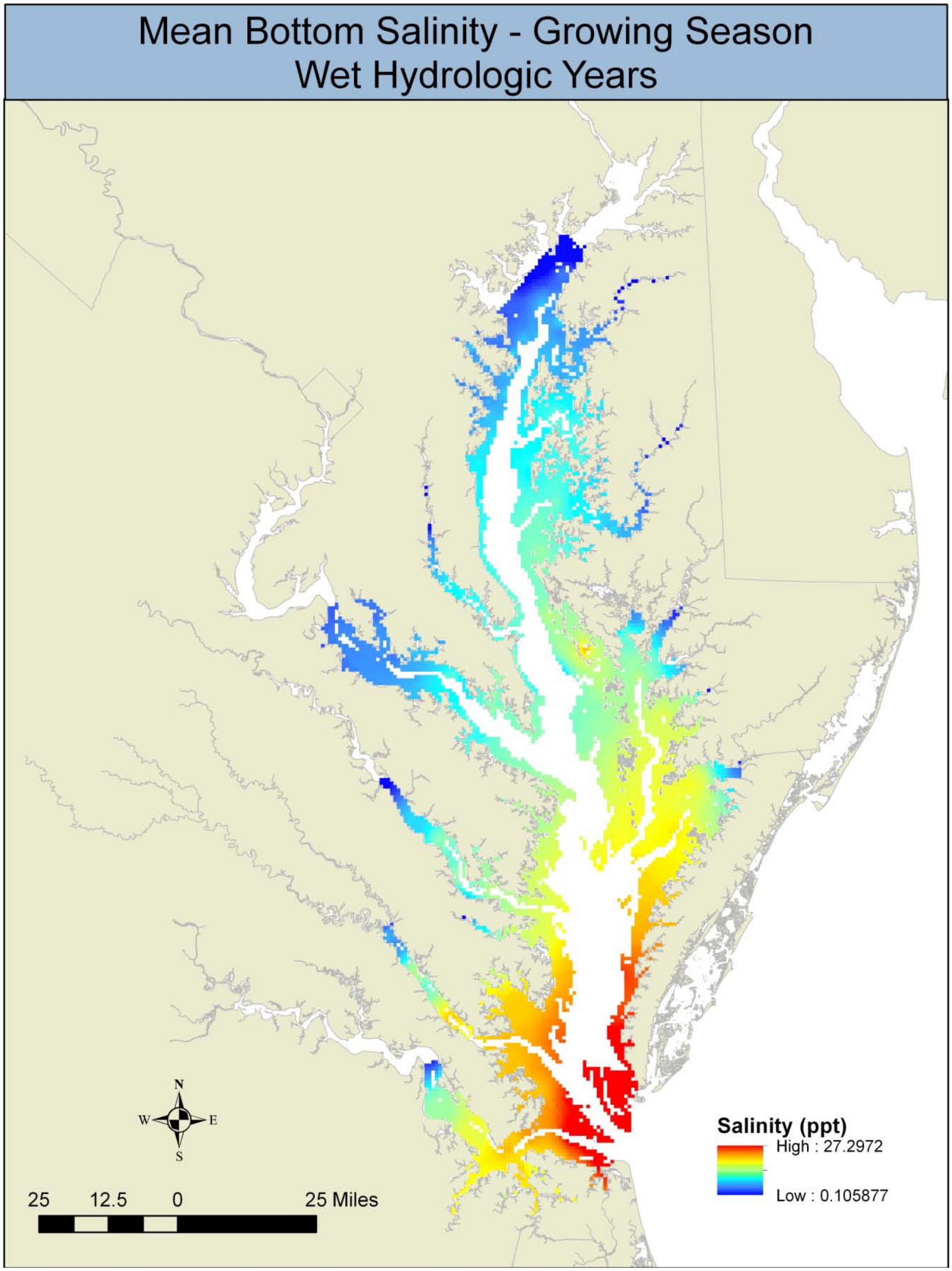


Figure C-4A: Mean Bottom Salinity during Growing Season in Wet Hydrologic Years

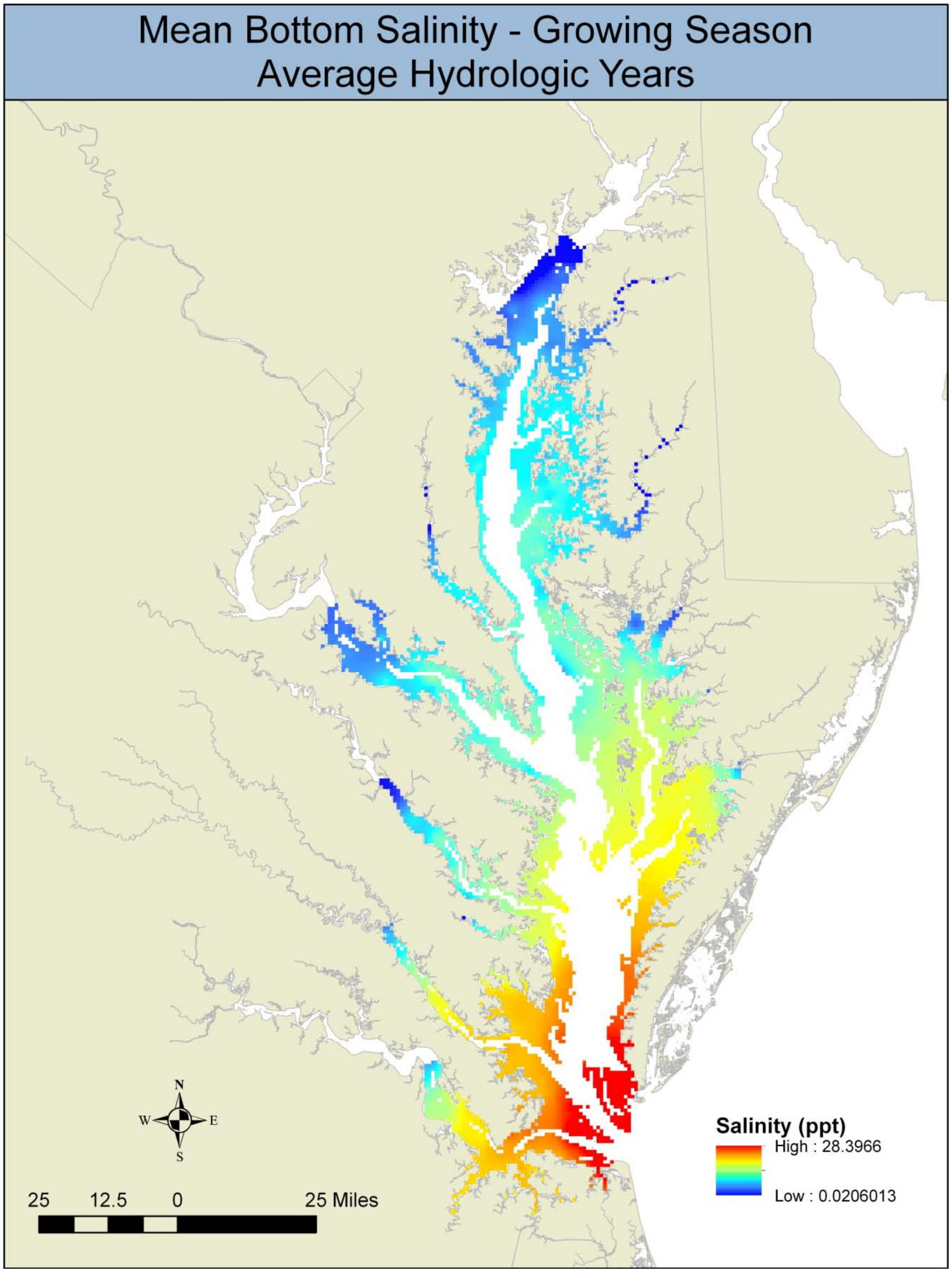


Figure C-4B: Mean Bottom Salinity during Growing Season in Average Hydrologic Years

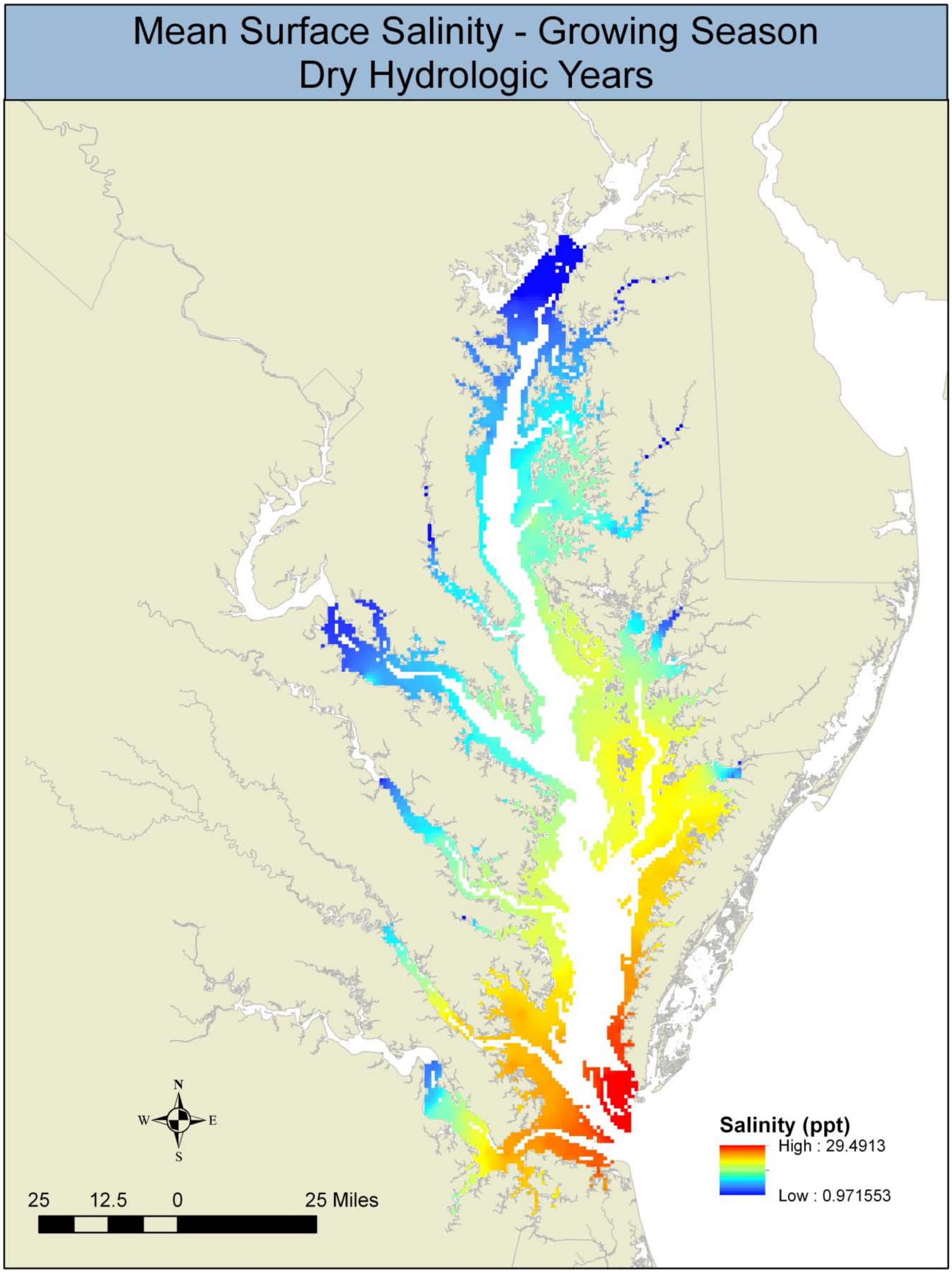


Figure C-4C: Mean Bottom Salinity during Growing Season in Dry Hydrologic Years

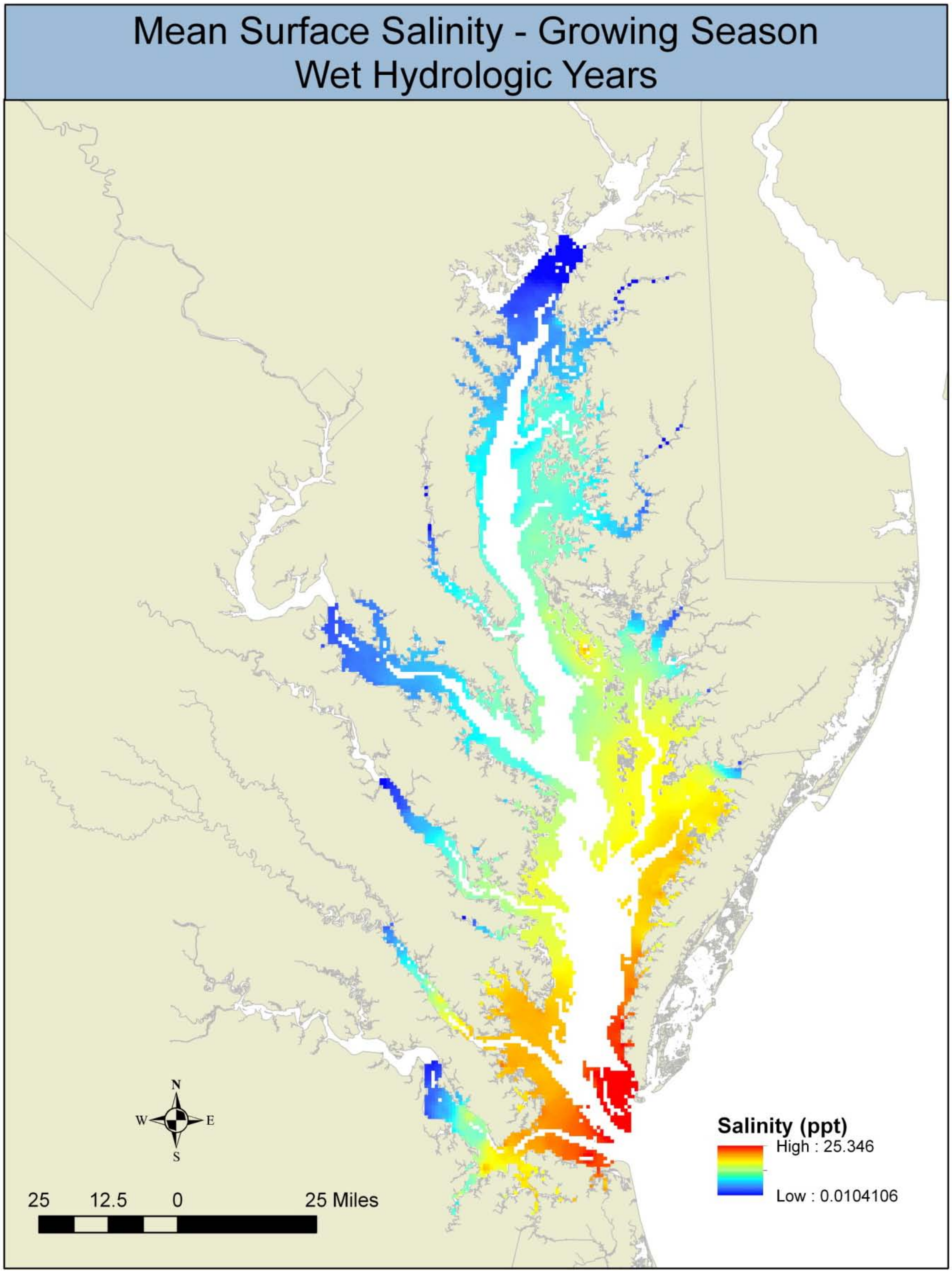


Figure C-4D: Mean Surface Salinity during Growing Season in Wet Hydrologic Years

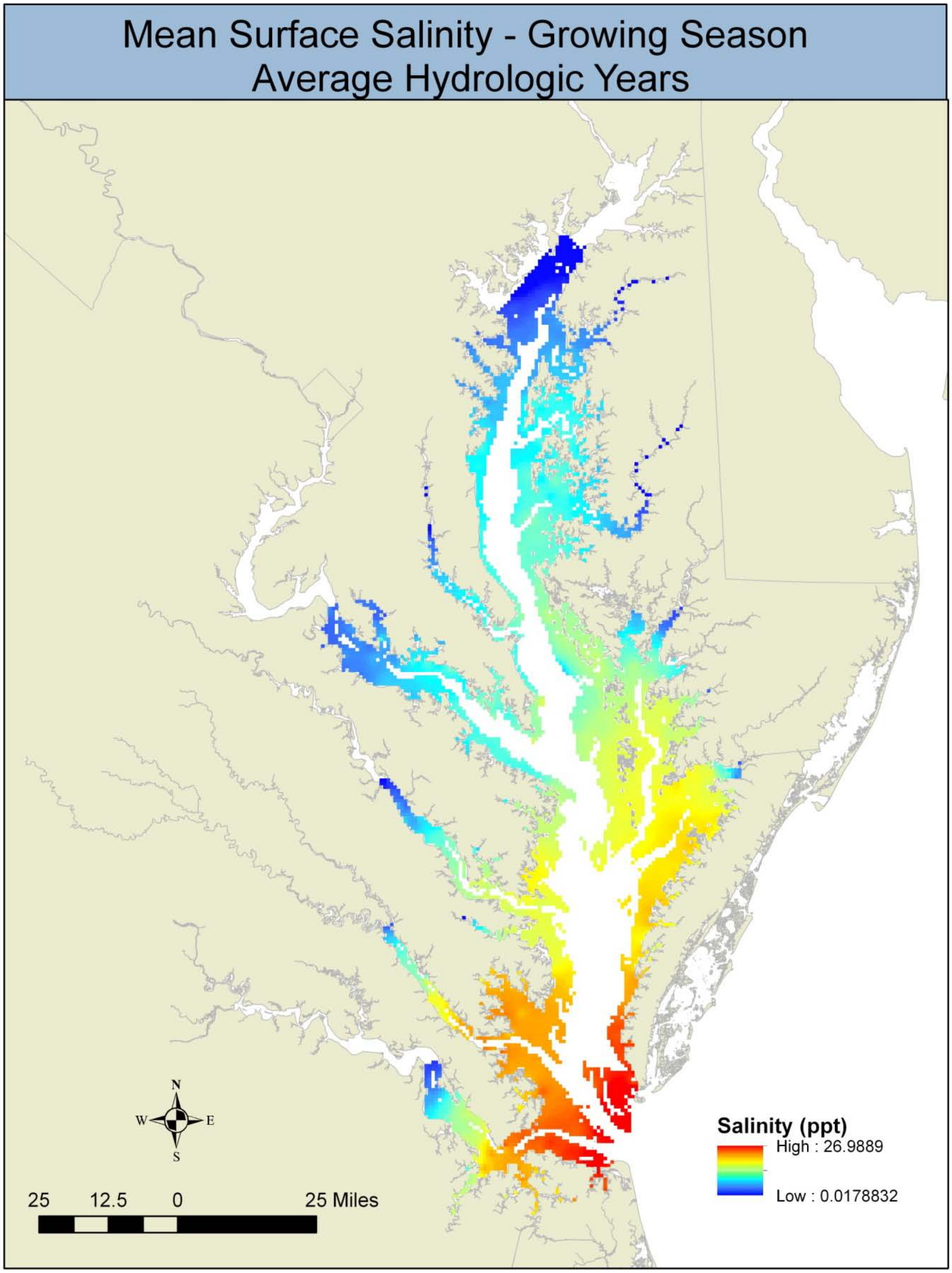


Figure C-4E: Mean Surface Salinity during Growing Season in Average Hydrologic Years

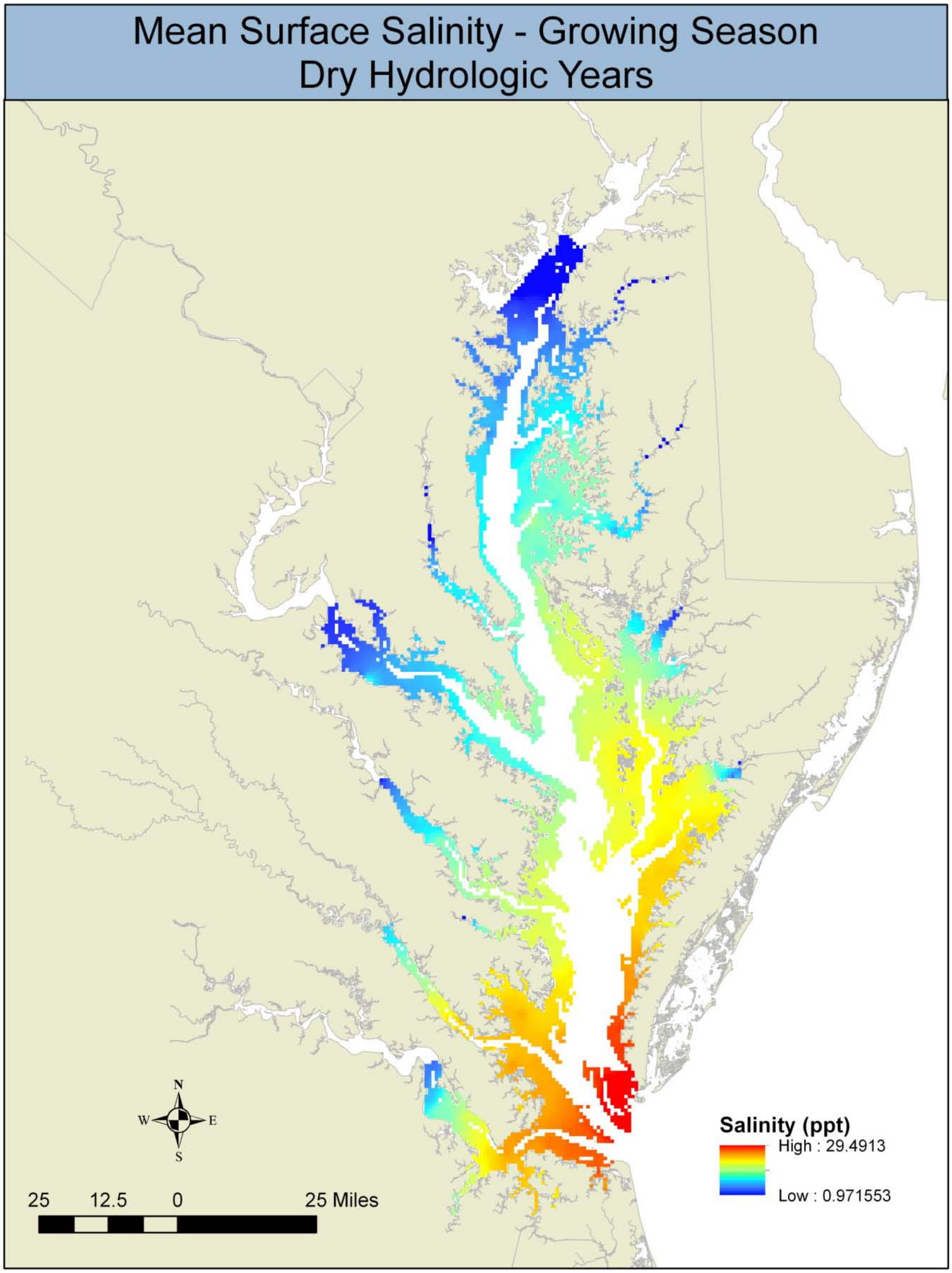


Figure C-4F: Mean Surface Salinity during Growing Season in Dry Hydrologic Years

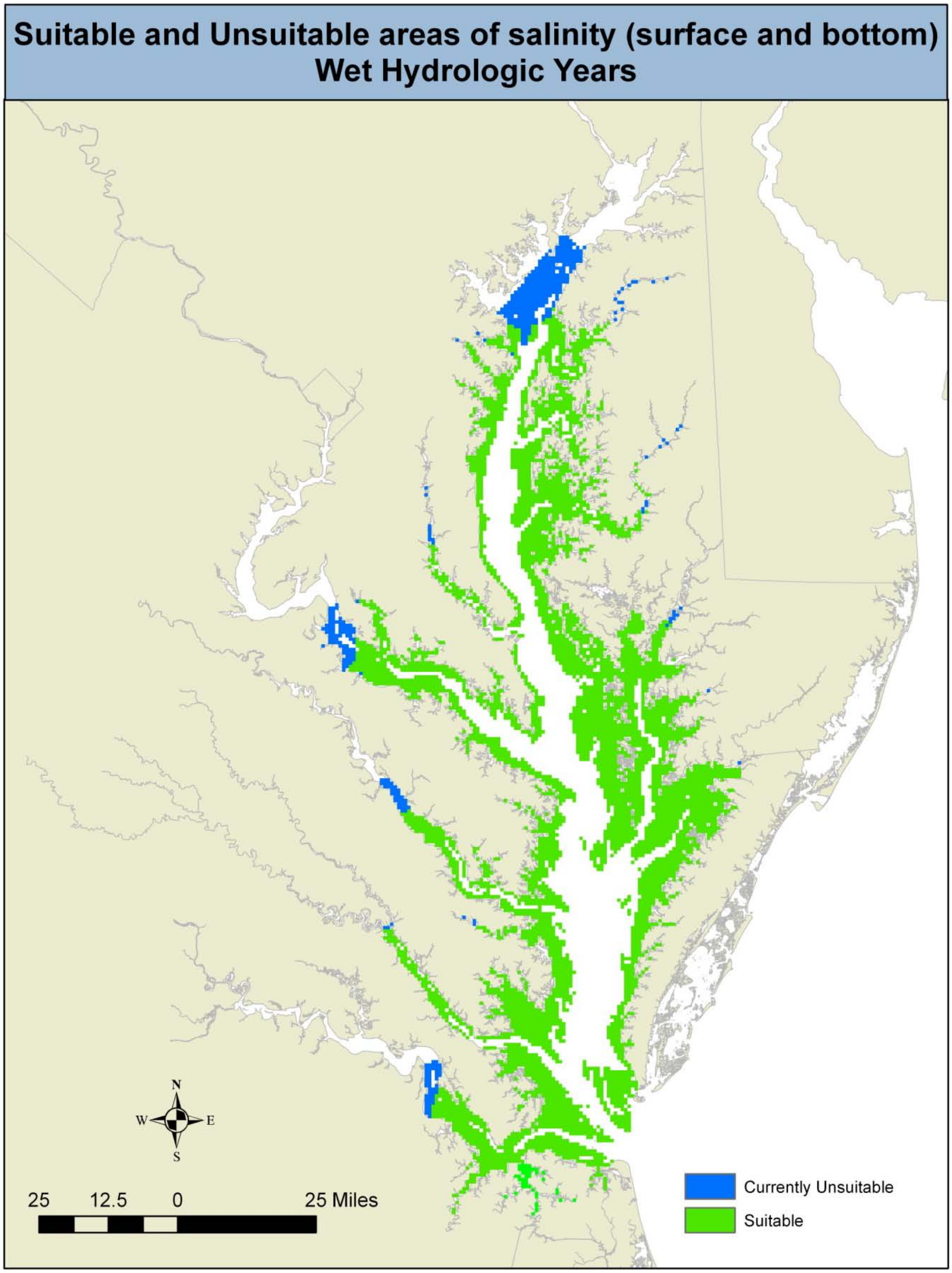


Figure C-4G: Suitable and unsuitable salinity (surface x bottom) in Wet Hydrologic Years

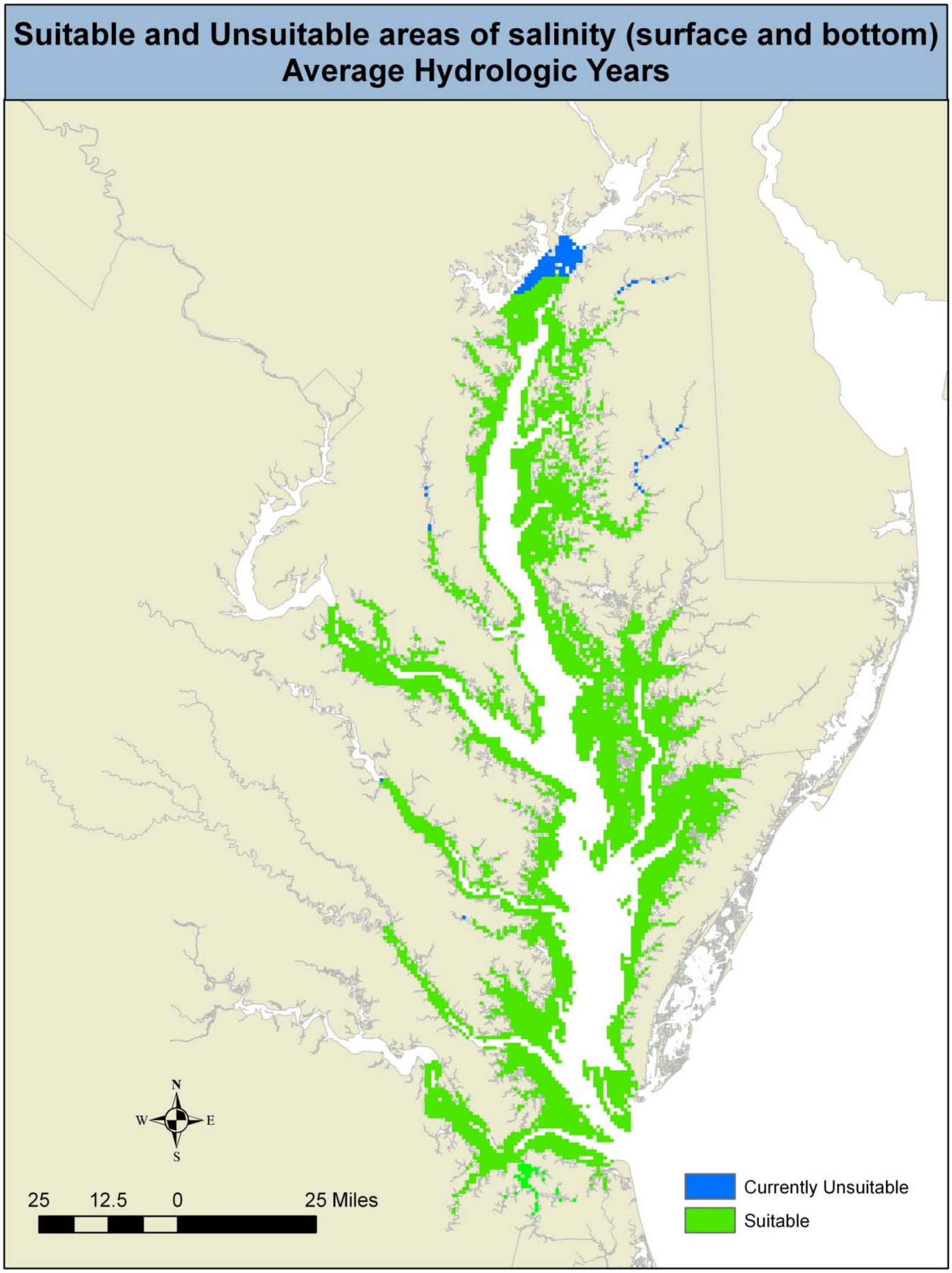


Figure C-4H: Suitable and unsuitable salinity (surface x bottom) in Average Hydrologic Years

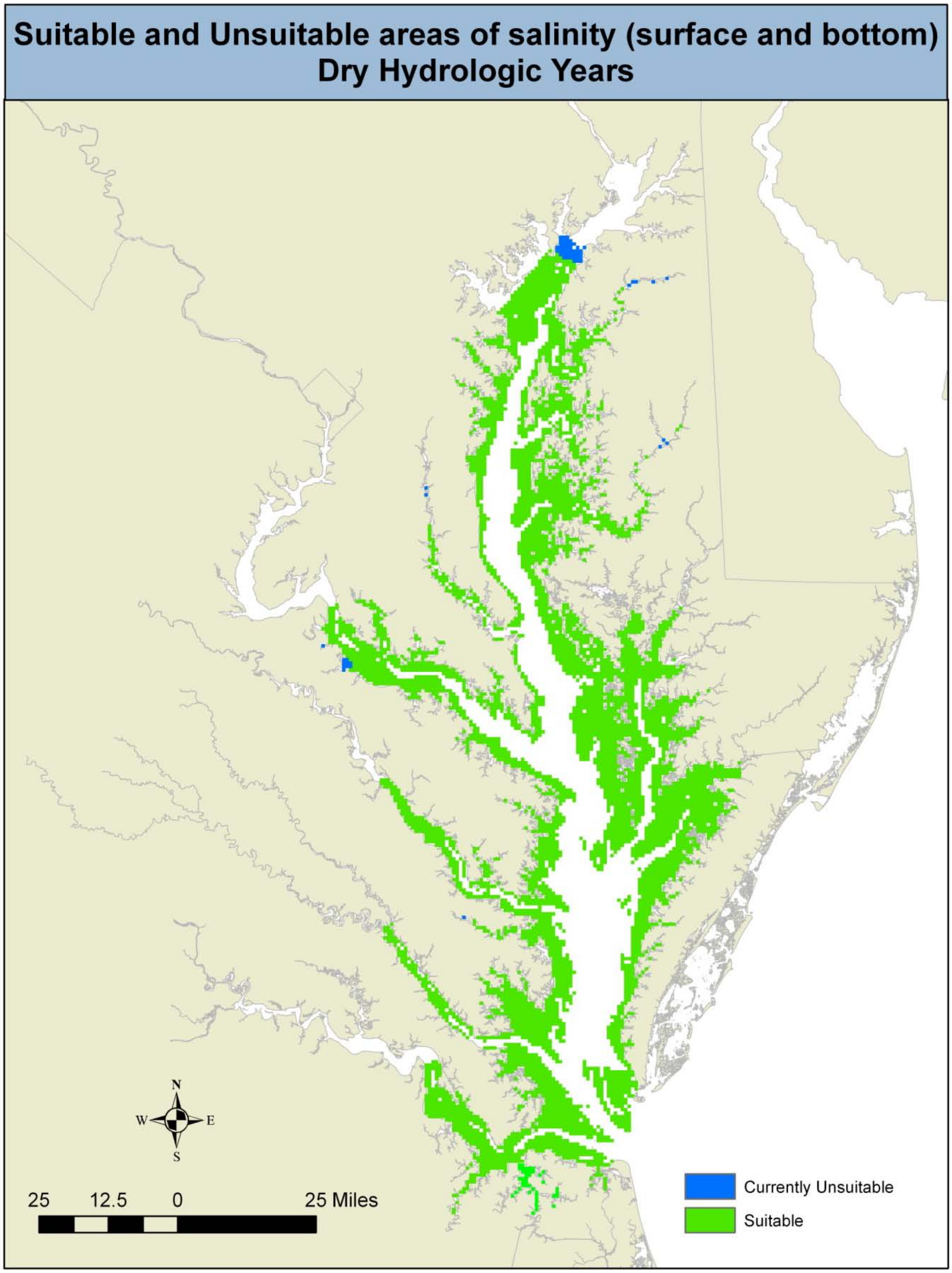


Figure C-4I: Suitable and unsuitable salinity (surface x bottom) in Dry Hydrologic Years

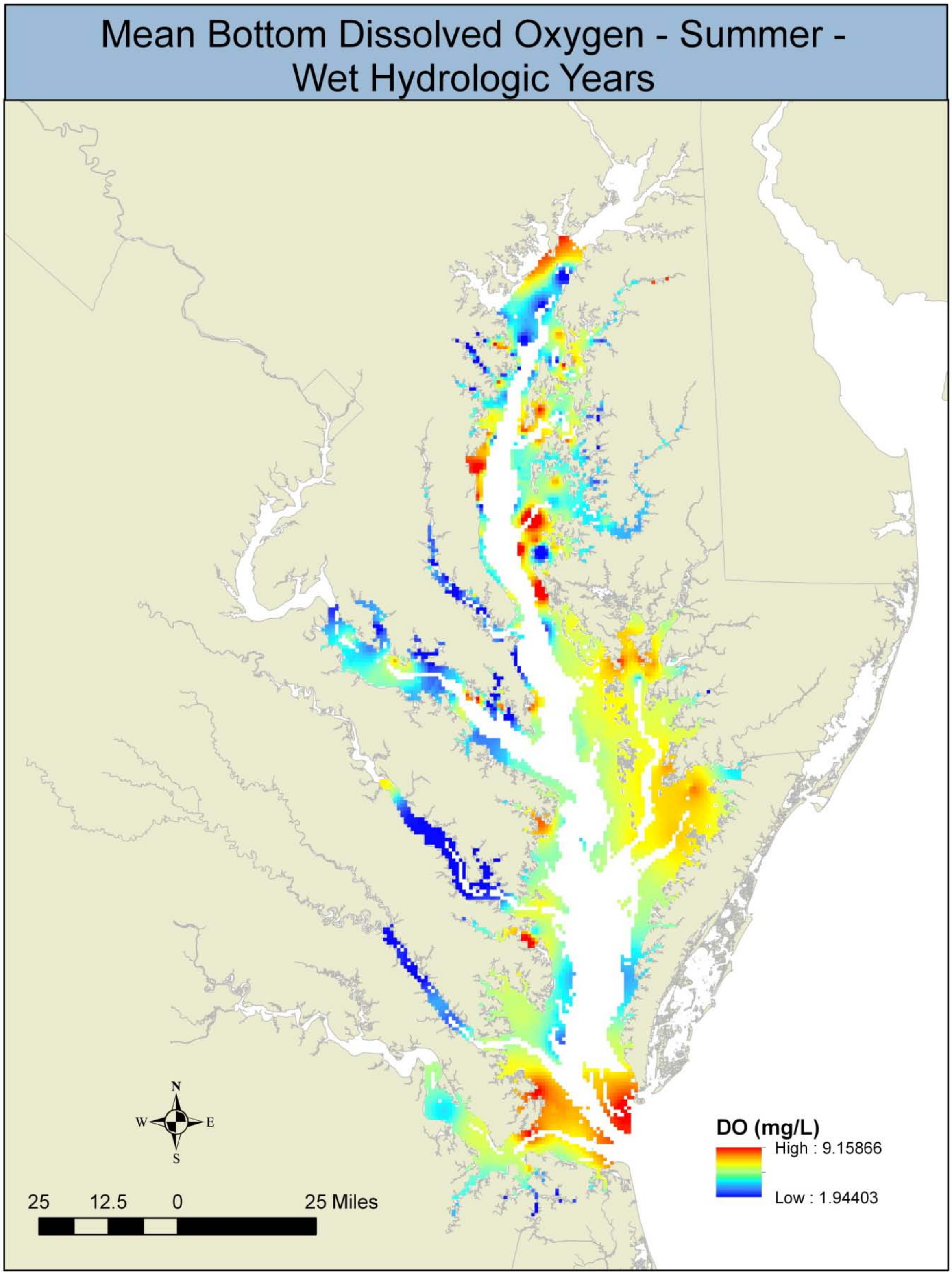


Figure C-4J: Mean Bottom Dissolved Oxygen during Summer in Wet Hydrologic Years

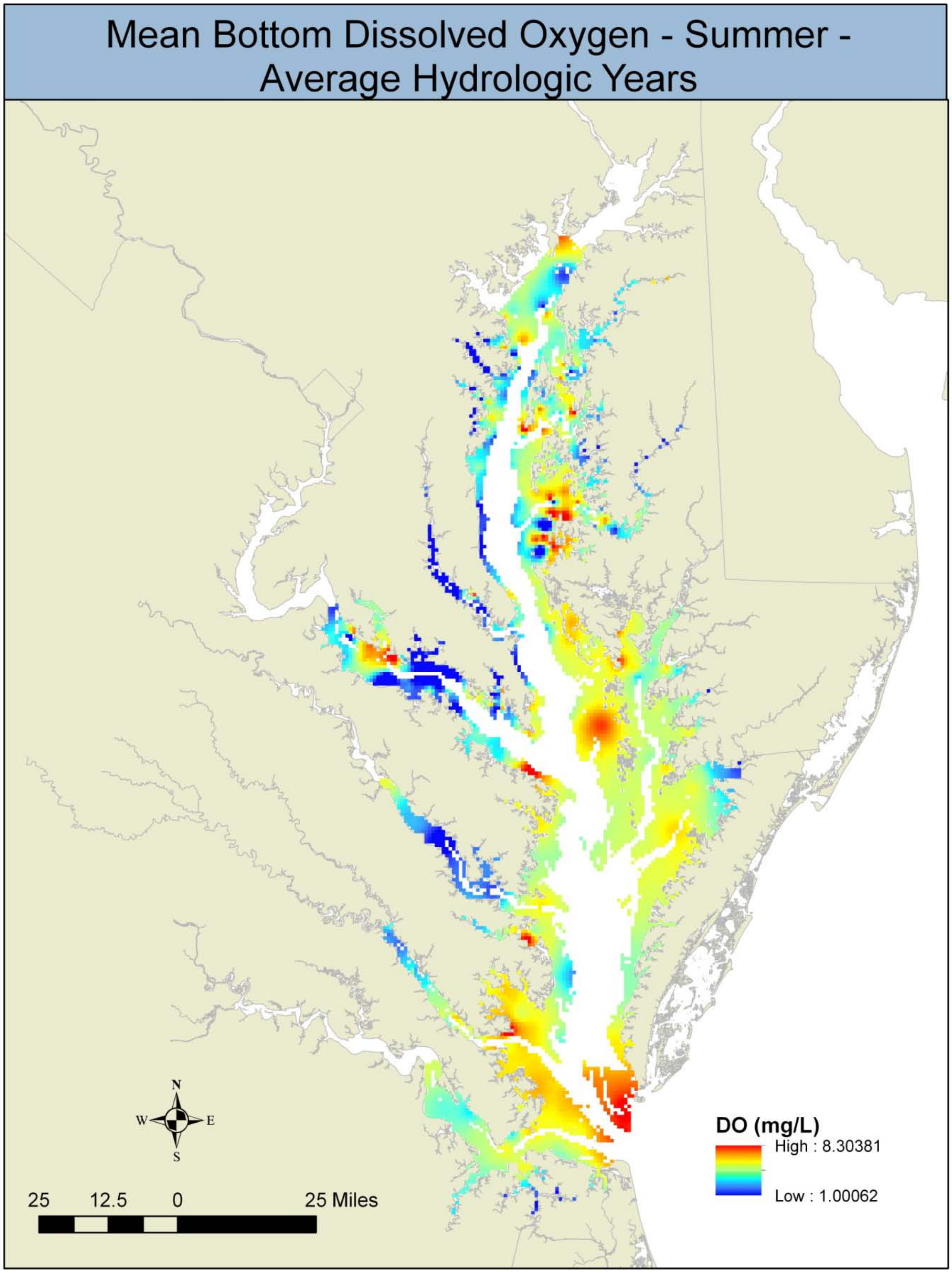


Figure C-4K: Mean Bottom Dissolved Oxygen during Summer in Average Hydrologic Years

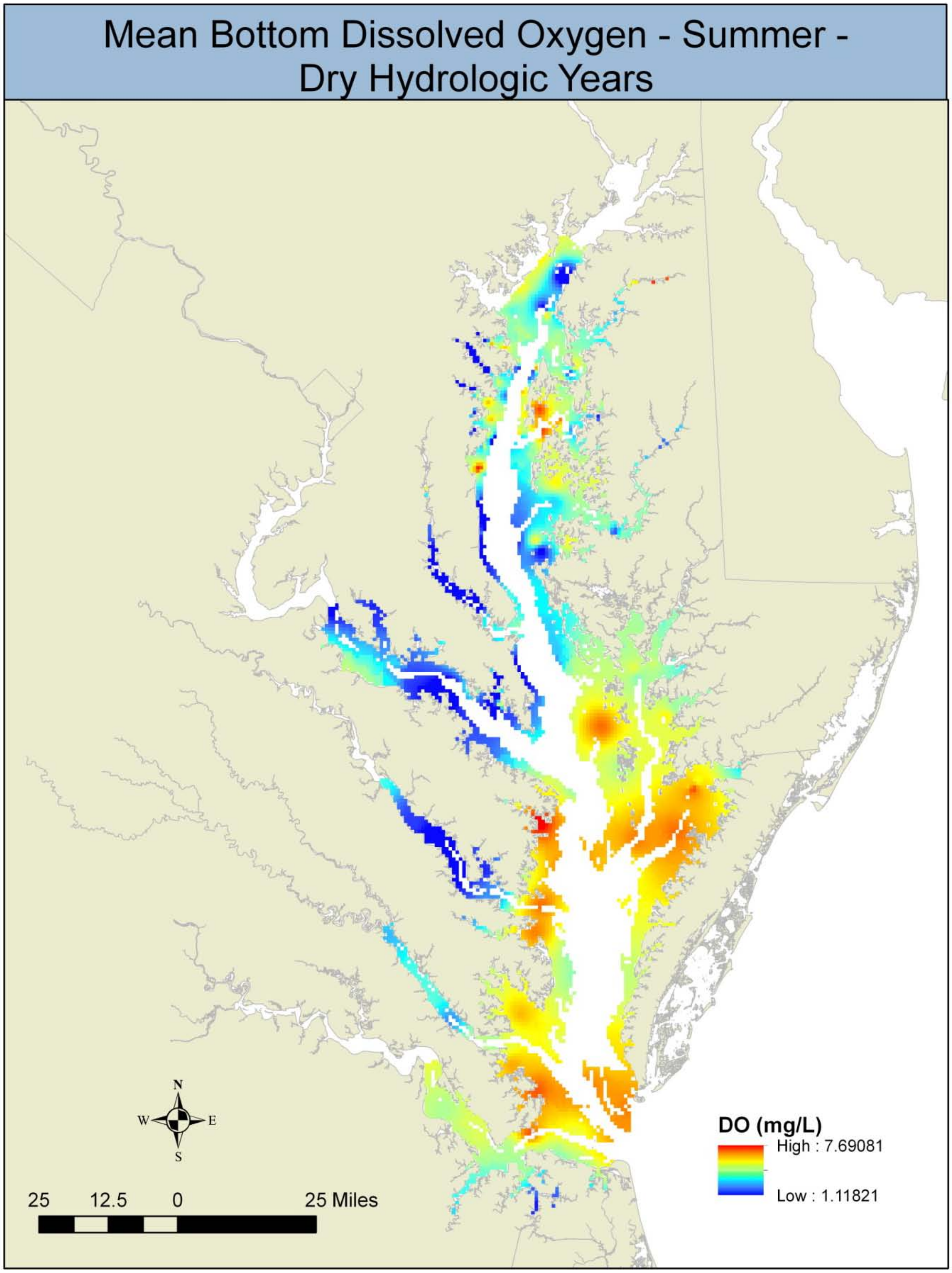


Figure C-4L: Mean Bottom Dissolved Oxygen during Summer in Dry Hydrologic Years

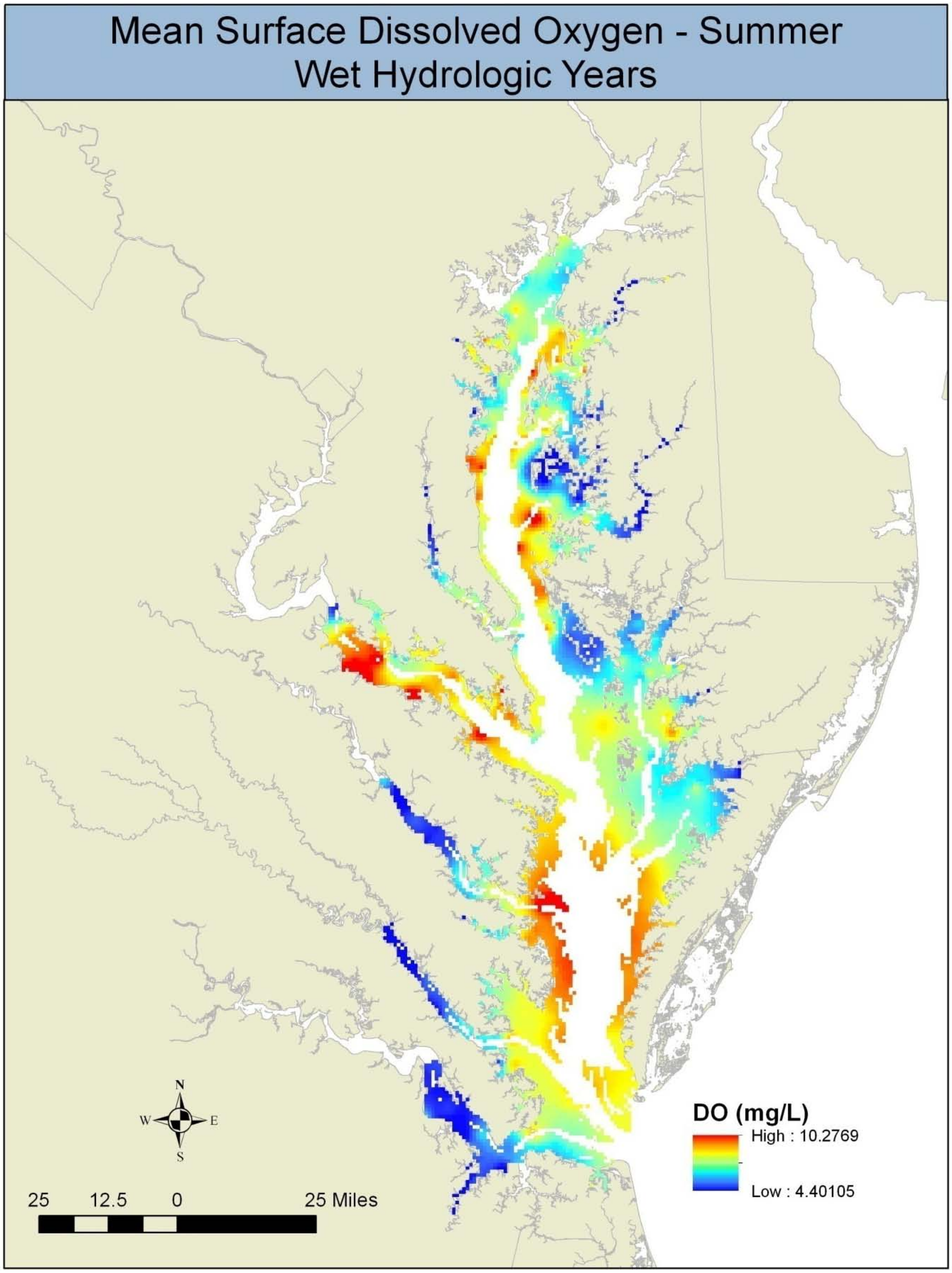


Figure C-4M: Mean Surface Dissolved Oxygen during Summer in Wet Hydrologic Years

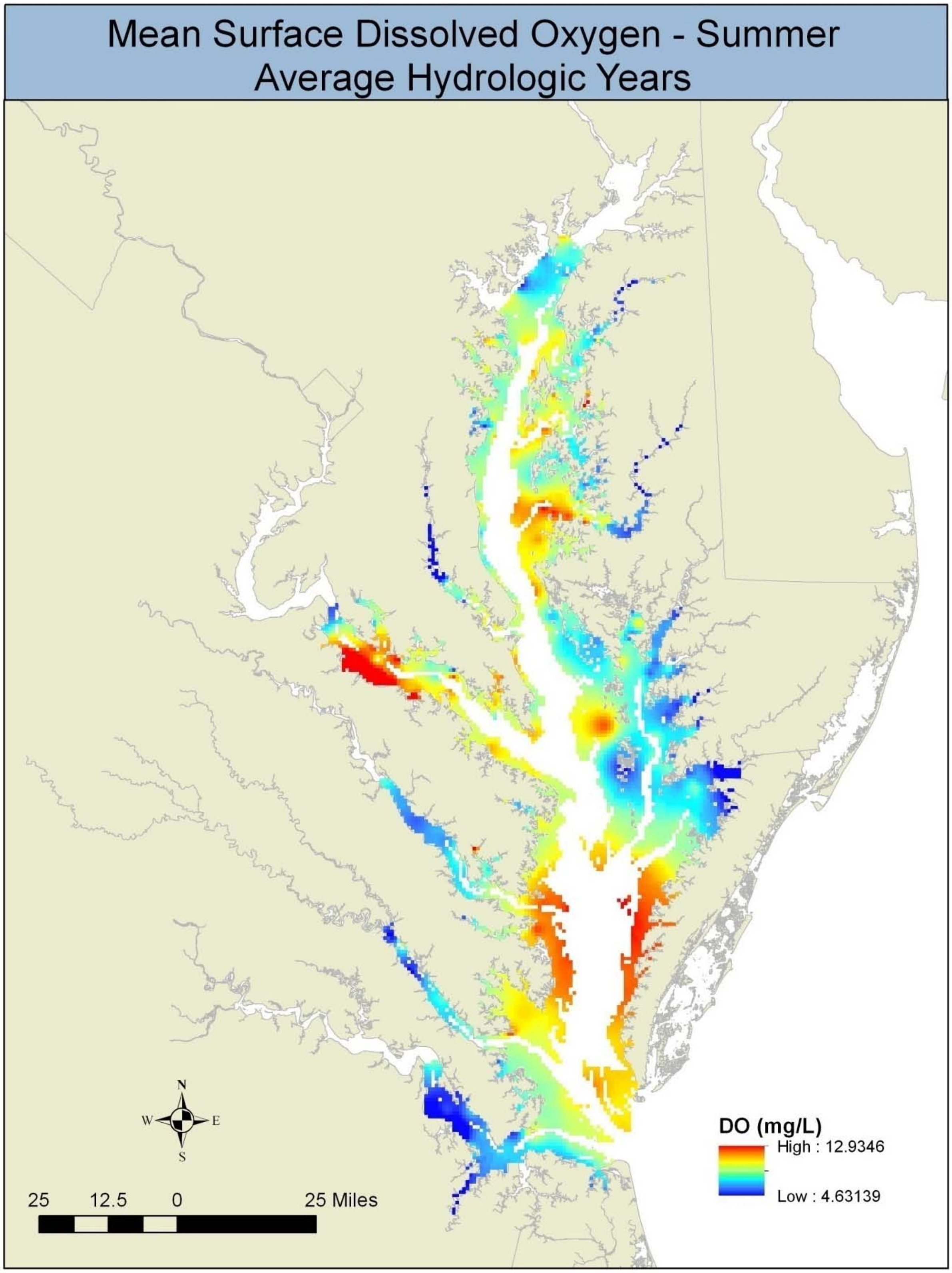


Figure C-4N: Mean Surface Dissolved Oxygen during Summer in Average Hydrologic Years

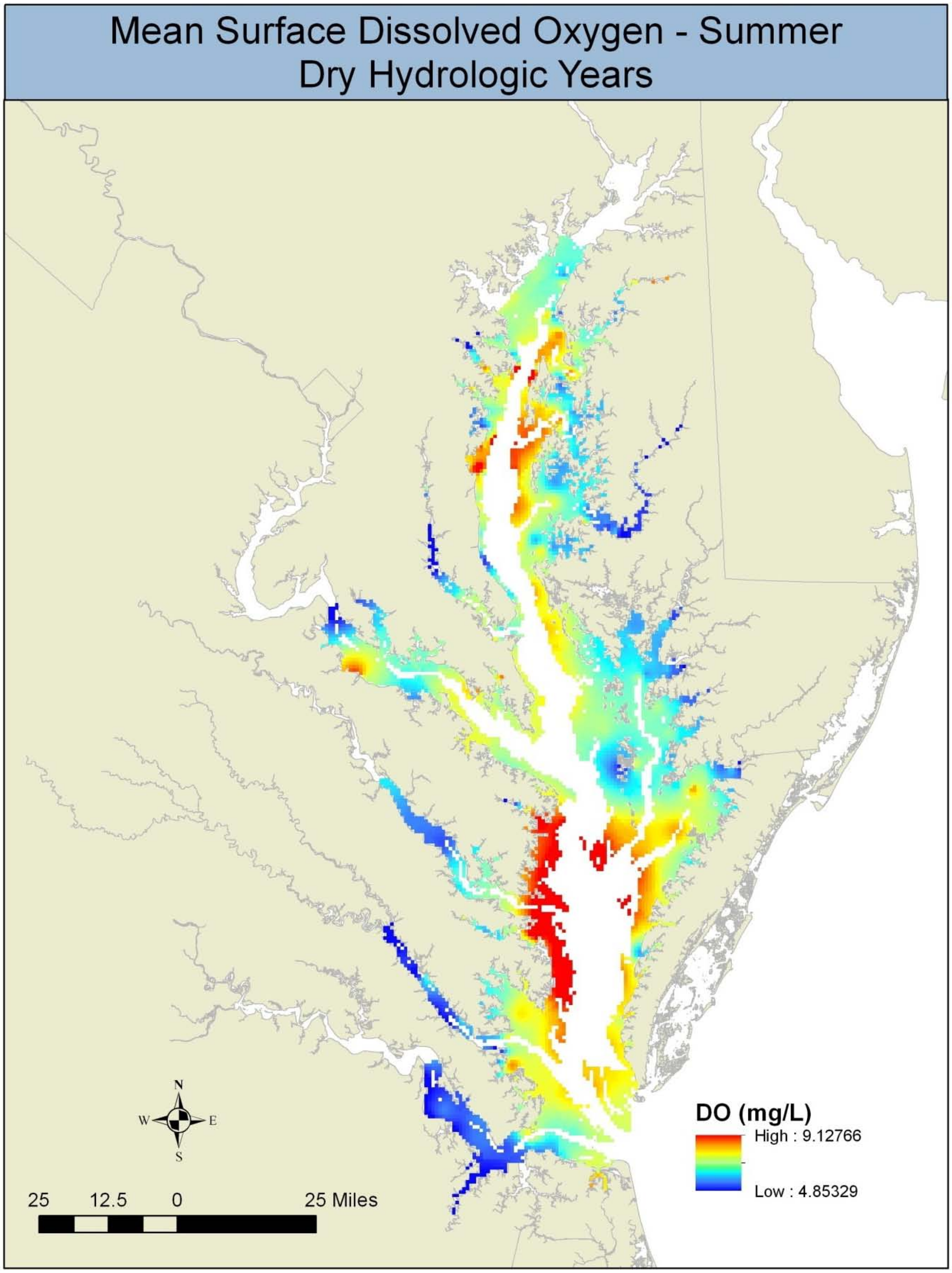


Figure C-4O. Mean Surface Dissolved Oxygen during Summer in Dry Hydrologic Years

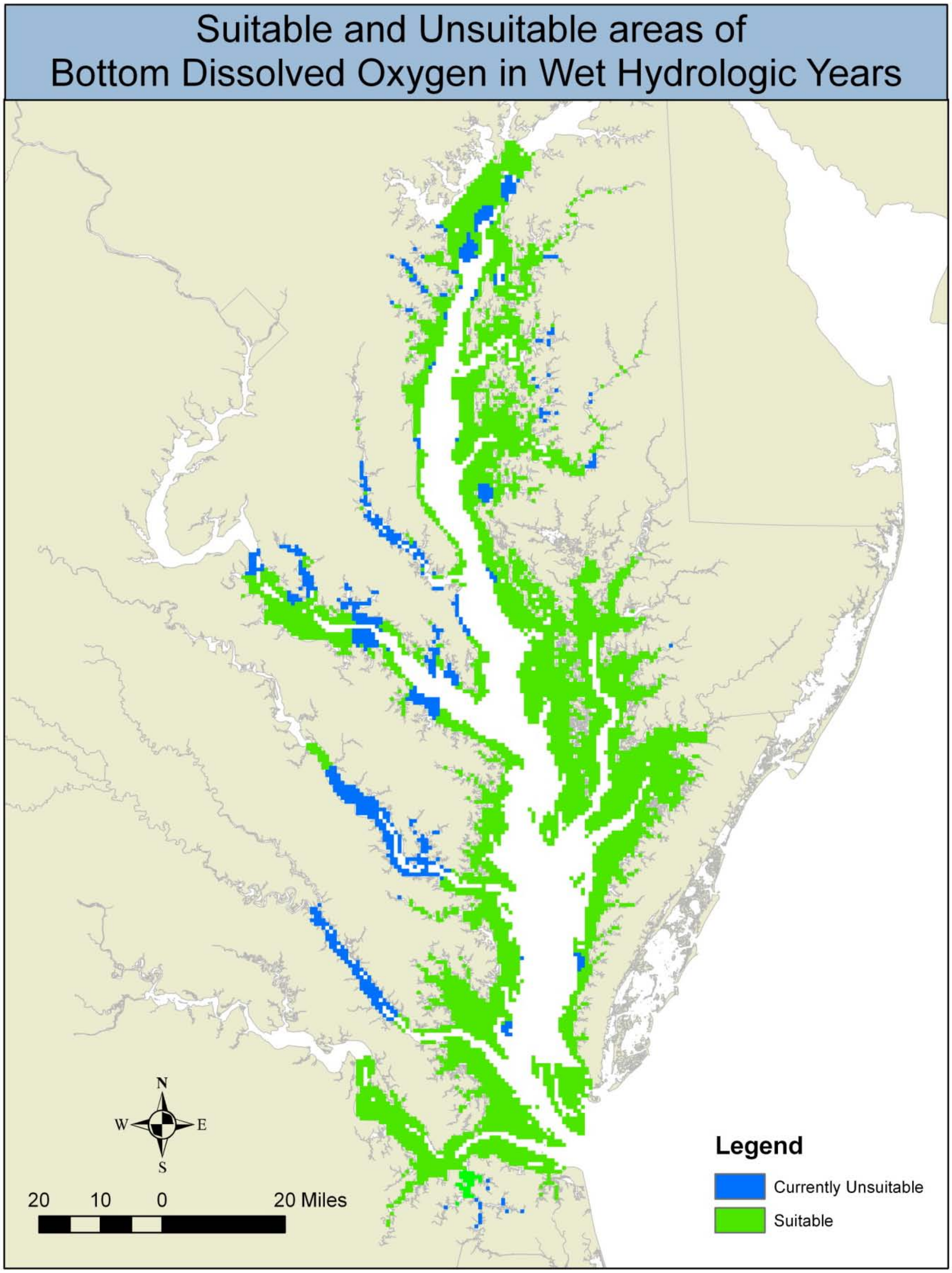


Figure C-4P. Suitable and unsuitable Bottom DO in Wet Hydrologic Years

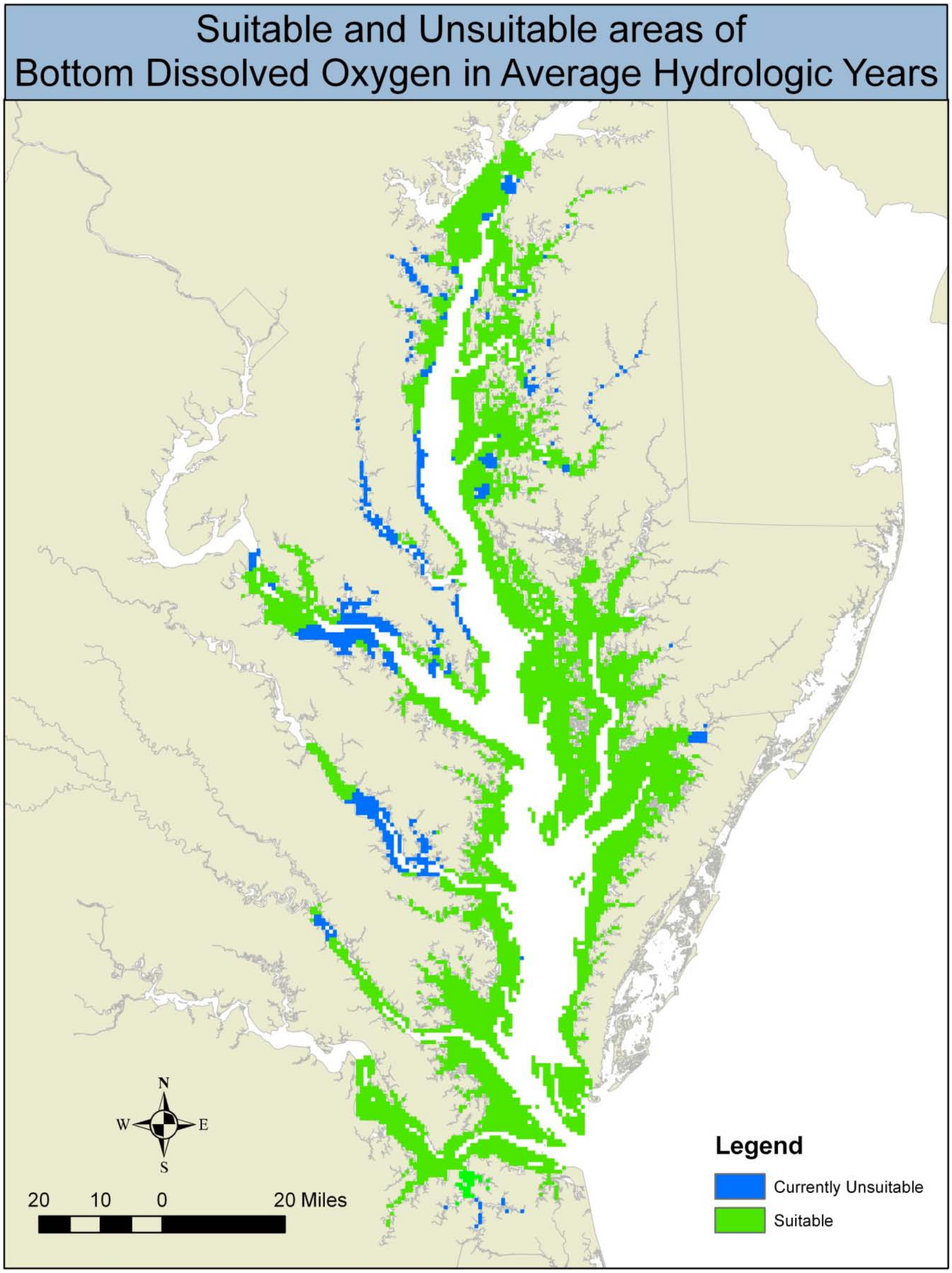


Figure C-4Q. Suitable and unsuitable Bottom DO in Average Hydrologic Years

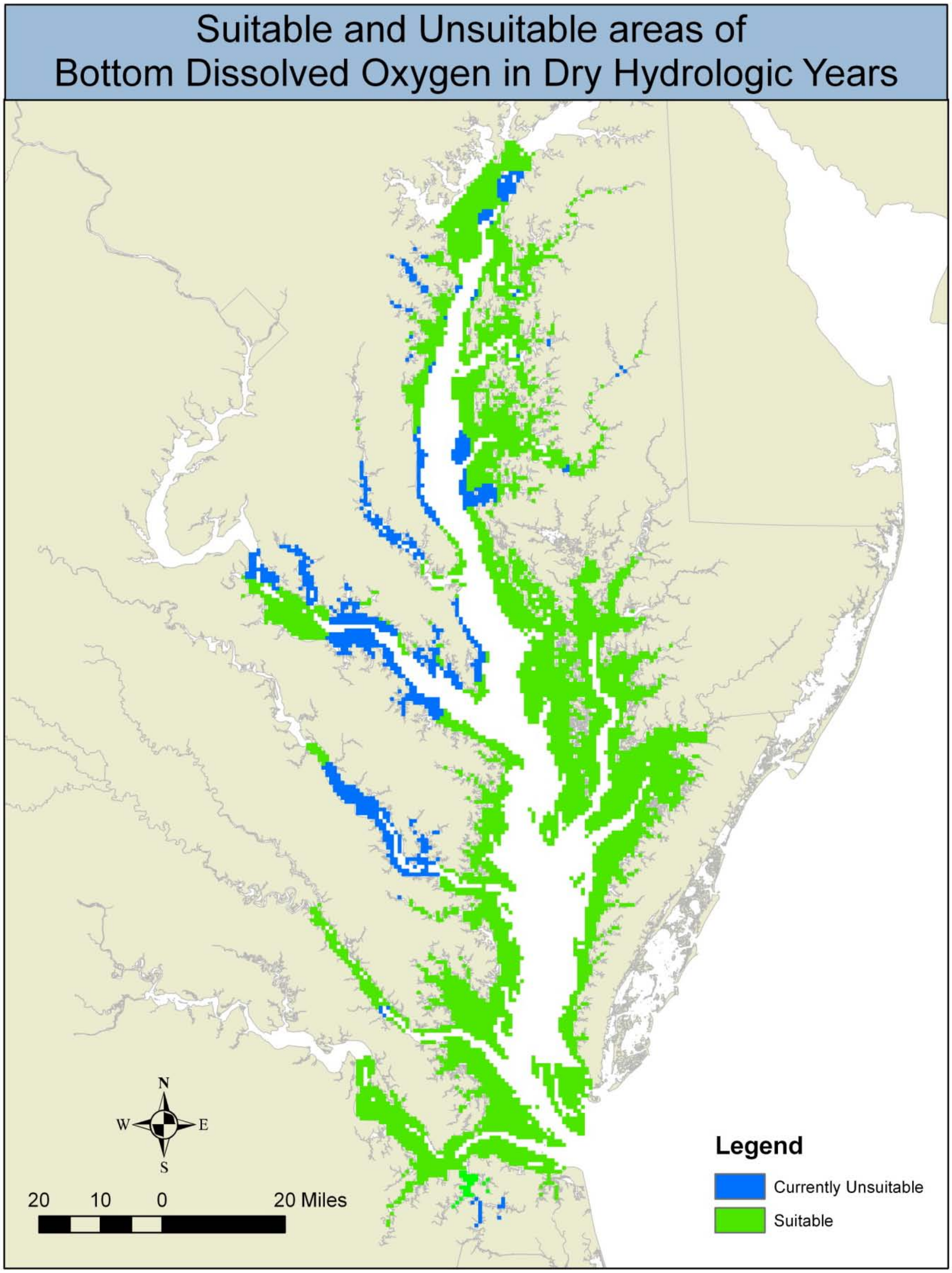


Figure C-4R. Suitable and unsuitable Bottom DO in Dry Hydrologic Years

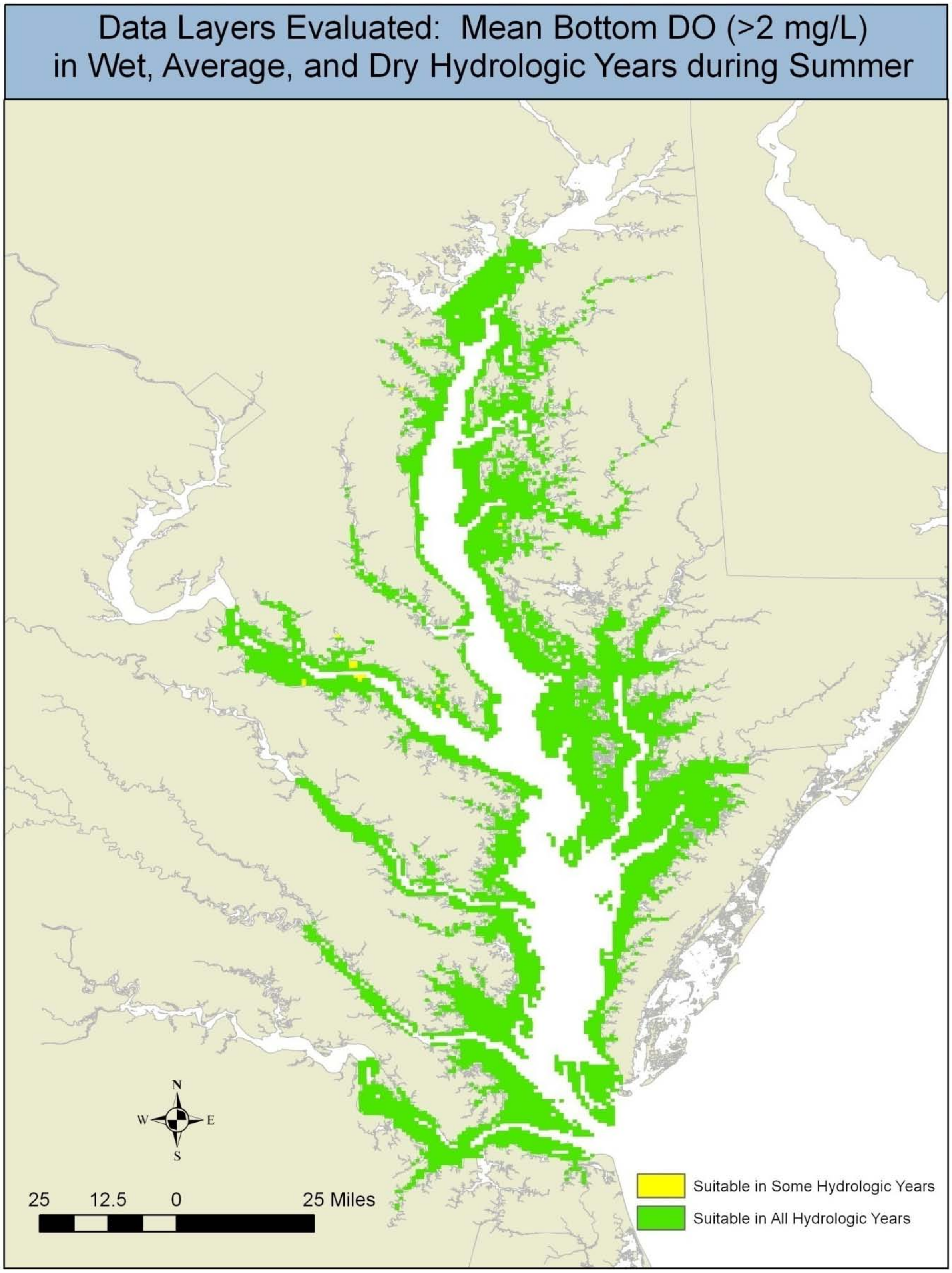


Figure C-4S: Suitability Analysis of setting the bottom DO Criteria at >2 mg/L

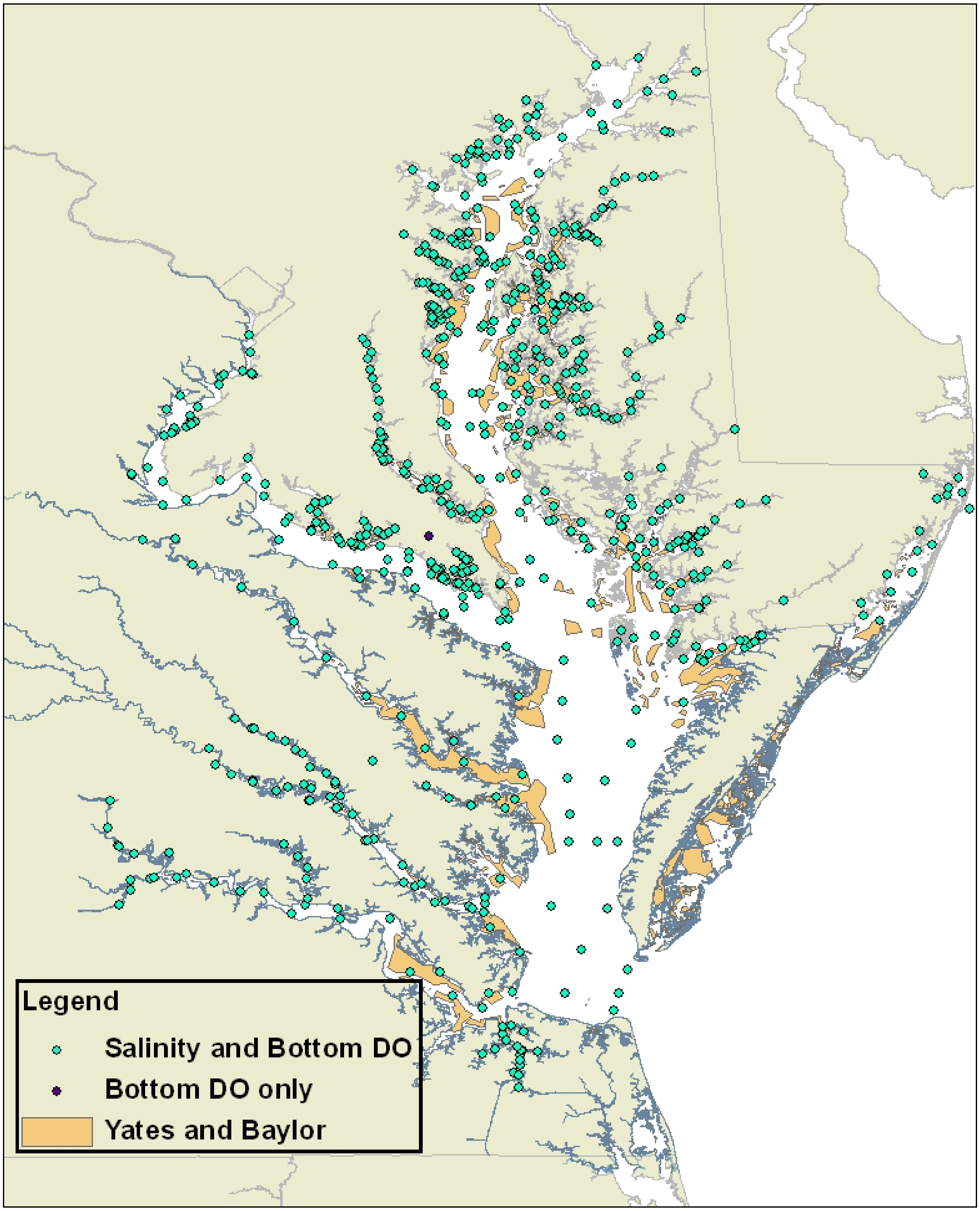


Figure C-4T. Salinity and Bottom Dissolved Oxygen Monitoring Stations

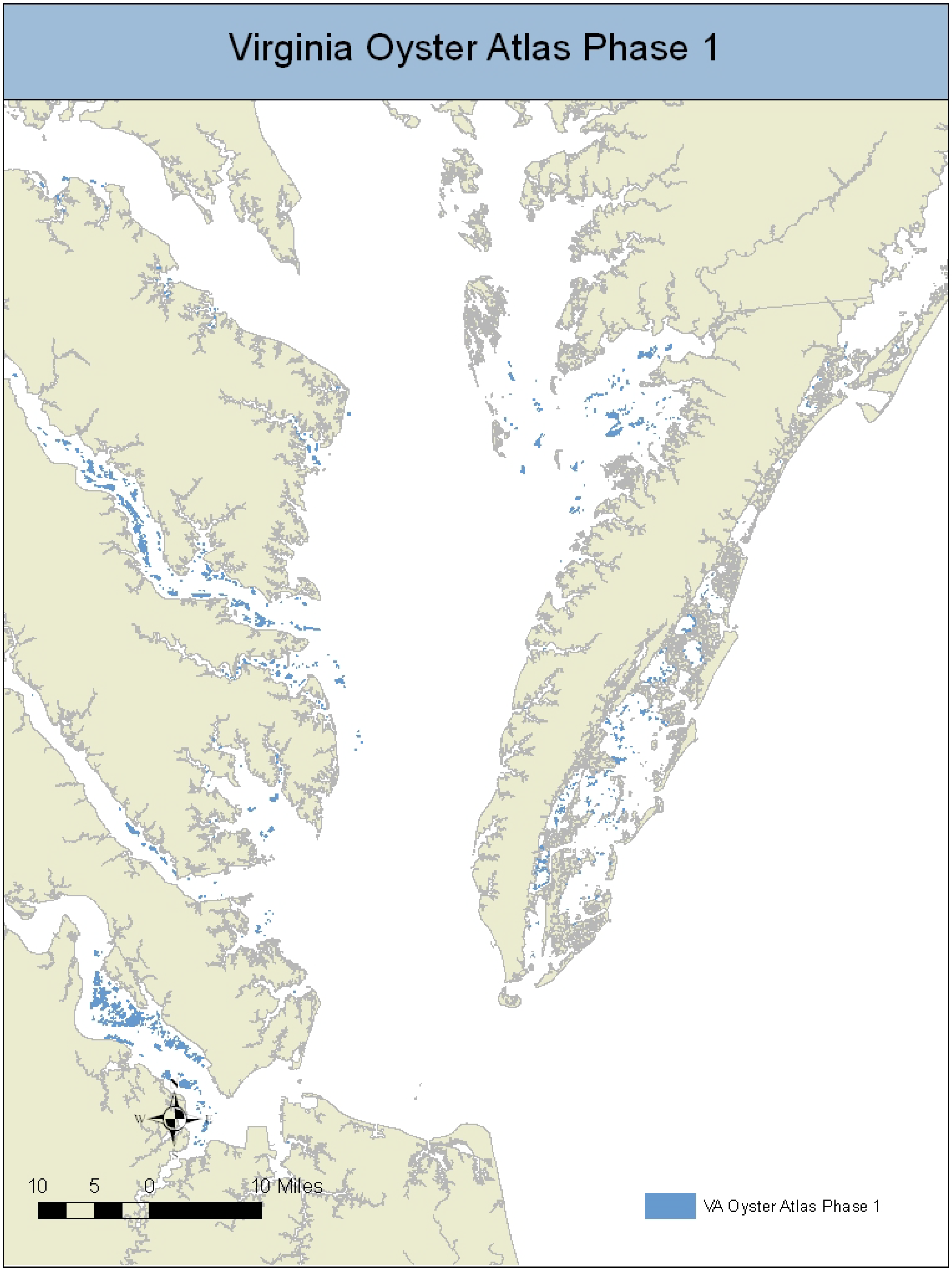


Figure C-4U. Virginia Oyster Atlas Phase I- Potential Habitat

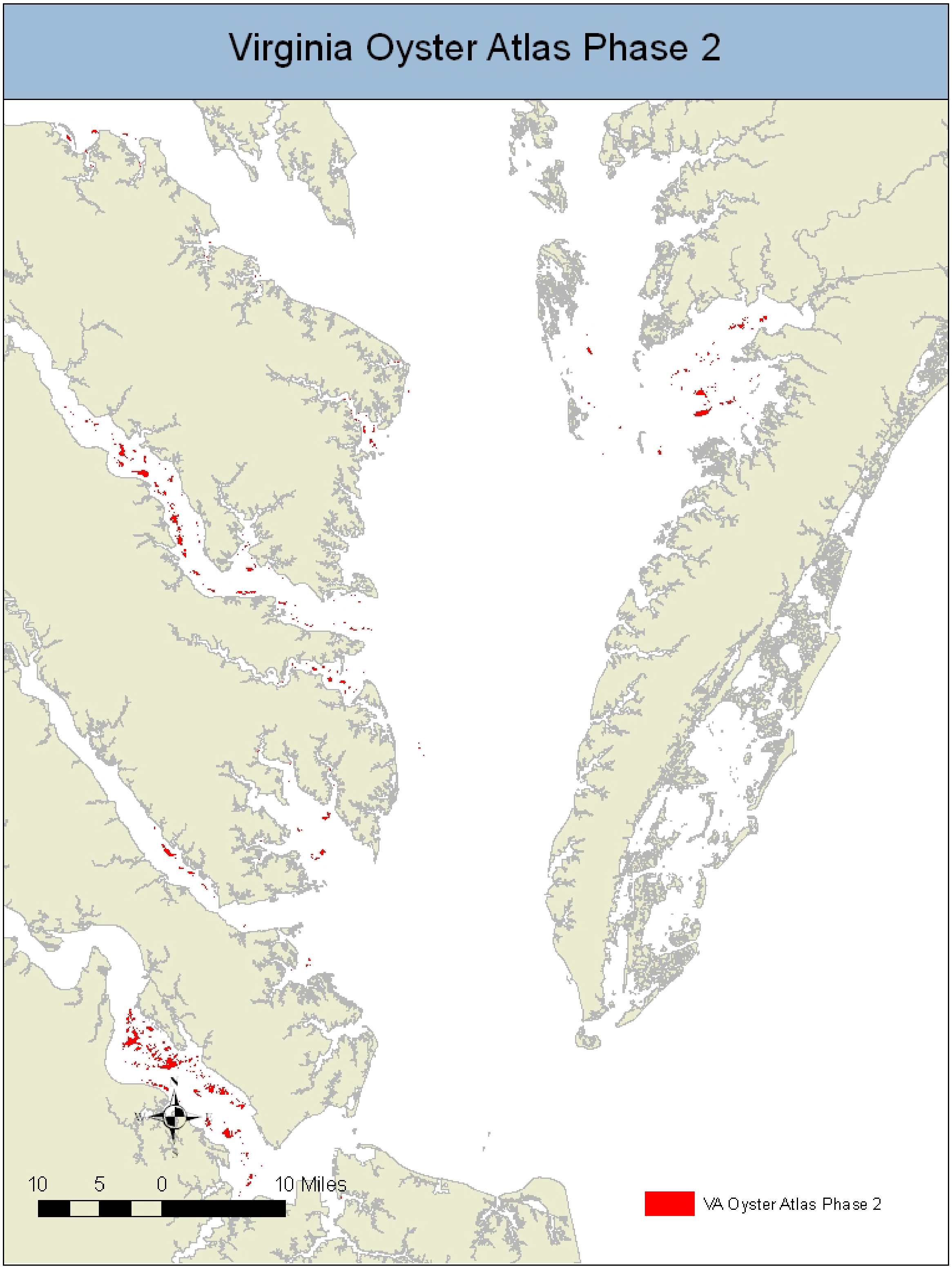


Figure C-4V. Virginia Oyster Atlas Phase 2- Optimal Habitat

Table C-4A. Restoration Acreage Identified in Virginia Oyster Atlas

	Water Body	Potential Habitat* (ac)	Optimal Habitat** (ac)
1	Nomini Creek	160	150
2	Lower Machodoc Creek	50	50
3	Yeocomico River	57	46
4	Glebe & Coan Rivers	36	33
5	Little Wicomico River	48	36
6	Great Wicomico River	248	248
7	Mouth of Rappahannock River	762	289
8	Rappahannock and Corratoman Rivers	579	429
9	Rappahannock River: Punchbowl Pt.- Towles Pt.	1076	867
10	Rappahannock River: Wares Wharf - Punchbowl	1054	953
11	Rappahannock River: Lowerys Pt.- Neals Pt.	52	20
12	Mouth of Piankatank River and Gwynn Island	199	35
13	Piankatank River	295	292
14	Chesapeake Bay	24	24
15	East River	138	138
16	North and Ware Rivers	27	27
17	Severn River	214	214
18	York River to Gloucester Pt.	28	27
19	York River - Beaver Dam to Roosevelt Pond	365	357
20	Upper York River	0.4	0
21	Poquoson River	76	66
22	Back River	5	5
23	Elizabeth and Lafayette Rivers	8	7
24	James and Nansemond Rivers	184	184
25	James River	2218	2005
26	James River- Burwells Bay	1921	1788
27	Lynnhaven Rivers and Broad Bay	0	0
28	Nassawadox and Occohannock Creeks	8	8
29	Tangier Sound	523	213
30	Pocomoke Sound	1439	1344

*'Potential habitat' was determined by considering public oyster grounds and shell bottom.

**Optimal habitat was determined by considering public oyster grounds, shell bottom, salinity, and water depth.

C-5: AVAILABLE BAYWIDE TOTAL SUSPENDED SOLIDS (TSS) DATA

Source: Chesapeake Bay Program

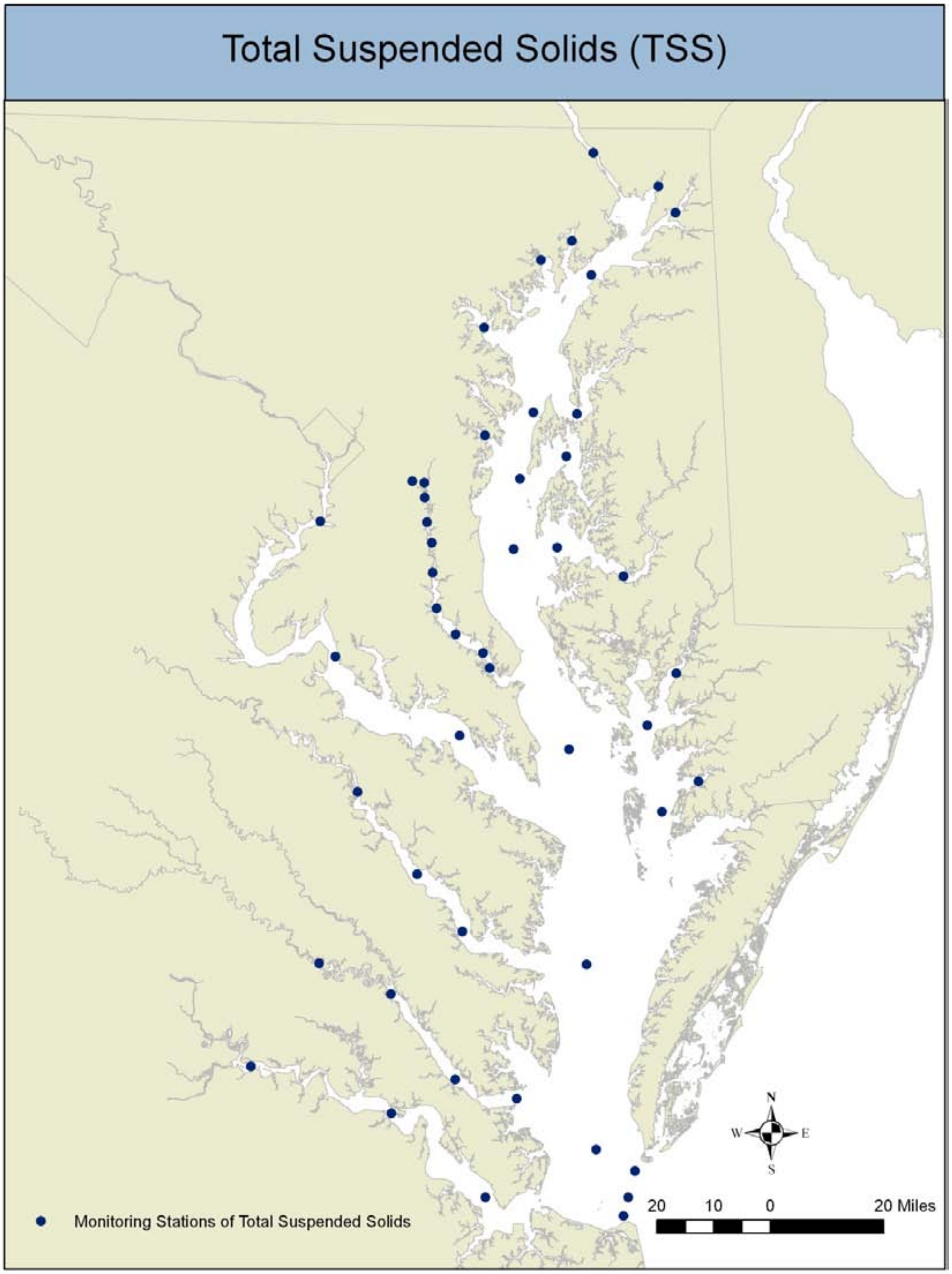


Figure C-51. Total Suspended Solids Monitoring Stations

Table C-5A. CBP TSS Data and Long-Term Average Deposition

Station	Basin	Tributary	State	average bottom TSS (g/m3)	net settling (m/d)	long-term average deposition (g/m2/d)
CB11	CB1TF	Susquehanna mouth	MD	12.54	0.1	1.25
CB22	CB2OH	mainstem- upper	MD	47.77	0.1	4.78
CB33C	CB3MH	mainstem- middle	MD	21.71	0.05	1.09
CB41C	CB4MH	mainstem- middle (east)	MD	15.12	0.05	0.76
CB42C	CB4MH	mainstem- middle	MD	12.90	0.05	0.65
CB52	CB5MH	mainstem- lower (east)	MD	16.10	0.05	0.81
CB61	CB6PH	mainstem	VA	22.18	0.05	1.11
CB73	CB7PH	mainstem	VA	22.90	0.05	1.15
CB74	CB7PH	Bay mouth	VA	27.54	0.05	1.38
CN74N	CB7PH	Bay mouth	VA	29.85	0.05	1.49
CB81E	CB8PH	Bay mouth	VA	28.14	0.05	1.41
EE11	EASMH	Eastern Bay-upper	MD	15.55	0.15	2.33
EE21	CHOMH1	Choptank River-lower	MD	17.48	0.15	2.62
EE31	TANMH	Tangier Sound- upper	MD	46.31	0.025	1.16
EE32	TANMH	Tangier Sound- lower	MD	23.33	0.025	0.58
ET11	ELKOH	Elk River	MD	21.75	0.15	3.26
ET23	BOHOH	Bohemia River	MD	42.67	0.025	1.07
ET42	CHSMH	Chester River-lower	MD	18.99	0.25	4.75
ET52	CHOMH2	Choptank River-upper	MD	16.41	0.25	4.10
ET62	NANMH	Nanticoke River	MD	60.46	0.15	9.07
ET91	BIGMH	Big Annemessex River	MD	18.51	0.25	4.63
LE11	PAXMH	Patuxent River- upper	MD	12.88	0.175	2.25
LE12	PAXMH	Patuxent River- lower	MD	10.74	0.175	1.88
LE13	PAXMH	Patuxent River- lower	MD	8.23	0.175	1.44
LE22	POTMH	Potomac River- lower	MD	20.16	0.15	3.02
LE32	RPPMH	Rappahannock R- middle	VA	16.19	0.2	3.24
LE42	YRKPH	York River- lower	VA	42.22	0.2	8.44
LE53	JMSMH	James River-lower	VA	35.77	0.1	3.58
RET11	PAXMH	Patuxent River-upper	MD	23.97	0.25	5.99
RET24	POTMH	Potomac River- upper	MD	42.78	0.15	6.42
RET32	RPPMH	Rappahannock R- upper	VA	26.21	0.1	2.62
RET43	YRKMH	York River- lower	VA	51.59	0.2	10.32
RET52	JMSOH	James River- upper	VA	86.75	0.1	8.67
TF12	PAXOH	tributary to Patuxent River	MD	18.34	0.25	4.59
TF13	PAXOH	Patuxent River- upstream	MD	17.94	0.25	4.49
TF14	PAXOH	Patuxent River-upstream	MD	26.12	0.25	6.53
TF15	PAXOH	Patuxent River-upstream	MD	43.07	0.25	10.77
TF16	PAXOH	Patuxent River-upstream	MD	57.78	0.25	14.44
TF17	PAXOH	Patuxent River-upstream	MD	37.92	0.25	9.48
TF21	POTTF	Potomac River-upstream	MD	42.14	0.05	2.11
TF33	RPPOH	Rappahannock R- upstream	VA	50.03	0.3	15.01
TF42	PMKOH	York River- upstream	VA	17.78	0.4	7.11
TF55	JMSOH	James River-upstream	VA	31.24	0.3	9.37
WE42	MOBPH	York River-lower-mouth/Mobjack Bay	VA	21.99	0.1	2.20
WT11	BSHOH	Bush River	MD	29.86	0.15	4.48
WT21	GUNOH	Gunpowder River	MD	26.48	0.15	3.97
WT51	PATMH	Patapsco River	MD	12.68	0.2	2.54
WT81	SOUMH	South River	MD	13.14	0.15	1.97

C-6: SEA LEVEL CHANGE CONSIDERATIONS

Methodology to make sea level rise projections

The National Research Council's (NRC) 1987 report *Responding to Changes in Sea Level: Engineering Implications* recommends a multiple scenario approach to deal with key uncertainties for which no reliable or credible probabilities can be obtained. USACE planning studies and engineering designs need to consider alternatives that are developed and assessed for the entire range of possible future rates of sea level change. Alternatives should be evaluated using "low," "intermediate," and "high" rates (i.e. scenarios) of future sea level change. Appendix X describes one method for estimating various sea level change projects for future projects. USACE will use the historic rate of sea level change as an estimate of the "low" rate and calculate the "intermediate" and "high" projections.

The NRC described these three scenarios using the following equation:

$$E(t) = 0.0012t + bt^2 \qquad (1)$$

in which *t* represents years, starting in 1986, *b* is a constant, and *E(t)* is the eustatic sea level rise, in meters, as a function of *t*. The NRC committee recommended "projections be updated approximately every decade to incorporate additional data." At the time the NRC report was prepared, the estimate of global mean sea level change was approximately 1.2 mm/year. Using the current estimate of 1.7 mm/year for global mean sea level change, as presented by the IPCC (IPCC 2007), results in this equation being modified to be:

$$E(t) = 0.0017t + bt^2 \qquad (2)$$

The three scenarios proposed by the NRC result in global eustatic sea level rise values, by the year 2100, of 0.5 meters, 1.0 meters, and 1.5 meters. Adjusting the equation to include the historic global mean sea level change rate of 1.7 mm/year results in updated values for the variable b being equal to $2.36E^{-5}$ for modified NRC Curve I, $6.20E^{-5}$ for modified NRC Curve II, and $1.005E^{-4}$ for modified NRC Curve III. The three global eustatic sea level rise scenarios updated from NRC (1987) are depicted in Figure C6-1.

Manipulating equation (2) to account for the fact that it was developed for eustatic sea level rise starting in 1986, while projects will actually be constructed at some date after 1986, results in equation (3):

$$E(t_2) - E(t_1) = 0.0017(t_2 - t_1) + b(t_2^2 - t_1^2) \qquad (3)$$

where t_1 is the time between the project's construction date and 1986 and t_2 is the time between a future date at which one wants an estimate for sea level rise and 1986 (or $t_2 = t_1$ + number of years after construction (Knuuti, 2002) For example, if a designer wants to know the projected eustatic sea level rise at the end of a project's period of analysis, and the project is to have a fifty year life and is to be constructed in 2008, $t1 = 2008 – 1986 = 22$ and $t_2 = 2058 – 1986 = 72$.

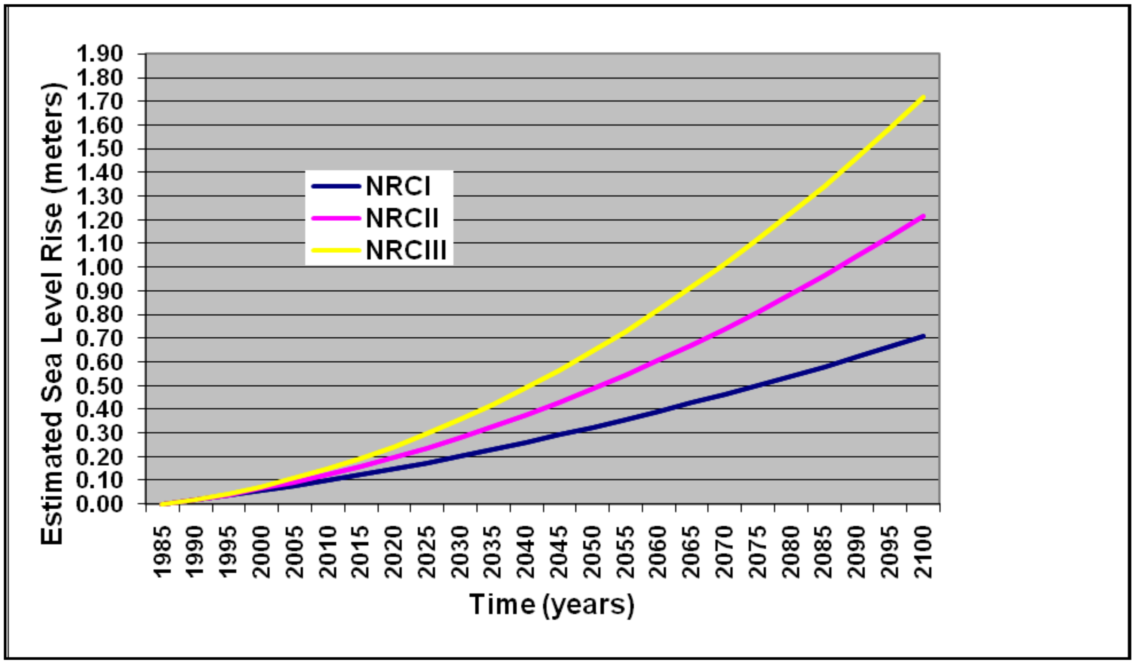


Figure C6-1. Scenarios for Eustatic Sea Level Rise (based on updates to NRC 1987 equation).

In order to estimate local historic trends for mean sea level, mean high water, mean higher high water information from long-term tidal gauges near the project site must be utilized. The period of record for the tidal gauges is a minimum of 40 years. The difference between the IPCC global rate of eustatic sea level rise (1.7 mm/yr) and the local tidal gauge rate must be determined. This new rate, L(t), can be used in Equation 1 to calculate estimates for total relative sea level rise in a particular tributary/project area.

$$E(t) = [\ 0.0017+L(t)\ ](t) + bt^2 \qquad (4)$$

where $E(t)$ is the eustatic sea level rise, in meters, as a function of t, where t is the time between the date at which one wants an estimate for sea level rise and 1986, and b is equal to $2.36E^{-5}$ for modified NRC Curve I, $6.20E^{-5}$ for modified NRC Curve II, and $1.005E^{-4}$ for modified NRC Curve III.

The NOAA website http://tidesandcurrents.noaa.gov/gmap3/ can be utilized to download data from local tidal gauges in Chesapeake Bay to determine relative sea level rise. There are a total of 18 tidal gauges placed throughout the Bay.

6.3.8.2 Application to the Master Plan

For the future follow-on projects the three scenarios for sea level rise should be calculated as follows:

The historic rate of sea level change will suffice as the "low" rate while the "intermediate" and "high" rates calculated as follows:

(1) Estimate the "intermediate" rate of local mean sea level change using the modified NRC Curve I and equations 2 and 3. Consider both the most recent IPCC projections and modified NRC projections and add those to the local rate of vertical land movement. Utilize local tide gauge information from http://tidesandcurrents.noaa.gov/gmap3 for relative sea level rise to adjust rates to Chesapeake Bay. There are a total of 18 tidal gauges in Chesapeake Bay so depending on site specific locations of proposed restoration sites; tidal gauges closest to these proposed sites should be utilized to modify sea level rise projections. The gauges are listed below in Table C6-1.

(2) Estimate the "high" rate of local sea level change using the modified NRC Curve III and equations 2 and 3. Consider both the most recent IPCC projections and modified NRC projections and add those to the local rate of vertical land movement. Utilize local tide gauge information from http://tidesandcurrents.noaa.gov/gmap3 for relative sea level rise to adjust rates to Chesapeake Bay. There are a total of 18 tidal gauges in Chesapeake Bay so depending on site specific locations of proposed restoration sites; tidal gauges closest to these proposed sites should be utilized to modify sea level rise projections.

Table C6-1. Tidal Gauges in Chesapeake Bay

Station Name	Station ID	Region	Year Established
Chesapeake City, MD	8573927	Upper Bay- Western Shore, C&D Canal	1972
Tolchester Beach, MD	8573364	Upper Bay- Eastern Shore	1971
Baltimore, MD	8574680	Patapsco River	1902
Annapolis, MD	8575512	Severn River	1978
Poplar Harbor Island, MD	8572271	Mid-Bay- Eastern Shore	2006
Cambridge, MD	8571892	Choptank River	1980
Solomons Island, MD	8577330	Patuxent River	1937
Bishops Head, MD	8571421	Upper Tangier Sound	2005
Washington, DC	8594900	Washington, DC	1924
Lewisetta, VA	8635750	Potomac River	1970
Windmill Point, VA	8636580	Rappahannock River	1970
Yorktown USCG Training Center, VA	8637689	York River	2004
Kiptopeke, VA	8632200	VA mainstem- eastern shore	1951
Chesapeake Bay Bridge Tunnel, VA	8638863	VA mainstem- lower Bay	1975
Sewells Point, VA	8638610	Lower James River- Hampton Roads	1927
Lafayette River, VA	8638671	Lafayette River	2011
Western Branch	8638339	Elizabeth River- Western Branch	2011
Money Point	8639348	Elizabeth River- Money Point	1997

REFERENCES

Intergovernmental Panel on Climate Change (IPCC). 2007. Fourth Assessment Report: Climate Change (AR4). Set of reports available online at http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml.

Knuuti, K. (2002) Planning for Sea-Level Rise: U.S. Army Corps of Engineers Policy. Solutions to Coastal Disasters '02, ASCE 2002.

National Oceanic and Atmospheric Administration (NOAA). 2011. Tides and Currents. [Online] Accessed November 17, 2011. Available at: http://tidesandcurrents.noaa.gov/gmap3.

The National Research Council (NRC). 1987. *Responding to Changes in Sea Level: Engineering Implications*. Washington, D.C.: National Academy Press. 148 pp.

APPENDIX D: *Draft* Tributary Plan

Draft Tributary Specific Site Selection Process for Native Oyster Restoration
NOAA Chesapeake Bay Office
Habitat Assessment Team
November 2011

Introduction

The NOAA Chesapeake Bay Office (NOAA CBO) Habitat Assessment Team worked closely with both internal (NOAA OHC Restoration Center and CBO Oyster Team) and external restoration partners (US Army Corps of Engineers (USACE) and Maryland Department of Natural Resources (MDNR)) to develop a process to guide the selection of sites for federally funded restoration activities in Maryland Oyster Sanctuaries. This process is designed to identify the information and analyses needed to provide optimal site locations and to most effectively allocate scarce restoration resources. Selecting and prioritizing tributaries for oyster restoration must be based on a high level understanding of the role that those tributaries play in maintaining a healthy oyster population throughout Chesapeake Bay. The USACE Chesapeake Bay Oyster Recovery Native Oyster Restoration Master Plan for Maryland and Virginia draft version dated June, 2011 (Draft USACE Master Plan 2011) uses this approach, and groups tributaries into hierarchical Tiers based on their size, ecological function, and current restoration potential. Once a tributary is selected, the next step is to identify the optimal sites for restoration action within that system. This document describes a process for selecting specific restoration sites within a tributary using established criteria and a suite of available restoration options. This oyster restoration site selection process is illustrated in Figure 1. This document and flow diagram (Figure 1) complement the Draft USACE Master Plan 2011, and use lessons learned from the Harris Creek Restoration Site Assessment of 2011, a recent effort to select specific sites within a tributary that was targeted for focused restoration activities. The lessons learned and applied to Harris Creek are anticipated to serve as an adaptable model for future restoration activities by Federal and State management partners in both Maryland and Virginia.

Site Selection Process Criteria

Numerous factors should be considered prior to detailed site selection. Some candidate tributaries will have adequate supporting datasets, and others will not. Regardless of the level of data available, multiple factors should be considered (Table 1) prior to initiating the site selection process.

Table 1. Factors to consider during site selection excluding benthic habitat data. Source USACE

Factors to consider in tributary plans/pre-project evaluation	Potential contributing partner
Freshets	USGS, academia, DNR
Local Water Quality (salinity, DO, T, toxics)	States, CBP, local watershed organization, academia
Water Flow- measure currents/water flow	DNR, academia, USACE
Sedimentation Rate- measure local rates	DNR, academia, USACE
Phytoplankton- characterize phytoplankton community, food availability	CBP, academia, DNR
Harmful Algal Blooms- presence/absence, frequency, species	academia, DNR
History of disease in region	DNR
Position relative to other estuarine resources- map SAV, wetlands, waterfowl	DNR, academia, USFWS
Existing harvesting closures/sanctuaries	DNR
Watershed Suitability- sustainable land use/planning	Local and State governments
Existing Population Surveys or Past Harvest Data	NOAA, USACE, DNR
Hydrodynamic and Larval Transport Modeling	academia
Recruitment Surveys including historic records	DNR, USACE

The criteria used to identify suitable sites for federally funded large-scale oyster restoration efforts under the auspices of the Chesapeake Bay Executive Order 13508 are identified in Table 2. These criteria reflect the current understanding of key environmental variables that may influence successful restoration in any given tributary. Table 2 includes physicochemical criteria derived from the Draft USACE Master Plan 2011, in addition to seabed characteristics crucial to restoration planning. The current draft of the Master Plan refers to these criteria points as "Absolute Criteria." This terminology was adopted in this document.

Table 2. Bathymetry, water quality, and bottom type criteria used to extract the area of potentially restorable bottom within oyster sanctuary boundaries in Chesapeake Bay. Source NOAA CBO

Absolute Criteria	**Threshold levels used to identify restorable bottom**
Bathymetry	Depths between intertidal and 20 feet MLLW
Bottom and Surface Salinity	Mean value greater than 5 ppt for the months April-October as determined from Chesapeake Bay Program water quality data
Bottom and Surface Dissolved Oxygen	Mean value greater than 5 mg/l for the months April-October as determined from Chesapeake Bay Program water quality data
Bottom Type	Hard bottom, sand, sand and shell, and shell bottom acoustically derived by the MD Geological Survey and the NOAA Chesapeake Bay Office using the Coastal and Marine Ecological Classification Standard (CMECS) Surficial Geological Component (SGC) scheme for Chesapeake Bay. If recent acoustic mapping data is missing, the MD Bay Bottom Survey (MBBS) or the VA Havens Survey (1980's) will be the source of bottom classification until all mapping is updated.

Site Selection Process Overview

In early 2011 the MD Native Oyster Restoration principle partner technical group, composed of MD DNR, USACE-Baltimore and NOAA CBO personnel, tasked the NCBO Habitat Assessment Team (HAT) to identify sites in the Harris Creek Oyster Sanctuary appropriate for alternative substrate reef creation. This began a process that initially examined existing broad (coarse) scale benthic habitat characterization data and subsequently included fine-scale ground validation and multibeam bathymetry surveys. Of the 4,518 acres within the Harris Creek Sanctuary only 22 acres were ultimately considered to be suitable for alternative substrate reef creation given a bathymetry range between 9 and 20 feet MLLLW, ground conditions, functional project/permitting constraints, and user group concerns, such as non-oyster fishing conflicts. The following narrative outlines a model site selection process depicted in Figure 1 that was derived from the Harris Creek experience. The elements of this model may be applied to other locations and restoration scenarios throughout the Chesapeake Bay.

Phase I: Identify Restorable Bottom

<u>Source Data Layers</u>

To use GIS as a tool for identifying potentially restorable bottom, data sources associated with the criteria identified in Table 2, such as salinity, DO, bathymetry and bottom type, need to be identified, acquired, and in some cases geo-referenced. This process replicates that of the Draft USACE Master Plan 2011 with one key exception: the USACE Master Plan did not include a bottom classification factor in its absolute criteria.

The bottom type analysis described in this document would ideally be based on the most recent Coastal and Marine Ecological Classification Standard (CMECS) Surface Geology Component (SGC) polygon dataset derived from recent acoustic mapping surveys conducted by NCBO and MGS. Additional acoustic survey data, specifically the original sidescan sonar mosaics (from which the habitat polygons are based), also have high utility. These data would not work bay-wide for initial tributary Tier and restoration target determinations since the entire range of oyster bottom has not been surveyed with sonar for the purpose of determining oyster bottom. In many instances, the Bay Bottom Survey (MD) and the Haven Survey (VA) of the 70’s and 80’s represent the only benthic classification data available. In some cases, these older bottom type datasets, which also used more rudimentary data collection methods, may have to be used for initial assessments, but ultimately new broad scale acoustic surveys of candidate tributaries will be conducted as a requirement ahead of any restoration project.

<u>Pre-Restoration Population Survey</u>

Executive Order oyster restoration goals and thresholds have been identified by the Oyster Metrics Workgroup, that is comprised of Federal (NOAA/USACE), State (MD-DNR/VMRC), Academic (U of MD/VIMS), and Non-Governmental (ORP/PRFC) partners. Initial population surveys are needed to contextualize restoration goals through baseline population estimates, in

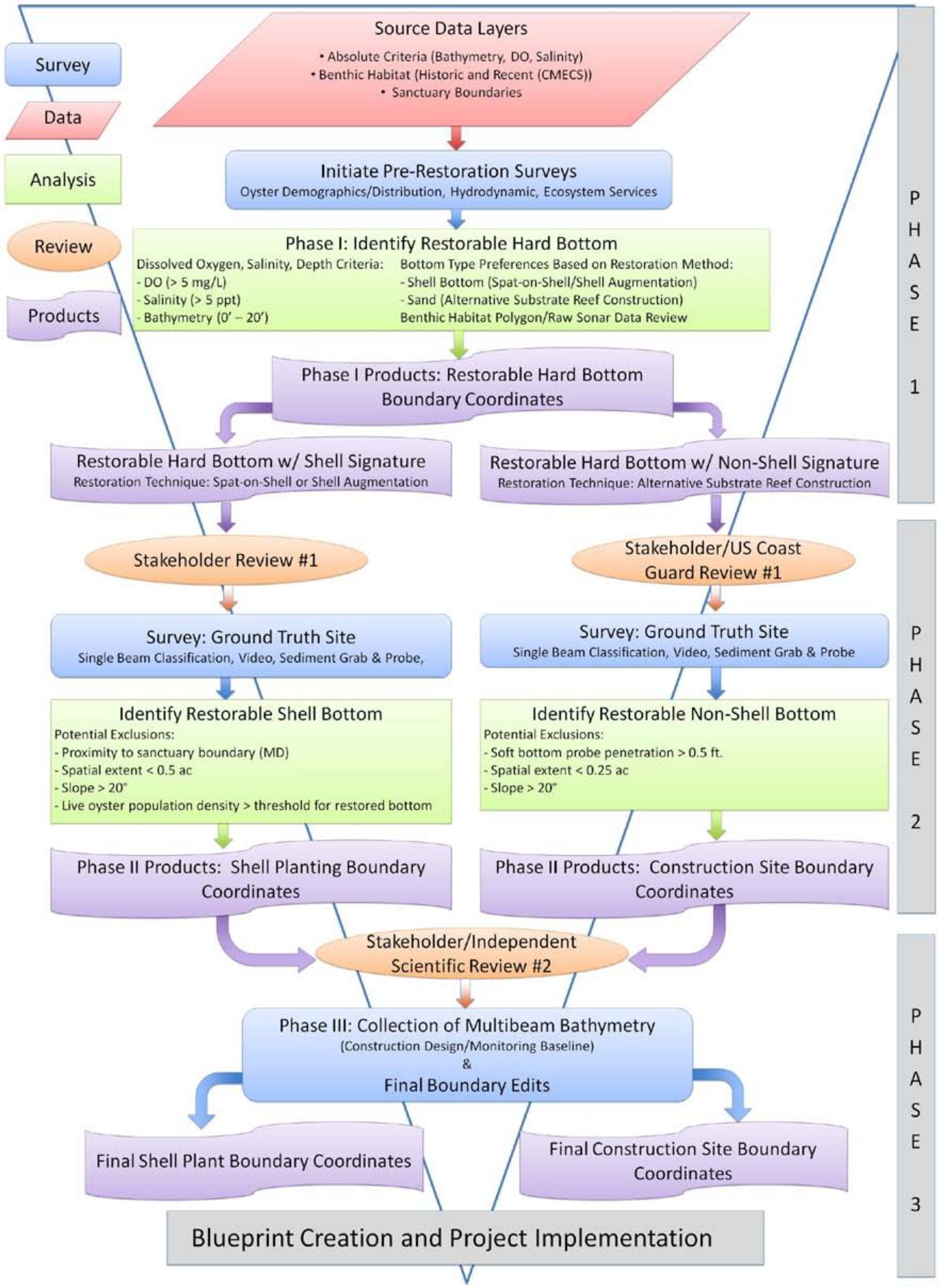


Figure 1. Restoration site selection process diagram based on lessons learned at Harris Creek, MD, in 2011.

addition to identification of the spatial variability in oyster density and extra validation of habitat mapping data. If augmentation of oyster populations with hatchery spat-on-shell is the designated restoration method, then some form of site specific density/abundance assessment is required to determine spatially explicit live oyster demographics. High oyster abundance, exceeding the threshold density 15 oysters per square meter, may preclude the need for restoration efforts in some areas, whereas lower oyster abundance may require the removal of live oysters for planting at other sites or replanting after shell augmentation or spat-on-shell planting occurs. Areas of high shell density per the habitat mapping and low live oyster density could be used for shell reclamation as a management option. Proposed population surveys should replicate the VMRC/VIMS sampling methodology, that uses patent tongs and a grid based randomized sampling scheme, and would meet Oyster Metrics specifications for assessment of bar-scale population demographics. Surveys would provide a determination for the need of restoration action as well as provide a baseline of population estimate to determine efficacy of the restoration project over time. The use of consistent methodology would also permit the use of these data in a bay-wide population assessment context.

Identification of Restorable Bottom: Functional Constraints and Analysis Primary functional constraints are the types of restoration activities planned and potential permitting restrictions. The restoration method is dependent on bottom type in addition to oyster demography and spatial distribution data. The state of MD wishes to reserve bottom with existing shell for augmentation with dredged shell and/or spat-on-shell restoration methods. Shelled bottoms, as determined from survey data, are therefore off limits to alternative substrate reef construction. Presumably this restriction would also apply in Virginia. Besides bottom type distinction, depth limitations may be significant additional restrictions due to the relatively shallow nature of most tributaries and the Bay. Currently, an 8 foot (Mean Lower Low Water) navigational limit is in place on construction projects in Maryland waters. USACE-Baltimore plans to revise existing NEPA documentation and coordinate with the U.S. Coast Guard to end the 8 foot restriction for future projects. Therefore, this restriction will not be included in future plans. In the future, restoration plans will undergo review by the U.S. Coast Guard to determine if any specific locations cause impairment to navigation.

Phase II: Refine Restoration Site Location

Stakeholder Review #1

The stakeholder review can involve waterman groups, recreational fishing groups, resource management authorities, county officials, and the public. The purpose is to present preliminary site boundaries and supporting data derived from Phase I actions and then gather feedback, address reasonable concerns, and attempt to reach consensus on site selection. Ultimately State management authorities, in Maryland's case Maryland DNR, will determine whether concerns over the proposed restoration areas warrant a revision to their boundaries before proceeding with more detailed investigations. In some cases additional investigations may continue if information on fine-scale ground conditions is needed.

Detailed Surveys/Ground Validation of Proposed Restoration Site

In some locations, existing benthic habitat data may not reflect current conditions because of insufficient ground validation during the original surveys and subsequent classification of habitat polygons. This deficiency may require additional site focused survey work with video, sediment grabs, single-beam acoustic seabed classification, and sediment probes to assess existing conditions and refine habitat datasets.

Identification of Restorable Bottom: Additional Constraints and Analyses

Existing coarse bathymetry data should be examined to determine if the slope at proposed site is excessive for restoration. At Harris Creek, slopes greater than 20 degrees that fell within shell or sand polygons were eliminated from the restorable bottom designation. Polygons less than 0.25 acres or sliver polygons (long/narrow) designated as sand or shell were also eliminated from the restorable bottom dataset. Other exclusionary factors include proximity to the sanctuary boundary and sediment penetration depth at potential alternative substrate reef sites. As mentioned above, oyster density values from the population surveys will be compared to thresholds established by the Oyster Metrics Workgroup to determine whether additional restoration activities on existing shell bottom are merited. Refined site boundaries derived from these analyses can be presented at the stakeholder/scientific review #2.

Phase III: Final Determination of Restoration Site Location

Stakeholder Review #2

The secondary stakeholder review can involve as many groups as the managing agency deems necessary, however, the restoration partners should ultimately conduct a collaborative re-assessment of proposed sites based on findings of the ground validation surveys. This final assessment will adjust site boundaries or remove sites from candidacy.

Multibeam Bathymetry Data Collection

Fine scale multibeam sonar bathymetry data should be collected at proposed sites to provide a baseline of habitat complexity conditions as well as to determine the construction specifics given available working depths. Depth data will be standardized to Mean Lower Low Water to determine whether construction heights will be within permit specified elevations. Final site boundary coordinates will be adjusted based on the bathymetry data. If shell bottom is apparent from the bathymetric surface and has previously avoided detection, the polygons will be revised. Final site polygons and vertex coordinates will be provided to the project implementation team for development of their restoration and construction planning documents.

APPENDIX E: Restoration Goals, Quantitative Metrics and Assessment Protocols for Evaluating Success on Restored Oyster Reef Sanctuaries – Report of the Oyster Metrics Workgroup to the Sustainable Fisheries Goal Implementation Team of the Chesapeake Bay Program

Restoration Goals, Quantitative Metrics and Assessment Protocols for Evaluating Success on Restored Oyster Reef Sanctuaries

Report of the Oyster Metrics Workgroup

Submitted to the
Sustainable Fisheries Goal Implementation Team
of the Chesapeake Bay Program.

October 2011

Workgroup Participants:

Steve Allen, Oyster Recovery Partnership
A.C. Carpenter, Potomac River Fisheries Commission
Mark Luckenbach, Virginia Institute of Marine Science
Kennedy Paynter, University of Maryland
Angela Sowers, U. S. Army Corps of Engineers, Baltimore District
Eric Weissberger, Maryland Department of Natural Resources
James Wesson, Virginia Marine Resources Commission
Stephanie Westby, NOAA Restoration Center (Chair)

1. Introduction

Concerted efforts over the past two decades to restore oyster reefs to the Chesapeake Bay have met with mixed success (1-4). A recent review of oyster restoration activities in Virginia and Maryland pointed to the lack of clear goals, established metrics of success, consistent sampling protocols and sufficient monitoring as contributing to our uncertainty surrounding their success (5). Monitoring activity has generally not been well coordinated with restoration activity, and different entities involved in the monitoring have used different sampling gear, monitoring approaches and assessment protocols. Despite explicit objectives of restoring ecological functions and ecosystem services provided by oyster reefs, few measures beyond the number of market-sized oysters have been used to judge success.

Executive Order 13508 *Strategy for Protecting and Restoring the Chesapeake Bay Watershed* established a goal of restoring oyster populations in 20 tributaries of Chesapeake Bay by 2025, further adding to the need to develop clear restoration goals, quantitative metrics and assessment protocols. This document represents an effort by state and federal agencies directly involved in oyster restoration in the Bay to develop clear and consistent objectives, definitions, sampling protocols and assessment techniques pursuant to achieving this goal and evaluating success.

To address these issues the Sustainable Fisheries Goal Implementation Team (GIT) established a technical workgroup comprised of representatives from NOAA, USACE, MDNR, VMRC and academic scientists from UMCES and VIMS. The specific charge to the group was to develop common bay-wide restoration goals, success metrics and monitoring and assessment protocols for <u>sanctuary reefs</u> that include progress toward achieving a sustainable oyster population that ultimately will provide increased levels of ecosystem services. The charge for the group specifically excludes fisheries-specific metrics since it is limited to sanctuary reefs, though the oyster population metrics are certainly germane to fisheries management. It is also important to point out that the group was tasked with identifying a minimum suite of metrics that should be measured across all sanctuary reefs, particularly for the purpose of assessing progress toward the Executive Order oyster goal. We recognize that some sanctuary reefs will need to be monitored more intensely to address specific issues (research priorities, ancillary goals, etc.). The minimum suite of metrics laid out herein should in no way be seen as limiting such additional monitoring and research activity. The workgroup recognizes that future research will inform oyster restoration practices, and strongly encourages the use of sound adaptive management practices. We view this report as a step towards a consensus document between the primary governmental agencies involved in oyster restoration in the Bay with respect to restoration goals, thresholds for success, and monitoring protocols. Our recommendations are informed by the best available science, restoration results to date, and the varying missions and resources of the agencies involved. As such, it accommodates the very different restoration approaches and observed success rates across different geographic areas of the Bay. We expect that, as the state of knowledge advances, targets and approaches outlined here will evolve.

2. Restoration Goals

The overarching goal of restoring a large oyster population, capable of providing valued ecosystem services and supporting a vibrant fishery, drives specific management actions and targets, such as those set forth in E.O. 13508. The crucial fact remains, however, that oyster populations in the Bay have undergone a dramatic regime shift over the past half century and that high natural mortality rates associated with disease, predation, siltation, and unaccounted harvest (poaching), along with negative shell budgets (i.e. shell loss rates > shell accretion rates) in many areas, pose significant challenges to achieving a greatly expanded oyster population. Implicit in the goal of restoring 20 tributaries is the notion that working on a tributary scale will be necessary to achieve sufficiently large changes in oyster populations. Moreover, the cumulative effects of restoration activities are unlikely to be linear; that is, there is an expectation

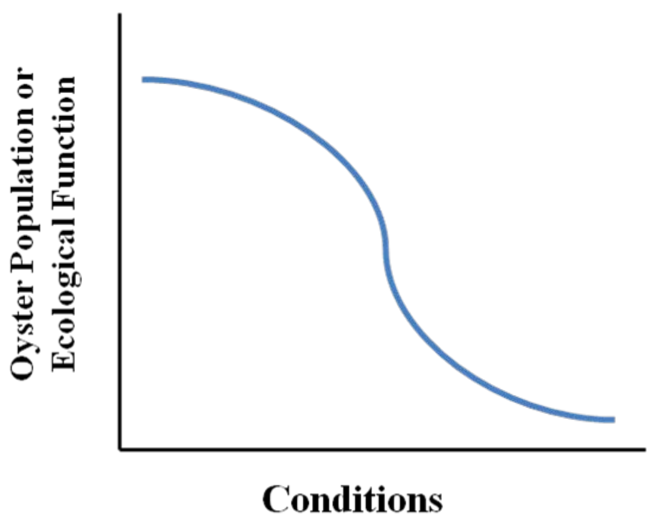


Figure 1. Generalized representation of a threshold response in which improvement in conditions (towards the left) must exceed a critical value to return the system to a stable improved state (upward).

that it will be necessary to exceed several threshold values (e.g. in shell volume, larval supply and survival, disease tolerance, etc.) to achieve a regime shift that supports greater population abundance. Figure 1 provides a simplified depiction of this condition graphically and helps to make the point that restoration of oyster populations and the ecological functions they provide may require exceeding threshold improvements in environmental conditions.

2.1. Tributary-level restoration – Central to our task of developing clear goals and measures of success is establishing what constitutes restoration at the level of a tributary. Is the end product a population of a certain size? Or, is it a percentage of historical oyster habitats occupied by restored reefs? Are we seeking an operational definition related to the amount of restoration activity (shell, alternative substrate or seed planting) or a functional one in which a tributary is not restored until a greatly expanded, sustainable oyster population is achieved? These are not trivial issues to resolve. The workgroup spent substantial time considering these issues and it is important to review a number of caveats before setting final targets.

The intent of setting a goal of restoring oysters to 20 tributaries by 2025 is to undertake restoration at a sufficiently large scale to dramatically increase oyster populations and realize enhanced ecosystem services at a tributary-wide scale. The workgroup discussed this intent at length, defining it as a functional goal. *Specifically, the goal of oyster restoration at the tributary-level is to dramatically increase oyster populations and recover a substantial portion of the ecosystem functions provided by oyster reefs within the tributary.* In effect the goal is to return to the higher plateau represented in Figure 1. As restoration proceeds, the workgroup believes that it is essential that these functional goals remain the primary target.

Exactly what will be necessary to achieve these functional goals is unknown. Simply stated, it has not been done previously. We lack both an empirical and theoretical basis for knowing how much oyster reef restoration is necessary within a given tributary to reach our functional goals. Our underlying assumption is that achieving this goal will require the *successful functional restoration* of a significant proportion of the historical oyster reefs within a tributary. As discussed in the following section, many years of post restoration monitoring will likely be necessary to determine successful functional restoration at the reef level. Additionally, there are several practical limitations on the scale of restoration that can be undertaken within a given tributary, including available restorable areas, the extent of private leases and designated fisheries bars, the availability of shell, and limits on the amount of spat-on-shell production.

Despite the ultimate goal of functional restoration success, restoration goals at the tributary level will need to include *operational goals*, e.g., the amount of shell planted or the quantity of spat-on-shell or the number of bars planted. The agencies and organizations involved in restoration must set operational targets for planning and staging their work. It is necessary, therefore, to establish target levels for restoration activity within a tributary that constitute operational or intermediate measures of success that facilitate restoration planning and implementation. Unfortunately, there is no clear answer to how much oyster reef habitat within a tributary should be targeted for restoration. Comparing detailed surveys by Winslow in Tangier Sound (6) and by Moore in the James River (7) with the more general Yates (8) and Baylor (9) surveys in Maryland and Virginia, respectively, USACE estimated that approximately 40% of the areas included in the Yates and Baylor surveys were hard oyster habitat. Further, using available information, USACE has projected that 8-16% (40x20% to 40x40%) of historic (Yates and Baylor) habitat needs to be restored in a tributary to effect a significant change. Other significant considerations in setting these targets are observed degradation of historical oyster bottom and practical limits associated with the amount of reef area within a tributary that can realistically be set aside as sanctuaries and restored.

“Restorable areas” have, at a minimum, hard bottom that will support shells or alternative substrates deposited on the bottom in a restoration effort (i.e. they will not sink into mud or silt). Other considerations for restorable areas include availability of public bottom (not leased) and appropriate water quality. The amount of reasonably restorable area varies considerably among tributaries. Surveys of oyster bars conducted during the late 19th and early 20th Centuries provide our base maps for historical oyster distributions (6-9). The most recent comprehensive survey of the condition of the Maryland Bay Bottom was conducted between 1974 and 1983. More recent surveys (11, 12) have attempted to characterize the currently-viable habitat and estimate habitat loss. In Maryland, a recent estimate suggested that less than 10% of the areas formerly classified as supporting oysters currently had suitable substrate for oyster restoration (12). In Virginia, surveys conducted in the 1980s suggested that only about 20% of areas formerly classified as oyster bars were viable (11, 13). These estimates do not necessarily precisely characterize the amount of bottom area that is suitable for restoration, but they do illustrate the point that conditions at many of the historical oyster bars are not currently favorable for conducting oyster restoration. In Virginia, an Oyster Restoration Atlas (14) has been developed by VIMS and VMRC, which incorporates the most recent substrate maps, the boundaries of public and leased oyster grounds, bathymetry and salinity in relation to current and potential restoration sites on a tributary by tributary basis. These maps not only target areas that are suitable for restoration, but make it quite clear that many areas are either not suitable or not available by nature of being privately leased. In Maryland, the Native Oyster Restoration and Aquaculture Development Plan designates some areas to be established as sanctuaries and others for aquaculture development, with other areas open to fishing. It is clear that tributaries will need to be selected for restoration based upon numerous criteria, including the amount of area suitable for restoration and how this area compares to the historic extent of oysters. Those with too little suitable area offer little chance for improvement, and those with too much are likely intractable.

These considerations lead us to recommend that tributaries slated for oyster restoration be carefully selected as those adequate in size to be meaningful, but not so large as to exceed reasonable expectations with available resources. Large-scale, tributary-based oyster restoration is in its infancy. Techniques and methods are only beginning to be identified and are largely untested at this scale. With this in mind, as well as recognized funding and resource limitations, it is recommended that small tributaries (creeks and small rivers) receive initial focus, given the tributaries meet other restoration criteria. (See Appendix A for examples of Chesapeake tributaries that fall into this size category.) It may also be reasonable to target geographically distinct sub-segments of larger tributaries for focused oyster restoration and still be consistent with the E.O. goal. Tributaries need to be further evaluated for the amount of available habitat that is suitable for restoration and the reality of establishing and maintaining the restoration sites as sanctuaries.

In accordance with this analysis, the workgroup suggests that an operational goal of restoring 50 -100% of currently restorable oyster habitat represents a reasonable target for tributary-level restoration. In selecting a tributary for focused restoration, it is also important to consider its historic oyster bottom where accurate data exist. As mentioned previously, USACE has projected that 8-16% of historic oyster bottom habitat needs to be restored in a tributary to effect a significant change. *Thus, an ideal candidate tributary is one where 50-100% of the currently restorable bottom is equivalent to at least 8%, and preferably more, of its historic oyster bottom.*

Final judgments about the ultimate success of these activities in catalyzing a regime shift to greatly enhanced, sustainable oyster populations may not come until many years after the actual restoration activities are completed. Functional success metrics for gauging the ultimate success of these efforts are discussed in sections below.

2.2. Reef-level restoration – Oyster restoration activity (planting of substrate or spat-on-shell) takes place at the level of an oyster bar (=reef). Again, however, we lack clear definitions of either operational or functional success at this level. Complete failure is easily observed as a lack of recruitment to planted shell, high mortality of planted seed, or the degradation and burial of shell before a population becomes established. Success, on the other hand, can be harder to define and quantify. Do we define operational success in restoring a reef only after 100% of that reef area has been planted with shell, alternative substrate or spat-on-shell? Or, is some lesser coverage sufficient? Is functional success achieved only when a threshold abundance of oysters (e.g., 100 oysters m^{-2}) is established, or a target value of an ecosystem service (e.g., 500 kg N removed $hectare^{-1}$ yr^{-1}) is reached? And, what is the time course over which this success is to be judged? Each of these requires some resolution if progress towards achieving the goal set forth in the E.O. is to be tracked in a consistent manner. We attempt to provide some clarity on these issues below.

Establishing operational goals and metrics is an imperative. Restoration activity on an individual bar must have a target value at the implementation phase. Do we target planting shell, alternative substrate or spat-on-shell on 100% of the bar before we consider our current activity at that bar complete or do we target planting 50% of the area, for instance? A relevant consideration here is that in their unexploited state oyster beds in the Chesapeake Bay did not exist as vast uniform reefs, but rather varied considerably in shape, size and degree of bottom coverage (6, 7, 15-17) with “hard-rock” and “mud-shell” areas occurring within an oyster bed (18). Practical considerations of planting techniques in current restoration practices also play a role in variable coverage of oysters on a reef. Thus, it seems apparent that restoration of an oyster bar should target planting something less than 100% of the historical bar area.

Unfortunately, we have only limited information on which to base specific recommendations for the amount of coverage that should be targeted with shell, alternative substrate or spat-on-shell plantings. Figure 2A shows a spatial view of intertidal oyster reefs in the coastal bays along Virginia's Eastern Shore. Individual patch reefs, typically 2 – 3 m^2 in area are separated by 1 – 4 m and larger scale patterns of reef distribution appear to the reflect flow patterns. We do not suggest that this pattern is typical of all subtidal reefs within Chesapeake Bay, but use it to illustrate that in a natural, seemingly healthy and stable oyster population that oysters do not cover 100% of the bottom within an area that might reasonably be termed a reef. Historical accounts from subtidal reefs in the Chesapeake Bay indicate that "reefs", even during the early phase of heavy exploitation, were not uniformly covered in oysters, but included extensive areas without oysters (6, 7). A lack of complete coverage of the bottom is

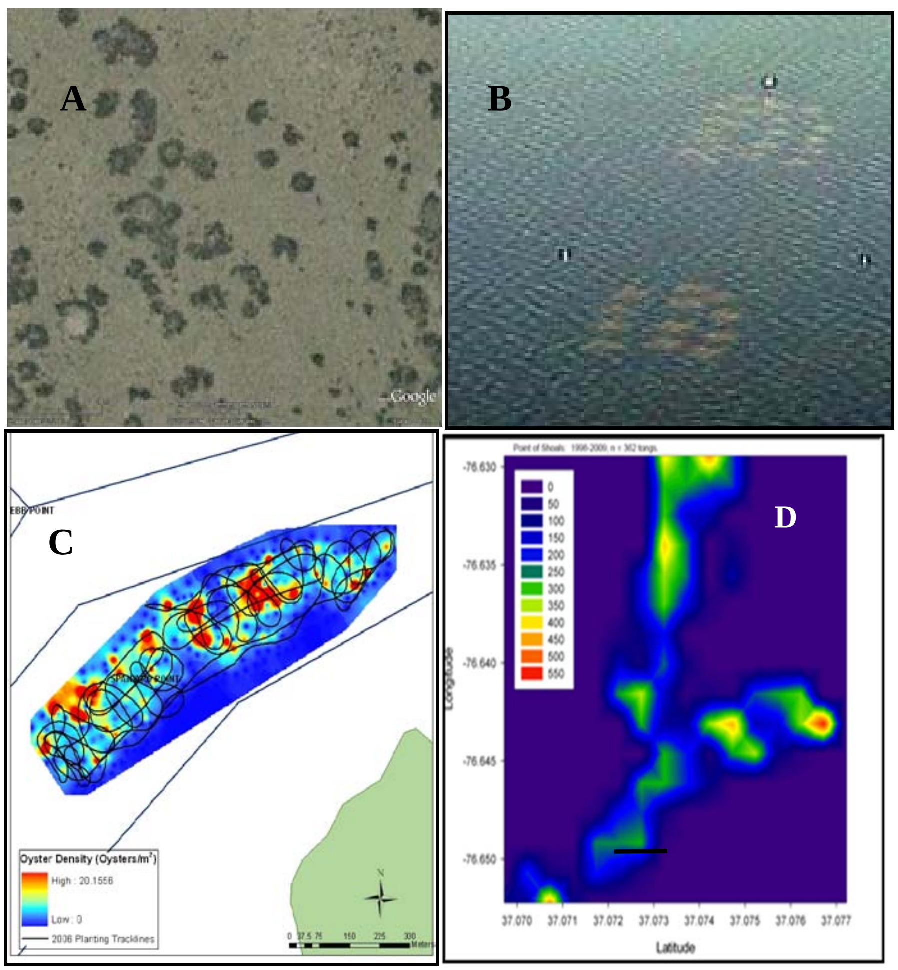


Figure 2. Shell and oyster coverage on natural and restored reefs: (**A**) Intertidal patch reefs in the VA coastal bays; (**B**) Shell plants in mounds in the Rappahannock River; (**C**) Track lines from seed planting and oyster densities on a restored reef in the Chester River; (**D**) Map of oyster density on Point of Shoals reef in the James River. (Figure credits: A. Image from VA Base Map Program via Google Maps; B. photo by P.G. Ross; C. figure from Ken Paynter; D. figure from Roger Mann.)

also evident in planting techniques currently in use (Fig. 2B, C) for planting shell and spat-on-shell in Virginia and Maryland, respectively, and on a natural reef in the James River (Fig. 2D).

There are two distinct reasons to establish minimal planting coverage operational targets: (1) to provide guidance on how much planting should be planned for a particular reef and (2) to establish a consistent approach to reporting the spatial extent of operationally restored reefs. In lieu of a more rigorously defined value, we suggest that at this time a minimum target of 30% coverage of a reef area be set as an operational practice. *That is, shell planting and spat-on-shell should result in a* <u>*minimum*</u> *of 30% of coverage of the restoration reef*[1]. We emphasize here that, as with the other targets that we are recommending, this minimum value represents a minimum consensus value that can be achieved across the range of restoration techniques and restoration sites in Chesapeake. For instance, it is reasonable that close to 100% coverage can be achieved at some restoration sites which receive shell only; however, areas in upper Bay for which spat-on-shell is the preferred restoration technique, 30% coverage of an oyster bar may be near the upper limited that can be practically achieved.

Operational targets for the oyster population size and structure within these planted areas also need to be established. Again, however, we lack a clear empirical or theoretical basis for setting these targets. We follow a few guiding principles in developing some tentative recommendations in this area. The first, and most compelling, is that our concept of a reef as a biogenic structure is unlikely to be achieved at very low densities of oyster (< 10 and perhaps 20 adult oysters/m^2). Indeed, the persistence of the reef itself is dependent upon densities above some minimal level. A positive shell budget will require sufficient numbers of oysters accreting at a rate that exceeds current sediment deposition and shell degradation rates, a condition that Mann and Powell (2) have pointed out is not currently achieved with many restoration efforts. In a successful modeling study of oyster populations in the James River, Mann and Evans (19) assumed, based upon a previous empirical study (20), that at a mean density of 100 oysters/m^2 fertilization efficiency was less than 10%. Because oysters are largely protandric

[1] This recommendation is not intended to suggest that restoration activity should select a region of the target area that is only 30% of the total and concentrate shell or spat-on-shell planting only in that region. Rather, it is a recognition that even a natural or fully restored reef is not a monolithic structure fully covered in oysters and shell. 30% is intended only as a <u>minimal</u> acceptable coverage within the area that was actually planted.

hermaphrodites, with most larger, older individuals being females, achieving high reproductive success may require that multiple ages classes are present to ensure adequate numbers of males and females. A second area of guidance in developing oyster density or biomass targets comes from studies of ecosystem services provided by oyster reefs. Though we lack quantitative relationships between oyster density and the various ecosystem services that we are seeking to recover via restoration, the studies to date that have documented such services have, to our knowledge, done so on reefs with mean densities well above 20 adult oysters/m^2 (e.g., 21-35).

Though a firm basis for establishing optimal mean density and age structure targets is lacking, *the workgroup recommends that a mean density of 50 oysters/m^2 <u>and</u> 50 grams dry weight /m^2 containing at least two year classes, and covering at least 30% of the reef area provides a reasonable target operational goal for reef-level restoration.*[2] A mean oyster density of 50 adults/m^2 over 30% of the bottom is comparable to the mean oyster density in Maryland 100 years ago, which was 10-15 oysters/m^2 over an entire oyster bar (36). The target of having a minimum of two year classes reflects the need in low recruitment-low mortality areas in the upper Bay to ensure that as oysters from initial plantings age and progressively contain more females that a younger year class with more males is present ensure fertilization. Thus, this criterion requires attention to the age and sex ratio of the oysters on restored reefs and may require that additional year classes be added.

We note that reefs with much lower densities than the target above may be on a positive restoration trajectory, be viable, and warrant continued restoration efforts because they provide some level of ecosystem services, and could serve as spat settlement substrate in subsequent years. Thus, for the purpose of consistently tracking progress toward the E.O. goal, the *workgroup recommends a <u>minimum</u> <u>threshold</u> for a successful reef as a mean density of 15 oysters/ m^2 <u>and</u> 15 grams dry weight/ m^2 containing at least two year classes, and covering at least 30% of the reef area.* Reefs that meet this minimum threshold will be considered minimally successful for the purposes of tracking E.O. goal progress, although the target goal is not achieved. Again, this minimum threshold would require either 15 oysters >3 inches/m^2 or a larger number of smaller oysters to achieve 15 g dry weight/m^2. Higher coverage with lower

[2] Note that 3 inch oyster has a dry weight of approximately 1 gram, so this target would require 50 adult oysters/m^2 or many more small oysters.

mean densities does not qualify. Higher abundances without 15 g dry weight/m^2 does not qualify, nor does >15 g dry weight/m^2 with fewer than 15 oysters/m^2. As with the minimal percent coverage target discussed above, this minimal value reflects a consensus view among the workgroup that accommodates those areas in the lower Bay for which high recruitment occurs, but that few oysters survive to greater than 3 inches. The workgroup believes the literature supports the establishment of a combination of minimum biomass, abundance and coverage for restoration to be deemed successful.

As noted above, a viable oyster reef must maintain a non-negative shell budget (2). Reef structure is itself necessary for the persistence of healthy benthic populations (24, 25), and influences the magnitude and type of ecosystem services provided. The basic tenet here is that structure should at a minimum be maintained, or ideally grow, from a post-restoration baseline to allow for reef sustainability. Restored structure to date generally consists of either shell mounds or alternative substrates (e.g., rock, crushed concrete, reef balls). Tracking the height, spatial extent, and shell budget on these areas over time is critical to understanding whether the structure is increasing, unchanged, or decreasing based on these metrics. Factors contributing to reef structural growth include natural spat set, oyster growth, set and growth of other hard-shelled organisms, and maintenance plantings of shell or seed oysters. Factors decreasing reef structure may include subsidence of constructed substrate and/or shell (e.g., post-construction subsidence into soft bottom), sedimentation, shell dissolution in excess of accretion, and illegal harvest activity. Thus, the workgroup recommends as *a structural goal that reef spatial extent, reef height, and shell budget should remain neutral or increase from a post-restoration baseline.*

Meeting operational targets does not, of course, ensure functional success of the restoration. The reality exists, however, that it may not be possible to determine functional success until at least several years after the initial restoration activity. The ultimate goal of restoring a reef is that it will persist as part of a larger *self-sustaining* population, with new substrate accruing or keeping pace with shell loss and providing desired ecosystem services. Limited success at achieving this goal at a greatly enhanced population level on a system-wide basis has led to the new emphasis on a tributary-scale approach to the problem with the hope that this will overcome some of the problems in the past. In the near-term an intermediate goal of *sustainable* reefs (for which some ongoing intervention, such as shell or spat plantings may be repeated every few years) is more realistic than entirely self-sustaining reefs. *On a time horizon of 2 – 10 years following restoration activity, we suggest that a stable or positive shell budget, stable or increasing oyster biomass and multi-year class age distributions represent reasonable goals.* Comprehensive monitoring, employed in an adaptive management approach, can inform the need for additional restoration activity on specific reefs following initial restoration activity to meet this intermediate goal. Likewise, timely monitoring data will allow managers to make the less desirable decision to cease restoration activities on a particular reef if the minimum restoration thresholds are not being achieved. The workgroup recommends that a technical panel with representatives from each of the organizations be convened to explore a joint database for all monitoring data collected toward tracking the reef-level and tributary-level goals laid out herein as a mechanism of tracking progress toward the E.O. goal of restoring 20 tributaries. The Comprehensive Oyster Database being developed by NOAA's Chesapeake Bay Office may serve this purpose.

2.3. Ecosystem services and ecological function – Oyster restoration efforts in the Chesapeake Bay and elsewhere in the U.S. have been motivated over the past two decades as much by the desire to recover lost ecological functions and ecosystems services provided by oysters and the reefs they build as by the desire to rebuild fisheries. Several studies over the past few years have demonstrated that healthy or restored oyster reefs provide enhanced ecosystem services over unrestored or non-reef habitats, including the growth rate of seagrasses (28), the abundance, biomass and diversity of reef resident organisms (24, 25), the abundance, biomass and diversity of nekton (22, 29-34), water quality improvement (26, 37, 38), nutrient cycling (27, 38, 39) and shoreline stabilization (35). Setting specific targets for any of these ecosystem services or ecological functions as quantifiable goals for oyster restoration poses several practical constraints. First, we lack both a historical basis and appropriate current reference sites to set targets for most ecological functions of interest. We currently do not know, for instance, how much fish production or denitrification was associated with historical oyster reefs in the Chesapeake Bay or how much would be associated with fully restored reefs in the present. Second, we cannot quantify the level of any of these services provided by a restored reef by sampling on reefs alone. The quantity of an ecosystem service (e.g., increased water clarity or enhanced blue crab populations) provided by a reef or a series of reefs in a tributary cannot be determined from sampling only on restored reefs, but requires comparisons to appropriate references areas in a well conceived BACI (Before-After-Control-Impact) design. Even in the uncommon situation when appropriate reference sites are available, the effects of restored oyster reefs on ecosystem services may be confounded by many other factors in the watershed and water body. We nevertheless appreciate the importance of evaluating the ecosystem services provided by oyster restoration activities and including these in our determinations of success. Thus, we outline an approach in the sections below on Assessment Protocols for estimating the ecological services provided by restored oyster reefs based upon combining the findings from experimental and/or modeling studies with routine reef monitoring.

3. Assessment Protocols

Evaluating reef-level restoration success minimally requires the determination of several parameters: (1) structure of the restored reef (reef spatial extent, reef height, and shell budget), (2) population density (as individual abundance and biomass) and (3) a total reef population estimate (biomass). Although measurement of the first two and calculation of the third parameters are straightforward, they have been the source of some consternation in the past, so we will first clarify the issues before making specific recommendations.

3.1. Reef area, height, shell budget **–** Original reef boundaries in the Chesapeake were mapped in the late 19th Century by using techniques such dragging a chain or probing the bottom with a pole (6-9). These techniques were adequate for coarse identification of broad areas with shell and oysters; however, it was recognized at the time (6, 7) and has been subsequently verified that these approaches did not accurately represent either the boundaries of the reefs or the heterogeneity within a reef. The practical implication of this today is that neither the Yates nor the Baylor surveys serve as appropriate benchmarks for scaling restoration targets.

Current-day techniques for assessing reef structural metrics include acoustic mapping, direct benthic sampling, under water video and aerial imagery. Acoustic mapping is a powerful tool for obtaining detailed bathymetric and textural information about bottom habitats, and may provide for simultaneously mapping reef boundaries and measuring reef spatial extent and reef height (as well as structural complexity). Acoustic mapping cannot be used in intertidal areas and must be combined with groundtruthing to distinguish shell from live oysters or shell under thin layers of sediment. For shallow water reefs where acoustic mapping may be inefficient or impossible, aerial photography may provide an accurate means of assessing reef area (see Fig. 2B or the Google Earth image of the Hume Marsh reefs in the Lynnhaven River at 36°53'26.47"N, 76° 5'6.15"W), though this approach requires groundtruthing as well. Direct sampling coupled with high resolution GPS data can be used to map reef perimeters, but large sample numbers are required to accurately define the reef perimeter. On these shallow water reefs, height can be obtained using a rod and level method.

Quantitative samples taken for oyster population measures by patent tong or diver can be used to measure volume. Recommended assessment methodology for measuring and tracking shell budget on subtidal reefs is by patent tong. During surveys for oyster populations, retrieved shell volume can be measured in each tong grab. Shell quality can also be subjectively judged in several ways including an estimation of 'anoxic' or black shell vs. 'oxic' or brown shell. It should be noted that acoustic mapping techniques cannot determine shell quality. Expectations would be that shell volume surveyed in this way would reflect general decline, maintenance or increase over time.

The accurate determination of total reef area is critical to estimating the amount of restored area, oyster population abundance, and ultimately the quantity of ecosystem services provided by oyster restoration. The most appropriate method or combination of methods for assessing reef area will vary by region and reef types. The majority of the subtidal restoration activities will occur in depths where acoustic mapping technologies can be applied; in these areas, acoustic mapping with groundtruthing appears to be the most accurate and efficient method for assessing the structural characteristics of a reef, including reef spatial extent and should be pursued as the standard wherever possible. We stop short, however, of recommending this approach as a minimal monitoring requirement on all restoration projects. The important point is that accurate determination of total reef area is, in particular, critical to estimating the amount of restored area, oyster population abundance and ultimately the quantity of ecosystem services provided by oyster restoration. *Determination of reef area, height, and shell budget should be an integral part of the assessment of restoration success on sanctuary reefs*.

3.2. Quantitative density estimates – There is historical precedent in portions of Chesapeake Bay for estimating oyster abundance based upon timed dredge tows and there are widely recognized limitations to this approach including unknown sample area and the dependence of gear capture efficiency on sample volume (40, 41). Density estimates obtained in this manner are usually expressed as numbers of live oysters per bushel of shell, but conversion to numbers of live oysters per unit bottom area have also been developed by Rothschild and colleagues (42). It was not in the purview of this workgroup to design sampling protocols for oyster fisheries assessment, so we will leave it to others to determine the appropriate sampling technique for that use. *However, we recommend oyster density estimates on sanctuaries and other protected reef restoration sites be obtained from quantitative grab samples*. These samples may be obtained from quadrate samples excavated by divers or by patent tongs or, in shallow-water and intertidal sites, by direct access. We point out, however, that the capture efficiency of quadrate grabs and tongs is less than 100% and that there is the need for careful calibration of these techniques.

Monitoring costs by any of the methods above can be high, especially when there are large areas to be assessed. Thus, there is often pressure to keep sample replicates to a minimum. Accurate and precise estimates of mean abundances in highly patchy populations nevertheless may require large sample sizes. The sample size required to obtain a desired level of precision in the estimated mean or total abundance can be determined by plotting the relationship between the relationship between the standard error of the mean and sample size. We recommend that monitoring programs employ this approach and optimize sample allocations.

Confusion has occurred in recent years regarding the inclusion of grab samples that contain no oysters into estimates of mean density. This uncertainty arises because oyster reefs (even natural healthy ones) are not monolithic structures with oysters distributed uniformly within what we would define as the reef perimeter (see Fig. 2 and discussion in Section 2.2). Thus, as we assess progress towards restoring (and conserving) reefs, we need to come to grips with the fact that restored area does not precisely match the area with oysters. This situation is particularly well illustrated in Figure 2A which shows an area with natural intertidal patch reefs. The currently available information suggests that this represents a fully developed reef complex that is comparable in spatial extent and density (though perhaps not oyster size and biomass) to historical reefs in the region. Estimating the mean density of oysters on these individual patch reefs (which average 2 – 3 m^2 in area) is straightforward, requiring only that we obtain adequate numbers of quantitative samples from randomly selected individual patch reefs over the area. The point of disagreement that has arisen is over how one determines either the total population size or the total area of restoration from these samples.

3.3. Oyster population assessment – In the intertidal situation represented in Figure 2A, the total population size of oysters in the reef complex is easily estimated as the product of the mean density on patch reefs and the total area of the individual patch reefs, because we can clearly count and measure the individual patch reefs within the area. The challenge emerges in subtidal reefs were obtaining a clear picture of the distribution of oysters prior to sampling is more difficult and costly. High-resolution side-scan sonar, coupled with extensive groundtruthing samples may provide such information precisely and reliably. *If current, validated maps of fine-scale reef distribution are available prior to quantitative density sampling, then sample allocation may be directed at those locations only and total population size estimated as in the intertidal example above*. In the more generalized case in which predetermined, high precision maps of oyster density or habitat quality are available, Wilberg (pers. com.) has shown that when underlying habitat strata explain a portion of the overall variance, stratified random sampling (STRS) provides a more precise estimate of total oyster abundance than simple random sampling (SRS) *for a given number of samples*. In the STRS scenario, regions within the reef of high, medium and low habitat quality are sampled in a stratified random design (see Fig. 2 C&D for maps of reefs exhibiting these conditions). This approach can provide a much more precise estimate of the true population abundance with far fewer samples than SRS (Wilberg, pers. com). This method is dependent upon the availability of high resolution maps reflecting the current reef conditions prior to sampling. Ideally these maps would be available and should be developed wherever possible; however, in the past such detailed knowledge about the underlying distribution of oysters on a reef has not always been available to guide sampling. When the underlying distribution of oysters (or even oyster habitat) within a restored reef is unknown or not known with sufficient accuracy, then a stratified sampling design is not possible. In this case two approaches have generally been used: systematic and simple random sampling (SRS). The systematic approach involves gridding out the sampling area and taking one sample from the centroid of each grid. The SRS approach has generally involved also gridding the sampling area, but taking samples from a random subset of grids. This type of systematic survey will provide information on both the population and its distribution across the target area. If distribution is not important, an SRS will suffice for population estimate and coverage. The number of samples required will be determined by the variance among samples and should be adjusted to reduce the variance of the population estimate to the point where additional samples will only minimally affect the variance.

The data from either systematic or SRS surveys can be used to estimate population size (total abundance) within the target restoration area. Specifically, the mean density of oysters in all samples (including zeros) taken within the target restoration area is multiplied by the entire target area. This approach, however, may not provide a valid estimate of density on the actual reef(s) resulting from the restoration activity. Such an estimate requires that the actual extent of the reef be defined, either via pre- or post-stratification, and that samples only from the reef strata be used to determine density. The committee recommends that a stratified random survey design be used whenever data on strata are available. All restoration projects should collect pre-construction data in order to assess the project's success and cost-effectiveness by comparing post-construction data. When stratification is possible, restoration efforts should be surveyed considering the strata rather than using SRS. We note, however, that determining failure rate of a restoration activity is equally as important as determining success rate. Consequently, sampling in areas that received restoration activity, but did not result in the formation and persistence of a reef is a critical requirement of the evaluation process. We note that there are at least two ways in which such "failures" can occur—(1) operational errors in which shell or spat-on-shell planting took place outside of the target area and (2) burial of planted materials within the target area. Both have occurred in various restoration efforts in Chesapeake Bay. Thus, those strata should be sampled as well but perhaps not with the frequency of the 'successful' strata. The important point here is that monitoring programs should sample in a manner that allows several questions to be answered: *How successful was the restoration activity? What is the oyster abundance and biomass within the target area? What is the density and abundance of oysters on the resultant reef?*

Although a stratified random sampling design requires fewer samples than either a simple random sampling or systematic sampling design to achieve the same level of precision in estimating population size under the conditions specified above, we stop short of recommending that all population assessments on restoration reefs employ a pre-sampling STRS design for two reasons. First, we are not in a position affirm that the technical resources (side-scan sonar or video imagery) will always be available to parties conducting these assessments in a timely fashion. More importantly, we have not evaluated the cost effectiveness of the various approaches. That is, it might be more cost effective for an agency to take many SRS than to conduct acoustic bottom surveys and take fewer STRS to achieve the same level of precision in estimating oyster population size. The important point here is that it is incumbent upon each monitoring program to employ a sample design that provides oyster population estimates with good accuracy and precision.

We emphasize that accurate and precise estimates of the total population size on a restored reef require that the actual extent of the reef be determined during post-restoration monitoring. Actual extent of the restored reef may differ from the target restoration area, both in the extent within the target area and expansion outside of the target area.

3.4. *Assessment Frequency*- The question ‘At what point in time can we call a reef restored?’ is not an easy one to answer, but the workgroup believes it is an essential part of our initial charge to come to consensus on this for the purpose of tracking progress toward the E.O. goal.

The recommended minimum assessment intervals for reef-level goals is established at 1) post-restoration activity to establish baseline (within 6 to 12 months of restoration activity); 2) again at three years post-activity; and 3) again at 6 years post-activity. The group recognizes that there is additionally a need for basic pre-construction monitoring to support site selection and gauge the accomplishments of restoration actions. Pre-construction monitoring should be designed based on the goals of the restoration project and the resources available. This, however, is not purview of this workgroup.

More frequent and intensive monitoring will likely be required, and is highly encouraged, on some restoration projects to facilitate, for example, research projects or ancillary goals. The above intervals are established only as *minimum* frequencies for assessment, and are in no way meant to preclude more frequent monitoring. The initial post-restoration assessment is essential for establishing a baseline against which to evaluate future project success. The three-year point is critical to allow for adaptive management. If, for example, a project shows at this point signs of needing additional seed or shell, a management decision can be made to do so to increase the likelihood of success. Conversely, the decision may be made that the project was poorly constructed, poorly sited, used inappropriate materials, etc., and that continued investment is ill advised. Determining the *causes* of failure is, of course, essential to adaptive management. Measuring parameters such as dissolved oxygen, pH, temperature, salinity, disease levels and sedimentation rates can help determine why failure occurred, allow for adaptive management, and avert recurrence.

By consensus, this workgroup establishes the six-year assessment as a reasonable point at which to determine whether a reef is 'successful' for tracking progress toward the E.O. goal.

Ecosystem services and ecological function – In Section 2.3 we indicated that monitoring alone would not be sufficient for assessing the level of ecosystem services provided by a restored oyster reef. Because this is an important concept, we will explain this assertion further and then recommend an assessment strategy that we believe is appropriate.

Most of the ecological functions and ecosystem services that we desire from a restored oyster reef are affected by a great many other factors. For instance, water clarity is affected by atmospheric and terrestrial inputs, phytoplankton dynamics and meteorological conditions, among other things. Thus, measuring changes in water clarity in a tributary and attempting to link those changes to oyster restoration success is highly problematic. Indeed, even as an increasing oyster population filters more water, changing land use practices could cause water clarity to decline. Similarly, measuring utilization of a restored reef by finfish does not account for numerous other factors (e.g., recruitment, natural mortality and fishing mortality) that may be affecting regional fish population size. Comparisons to a nearby non-reef control sites may overcome some of these uncertainties; however, such a monitoring scheme quickly becomes intractable to do at all restoration sites.

A much more tractable approach is to make use of the results from targeted monitoring programs, controlled experiments and modeling studies to develop generalizable relationships between characteristics of an oyster reef (e.g., reef size, oyster abundance, oyster biomass, reef complexity or other measures) and the quantity of various ecosystem services. For instance, if a carefully designed study was to estimate:

$$\text{Biodeposition} = f\,(\text{reef size, oyster biomass, total suspended solids [TSS] and temp.}),$$

then routine monitoring of reefs at other sites together with measurements of TSS could be used to estimate biodeposition provided by those reefs. Similarly, if a controlled, replicated experiment was used to generate a relationship between the numbers (or biomass) of oysters on a reef and the resulting amount of additional finfish production, then routine monitoring of oyster population characteristics described above could be used to estimate potential finfish production associated with restored reefs in varying conditions. As a final example, if controlled, replicated experiments were employed to quantify nitrogen fluxes from the sediment as a partial function of oyster biomass (as well as temperature and seston concentrations), then routine monitoring data could be used to estimate nitrogen fluxes attributable to a particular restored reef.

Apart from the obvious benefits of feasibility, this approach towards evaluating success of reef restoration relative to ecosystem services provides a means of estimating the amount of ecosystem services provided by restored reefs that vary in their success. That is, hypothetically, a reef with 100 g dry weight biomass m^{-2} may provide 20-times the nitrogen removal capacity of an unrestored reef, while a reef with only 10 g dry weight biomass m^{-2} may provide only 5-times the removal capacity.

Determining such relationships will require carefully designed monitoring, experimental or modeling studies conducted over the next several years. We are careful here not to identify specific ways in which these relationships should be determined acknowledging that it will require creative studies by various investigators. As long as those studies equate absolute or relative values of ecosystem services to quantitative metrics related to the oyster population or reef characteristics that are being measured as part of a routine monitoring program, then they will provide the best means available of assessing success in this area. *Funding these types of studies will be neither cheap nor politically popular, but we emphasize that they are the only reliable means of quantitatively assessing the ecosystem services associated with reef restoration* *and they are much less expensive than attempting to directly measure ecosystem services on all restored reefs.*

4. Evaluating Success

As stated previously, success in oyster restoration efforts will need to be evaluated on several levels over varying spatial and temporal scales. Targets and metrics of operational success are required to guide restoration activity, such as what percentage of a historical bar or other area should be planted with shell or spat-on-shell. Monitoring of individual reefs following initial restoration activity will be required to determine success at various stages by evaluating recruitment success, early post-settlement or post-planting survival, natural mortality, disease status, growth, reproduction and shell accumulation. Evaluating success at the tributary level likewise will need to involve operational definitions about the amount of area within the tributary that needs to be rehabilitated and functional measures of the status of those areas several years after the restoration activity. Table 1 summarizes the goals, assessment protocols and success metrics that we have discussed above.

Table 1. Summary of goals, assessment protocols, assessment frequency and success measures

Goal	Success metrics (targets and/or thresholds)	Assessment Protocol	Minimum Assessment Frequency (assumes pre-restoration survey)
Operational Goals: Defined programmatic and planning outcomes for reef construction and tributary level restoration			
Reef-level 1. Appropriate amount of substrate and/or spat-on-shell was planted. 2. Presence of substrate and/or spat-on-shell within the target area.	Shell, alternative substrate, or spat-on-shell should cover a minimum of 30% coverage throughout the target reef area.	Patent tong or diver grabs	Within 6-12 months of restoration activity
Tributary-level target: 1. Appropriate amount of area within the tributary has met reef-level operational goals.	A minimum of 50% of currently restorable area that constitutes at least 8% of historic oyster habitat within a given tributary meets the reef-level goals defined above.	GIS-based analysis of restoration activity within the tributary	Annual
Functional Goals: The desired ecological outcomes at reef and tributary scales			
Reef-level goals			
Significantly enhanced live oyster density and biomass	Target: An oyster population with a minimum mean density of 50 oysters and 50 grams dry wt/m^2 covering at least 30% of the target restoration area at 3 years post restoration activity. Evaluation at 6 years and beyond should be used to judge ongoing success and guide adaptive management. Minimum threshold: An oyster population with a mean density of 15 oysters and 15 grams dry wt biomass · m^{-2} covering at least 30% of the target restoration area at 3 years post restoration activity. Minimum threshold is defined as the lowest levels that indicate some degree of success and justify continued restoration efforts.	Patent tong or diver grabs	Minimum 1, 3 and 6 years post restoration
Presence of multiple year classes of live oysters	Minimum of 2 year classes at 6 yrs post restoration.	Patent tong or diver grabs	Minimum 3 and 6 years post restoration

Table 1 (cont.)

Positive shell budget	Neutral or positive shell budget.	Quantitative volume estimates shell (live and dead) per unit area	Minimum 1, 3 and 6 years post restoration
Stable or increasing spatial extent and reef height	Neutral or positive change in reef spatial extent and reef height as compared to baseline measurements.	Multi-beam sonar, direct measurement, aerial photography	Within 6 -12 months post-restoration, and 3 and 6 years post restoration
Tributary-level goals			
Expanding oyster population beyond the restored reefs	Will need to be determined as restoration proceeds.	Quantitative assessment of oyster populations throughout the tributary.	Will need to be determined from future assessments.
Return of the oyster population within a tributary to an enhanced stable state.	Specific targets will need to be developed on a tributary-specific basis as restoration proceeds.	Quantitative assessment of oyster populations throughout the tributary.	Will need to be determined from future assessments.
Enhanced ecosystem services in the tributary	Currently unknown. Specific targets will likely be informed by the results of experiments relation ecosystem services to structural metrics.	Determine relationships between structural reef characteristics (e.g., reef size, oyster abundance, or oyster biomass) and the quantity of various ecosystem services via controlled experiments and modeling studies. Use measured values of structural metrics to estimate levels of specific ecosystem services.	Currently unknown

5. Applying Adaptive Management

Throughout this document we refer to applying adaptive management principles to restoration techniques and activities (e.g. placing subsequent additions of shell or spat-on-shell as informed by monitoring data). But, adaptive management means more than simply adjusting techniques. It means gathering data to answer specific questions at known decision points. For instance, in areas with only intermittent recruitment, it may mean monitoring shortly after the potential recruitment period to make a decision about the need to use spat-on-shell at that location. More fundamentally, fully adaptive management makes use of knowledge gained through data collection to refine both targets and metrics in route to meeting its ultimate goal. This will almost certainly be the case for oyster restoration in Chesapeake Bay. We have suggested restoration targets in this document that reflect the experiences not only of the workgroup members, but their organizations and the consulting scientist. There was seldom unanimity of opinion and in some cases our recommendations represent compromises between organizations; in others; they can be described as informed guesses. We strongly encourage those organizations involved in efforts to restore oyster populations and the ecosystem services that they provide in Chesapeake Bay to a higher stable state (Fig. 1) to rigorously evaluate and reassess the targets and the metrics established here as more data becomes available.

Literature Cited

1. Hargis, W.J., Jr., and D.S. Haven, 1999. Chesapeake oyster reefs, their importance, destruction and guidelines for restoring them, pp 329-358. In: M. W. Luckenbach, R. Mann and J. A. Wesson, editors. Oyster reef habitat restoration: a synopsis and synthesis of approaches. VIMS Press, Gloucester Point, VA.
2. Mann, R. and E. N. Powell. 2007. Why oyster restoration goals in the Chesapeake Bay are not and probably cannot be achieved. J. Shellfish Res. 26:905-917
3. Schulte, D. M., R. P. Burke and R. N. Lipcius. 2010. Unprecedented restoration of a native oyster metapopulation. Science 325:1124-1128.
4. Paynter, K. T., V. Politano, H.A. Lane, S.M. Allen, and D. Meritt. 2010. Growth rates and prevalence of *Perkinsus marinus* in restored oyster populations. J. Shellfish Res. 29: 309-317.
5. Kennedy, V. S., D. L. Breitburg, M. C. Christman, M. W. Luckenbach, K. Paynter, J. Kramer, K. G. Sellner, J. Dew-Baxter, C. Keller and R. Mann. (*In review*) Lessons Learned from Efforts to Restore Oyster Populations in Maryland and Virginia, 1990-2007. J. Shellfish Res.
6. Winslow, F. 1889. Report on the oyster beds of the James, River, Virginia, and of Tangier and Pocomoke Sounds, Maryland and Virginia. U.S. Coast and Geodetic Survey Report for 1881:1-87.
7. Moore, H. F. 1910. Condition and extent of oyster beds in the James River, Virginia. U.S. Bureau of Fisheries. Doc. No. 729. Washington, D. C., 83 pp.
8. Yates, C. C. 1913. Summary of oyster bars of Mayland 1906-1912. United States coast and geodetic survey. U.S. Government Printing Office, Washington, D. C. 79 pp. plus charts.
9. Baylor, J. B. 1894. Complete survey of the natural oyster beds, rocks, and shoals of Virginia. Report to the Governor of Virginia, 1895. Superintendent of Public Documents, Richmond, VA.
10. National Research Council (NRC). 2001. Marine Protected Areas: Tools for Sustaining Ocean Ecosystem, 2001. Committee on the Evaluation, Design, and Monitoring of Marine Reserves and Protected Areas in the United States, Ocean Studies Board, National Research Council, 288 pgs.
11. Haven, D. S., J. P. Whitcomb and P. Kendall. 1981. The present and potential productivity of the Baylor Grounds in Virginia. Va. Inst. Mar. Sci., Spec. Rep. Appl. Mar. Sci. Ocean. Eng. No. 243: 1-154.
12. Smith, G.F., D.G. Bruce, E.B. Roach, A. Hansen, R.I.E. Newell, and A.M. McManus. 2005. Assessment of recent habitat conditions on eastern oyster *Crassostrea virginica* bars in mesohaline Chesapeake Bay. North American Journal of Fisheries Management 25: 1569-1590.
13. Haven, D. S. and J. P. Whitcomb. 1983. The origin and extent oyster reefs in the James River, Virginia. J. Shellfish Res. 3:141-151.

14. Berman, M., S. Killeen, R. Mann and J. Wesson. 2002. Virginia oyster restoration atlas. Comprehensive coastal inventory. Center for Coastal Resource Management, Virginia Insitute of Marine Science, Gloucester Point, VA (http://web.vims.edu/mollusc/oyrestatlas/index.htm)

15. Kennedy, V. S. and L. P. Sanford. 1999. Characteristics of relatively unexploited beds of the Eastern Oyster, *Crassostrea virginica*, and early restoration programs. Pp. 25-46 *In:* M. W. Luckenbach, R. Mann and J. A. Wesson (eds.) Oyster Reef Habitat Restoration: A Synopsis and Synthesis of Approaches. Virginia Institute of Marine Science Press, Gloucester Point, VA.

16. Moore, H. F. 1897. Oysters and methods of oyster-culture with notes on clam-culture. Rep. U.S. Comm. Fish and Fisheries for 1897263-340.

17. Moore, H. F. 1907. Surveys of oyster bottom in Matagorda Bay, Texas. Bureau of Fisheries Document 610:1-87.

18. DeAlteris, J. T. 1989. The role of bottom current and estuarine geomorphology on the sedimentation processes and productivity of Wreck Shoal, an oyster reef of the James River, Virginia. Pp. 279-307 *In:* B. J. Neilson, A. Kuo and J. Brubaker (eds.) Estuarine Circulation. Humana Press, Clifton, NJ.

19. Mann, R. and D.E. Evans. 1998. Estimation of oyster, *Crassostrea virginica*, standing stock, larval production, and advective loss in relation to observed recruitment in the James River, Virginia. J. Shellfish Res. 17: 239-253.

20. Levitan, D.R., M.A. Sewell and F.-S. Chia. 1991. Kinetics of fertilization in the sea urchin *Strongylocentrotus franciscanus*: interaction of gamete dilution, age and contact time. Biol. Bull. 181 371-381.

21. Wells, H. W. 1961. The fauna of oyster eds, with special reference to the salinity factor. Ecol. Monongr. 31:266-329.

22. Dame, R. F. 1979. The abundance, diversity and biomass of macrobenthos on North Inlet, South Carolina, intertidal oyster reefs. Proc. Natl. Shellfish. Assoc. 68:6-10.

23. Peterson C. H., J. H. Grabowski and S. P. Powers. 2003. Estimated enhancement of fish production resulting from restoring oyster reef habitat: quantitative valuation. Marine Ecology Progress Series 264:249-264

24. Luckenbach, M.W., L.D. Coen, P.G. Ross Jr, and J.A. Stephen. 2005. Oyster reef habitat restoration: Relationship between oyster abundance and community development based on two studies in Virginia South Carolina. Journal of Coastal Research 40: 64-78.

25. Rodney W. and K. Paynter. 200. Comparisons of macrofaunal assemblages on restored and non-restored oyster reefs in mesohaline regions of Chesapeake Bay in Maryland. J. Exp. Mar. Biol. Ecol. 335:39-51

26. Grizzle R. E., J. K. Greene and L. D. Coen 2008. Seston removal by natural and constructed intertidal eastern oyster (*Crassostrea virginica*) reefs: A comparison with previous laboratory studies, and the value of in situ methods. Estuaries and Coasts 31:1208-1220.

27. Kellogg M. L., J. C. Cornwell, K. T Paynter and M. S. Owens 2011. Nitrogen removal and sequestration capacityof a restored oyster reef: Cheasapeake Bay experimental studies. Final Report to the Oyster Recovery Partnership, Annapolis, MD.

28. Booth D. M. and K. L. Heck, Jr. 2009. Effects of the American oyster *Crassostrea virginica* on growth rates of the seagrass *Halodule wrightii*. Marine Ecology Progress Series 389:117-126.

29. Meyers, D. L. and E. C. Townsend 2000. Faunal utilization of a created intertidal oyster reef (*Crassostrea virginica*) in the southeastern United States. Estuaries 23:34-45.

30. Tolley, S.G. and A.K. Volety. 2005. The role of oysters in habitat use of oyster reefs by resident fishes and decapod crustaceans. J. Shellfish Res. 24: 1007-1012.

31. Stunz, G.W., T.J. Minello, and L.P. Rozas. 2010. Relative value of oyster reef as habitat for estuarine nekton in Galveston Bay, Texas. Marine Ecology Progress Series 406: 147-159.

32. Harding, J.M. and R. Mann. 2001. Oyster reefs as fish habitat: Opportunistic use of restored reefs by transient fishes. J. Shellfish Res. 20: 951-959

33. Lehnert, R.L. and D.M. Allen. 2002. Nekton use of subtidal oyster shell habitat in a southeastern U.S. estuary. Estuarie*s* 25: 1015-1024.

34. Shervette, V.R. and F. Gelwick. 2008. Relative nursery function of oyster, vegetated marsh edge, and nonvegetated bottom habitats for juvenile white shrimp *Litopenaeus setiferus*. Wetlands Ecology and Management 16: 405-419.

35. Meyer, D. L., E. C. Townsend and G. W. Thayer. 1997. Stabilization and erosion control value of oyster cultch for intertidal marsh. Restoration Ecology 5:93-99.

36. Shellfish Commission of Maryland. 1912

37. Newell, R.I.E., 1988. Ecological changes in Chesapeake Bay: Are they the result of overharvesting the American oyster, *Crassostrea virginica*? Pages 536-546 in M.P. Lynch and E.C. Krome (eds.). Understanding the Estuary: Advances in Chesapeake Bay Research. Chesapeake Research Consortium, Publication 129 CBP/TRS 24/88, Gloucester Point, VA.

38. Newell, R.I.E., M. S. Owens and J. C. Cornwell. 2002. Influence of simulated bivalve biodeposition and microphytobenthos on sediment nitrogen dynamics. Limnology and Oceanography 47:1367 1369.

39. Dame, R. F., R. G. Zingmark and E. Haskins. 1984. Oyster reefs as processors of estuarine materials. J. Exp. Mar. Biol. Eco. 164:147-159.

40. Chai, A-L., M. Homer, C-F Tsai, and P. Goulletquer. 1992. Evaluation of Oyster sampling efficiency of patent tongs and an oyster dredge. North American Journal of Fisheries Management. 12: 825-832.

41. Mann, R, M., M. Southworth, J. M. Harding and J. A. Wesson. 2004. A comparison of dredge and patent tongs for estimation of oyster populations. J. Shellfish Research. 23: 387-390.

42. Rothschild, S., P. Jones and B. Rothschild. 2011. Estimation of oyster densities from Maryland Fall Survey data 2005 – 2007. Report to Maryland Department of Natural Resources.

Appendix A

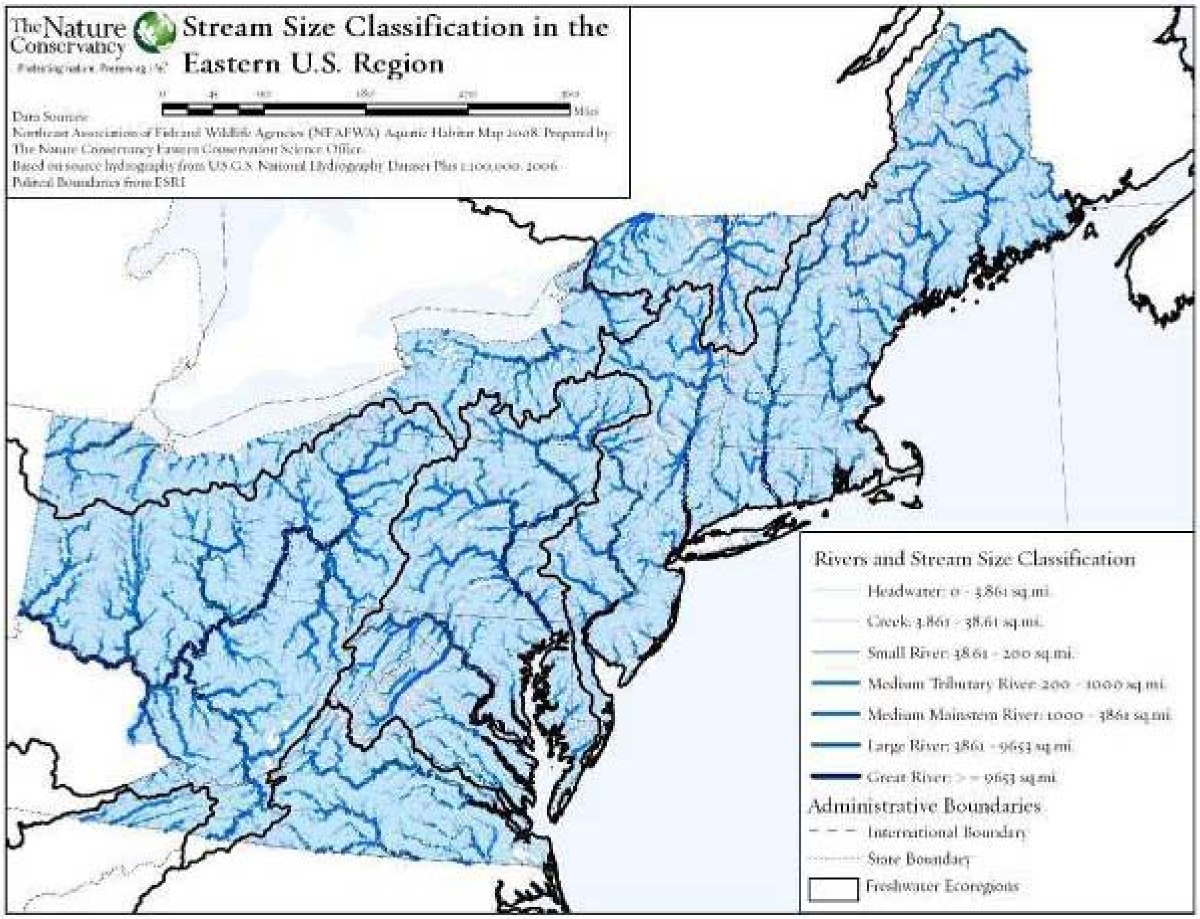
The Nature Conservancy River Size Classification

The Nature Conservancy has developed a stream size classification for the eastern U.S. based on watershed size (upstream drainage area in square miles) as listed below:

- Headwaters (<3.861 sq.mi.)
- Creeks (>= 3.861<38.61 sq.mi.)
- Small Rivers (>=38.61<200 sq. mi.)
- Medium Tributary Rivers (>=200<1000 sq.mi.)
- Medium MainstemRivers (>=1000<3861 sq.mi.)
- Large Rivers (>=3861 < 9653 sq.mi.)
- Great Rivers (>=9653 sq.mi.)

The size breaks were initially developed as part of TNC's Northeast Aquatic Stream classification project for the Northeast Association of Fish and Wildlife (NEAFWA) (http://rcngrants.org.spatialData, see map below). The stream classification is regional and is appropriate to apply across the northeast region and within the Chesapeake Bay watershed. All 13 northeast states participated and contributed to its development. According to TNC, the classification has been used in a number of regional projects for planning and reporting. The table below shows the application of the stream classification to some of the tributaries of the Chesapeake Bay.

Tributary	TNC classification	Tributary	TNC classification
MARYLAND		***VIRGINIA***	
Chester River	medium trib	**James River**	great river
Corsica River	Small river	Elizabeth River	small river
Choptank River	medium mainstem	Nansemond River	medium tributary
Broad Creek	Creek	**Pocomoke Sound**	(medium tributary)
Harris Creek	Creek	**Rappahannock River**	medium mainstem
Little Choptank	Small river	Corrotoman River	small river
Eastern Bay	Small river	**York River**	medium mainstem
Patuxent River	medium trib	Back River	small river
Potomac River	great river	Cherrystone Inlet	small river
St. Mary's River	small river	Cockrell Creek	creek
Tangier Sound	(small river)	Great Wicomico R.	small river
Big Annemessex River	small river	Hungars Creek	creek
Fishing Bay	medium trib	Little Wicomico R.	creek
Little Annemessex River	small river	Lynnhaven Bay	small river
Manokin River	small river	Mobjack Bay	(small river)
Monie Bay	(small river)	Nandua Creek	creek
Honga River	small river	Nassawaddox Creek	creek
Magothy River	small river	Occohannock Creek	creek
Rhode River	creek	Old Plantation Creek	creek
Severn River	small river	Onancock Creek	creek
South River	small river	Piankatank River	small river
West River	creek	Poquoson River	small river
		Pungoteague Creek	small river
		Severn River	small river


The Nature Conservancy
Stream Size Classification in the Eastern U.S. Region
Data Sources
Rivers and Stream Size Classification
Headwater: 0 - 3.861 sq.mi.
Creek: 3.861 - 38.61 sq.mi.
Small River: 38.61 - 200 sq.mi.
Medium Tributary River: 200 - 1000 sq.mi.
Medium Mainstem River: 1000 - 3861 sq.mi.
Large River: 3861 - 9653 sq.mi.
Great River: >= 9653 sq.mi.
Administrative Boundaries
International Boundary
State Boundary
Freshwater Ecoregions

APPENDIX F: Agency Coordination

F-1: AGENCY COORDINATION MEETING SUMMARY MARCH 16, 2009

MEMORANDUM FOR RECORD

SUBJECT: Chesapeake Bay Oyster Recovery Project, MD and VA, Native Oyster Restoration Master Plan, Agency Coordination Meeting

1. On 16 March 2009, the second agency coordination meeting for the Chesapeake Bay Oyster Recovery Project, MD and VA, Native Oyster Restoration Master Plan, was held at the office of the Potomac River Fisheries Commission in Colonial Beach, Virginia. The following participated:

Mike Naylor	MDNR	mnaylor@dnr.state.md.us
Paula Jasinski	NOAA Ches Bay Office	Paula.jasinksi@noaa.gov
Jeff Shenot	NOAA Fisheries Habitat restoration	Jeff.shenot@noaa.gov
Rich Takacs	NOAA Restoration Center	Rich.takacs@noaa.gov
AC Carpenter	PRFC	--
Ellen Cosby	PRFC	Ellen.prfc@verizon.net
Angie Sowers	USACE-Baltimore	angie.sowers@usace.army.mil
Anna Compton	USACE-Baltimore	anna.m.compton@usace.army.mil
Claire O'Neill	USACE-Baltimore	Claire.d.oneill@usace.army.mil
Larry Oliver	USACE-New England	Lawrence.r.oliver@usace.army.mil
Craig Seltzer	USACE-Norfolk	Craig.l.seltzer@usace.army.mil
Barbara Okorn	USEPA	Okorn.barbara@epa.gov
George Ruddy	USFWS	George_ruddy@fws.gov
Jack Travelstead	VMRC	Jack.travelstead@mrc.virginia.gov

2. Introductions and Purpose -

Larry opened the meeting and had everyone introduce themselves. He noted that the purpose of this meeting was to reinitiate project coordination with cooperating agencies and that the focus would be on providing an overview of the NORMP status. He emphasized that any technical issues will be discussed in future, separate meetings.

3. Highlights of May 2006 meeting -

Larry discussed the highlights of the last NORMP cooperating agencies meeting which was held in May 2006. He indicated the schedule for the NORMP was delayed to coordinate its timing with the NN EIS (the timing of NORMP needed to be integrated with the decision made on the recommended plan from the NN EIS). Mike Naylor noted that MDNR had funded a large amount of the work for the NN EIS yet the agency was not considered a decision maker on the project. Claire noted that any native oyster work done by the state of Maryland for the NN EIS could be credited as in-kind services and be a part of the cost-sharing agreement for the

NORMP. She indicated that both project sponsors (MD and VA) would be decision makers. Larry noted that much of the information used in the NN EIS would be incorporated by reference in the NORMP. He also added that projects implemented from the NORMP would be adaptively managed and the NORMP itself would be a living document.

Larry noted that per USACE regulations the NORMP would undergo external peer review. There was discussion amongst the group on scientific peer review and some of the problems encountered and lessons learned from the NN EIS. Jack noted it is critical to involve the scientific community. Throughout the NN EIS development there seemed to be two camps: 1.) native restoration is happening and there have been successes on a local scale; 2.) native restoration won't work. Jack questioned if the NORMP process could be used to get some agreement between these two camps in the scientific community. Craig suggested that the team consider conflicting journal articles and determine if what scientists are predicting in journals is occurring in real world application.

Jeff pointed out that NEPA needs are really a legal/regulatory review, not a scientific peer review. Larry asked how to incorporate the scientific community in the process. Jeff suggested that a NOI should be reissued (last one was issued in 2006) once the final NN EIS is released. It should include information on what USACE is looking for and the process USACE is undertaking.

Jack felt that it would be important to define what restoration means in terms of scale and timeframe in the NORMP. What constitutes full restoration in a local area; should there be short-term or long-term goals? There needs to be a clear definition of oyster restoration and ultimate objectives and monitoring should be included to prove success. The group discussed the need for a database of restoration projects.

Paula mentioned a study by Dr. Jonathan G. Kramer (Director, Maryland Sea Grant College Program) of historical records that were peer reviewed which is just being wrapped up (after the meeting USACE contacted Dr. Kramer requesting this report). She also said that setting up a comprehensive database where all oyster restoration data can be housed and available is important too. The group generally agreed that the NORMP should emphasize follow-up monitoring to assess success of restoration activities. Larry clarified that the NORMP would not dictate to others how they must do restoration and follow-up monitoring, but it is expected that others may use it as guidance.

AC asked for definition of a Federal sanctuary. Rich replied that ultimately sanctuaries are State resources in State waters. The Federal government does not have the authority to establish sanctuaries in State waters; however they have the authority to spend Federal dollars in State-designated sanctuaries and to make permanent sanctuary designation a legal requirement for expenditure of USACE Federal dollars. Claire noted that the USACE mission is ecosystem restoration which requires creation of permanent sanctuaries. Rich asked if the NORMP will address non-sanctuary sites. Larry and Angie agreed that the NORMP would address non-sanctuary areas by considering placing restoration site sanctuaries where they will contribute larvae to harvest areas.

There was discussion on establishing a goal of "self-sustaining" vs. using "sustainable" to describe successful oyster populations. The general consensus was that the goal is to have a "self-sustaining" population. However AC noted that it will be important for the NORMP team to revisit the NN EIS discussions because often a goal of "self-sustaining" populations for oyster restoration was in direct conflict with "sustainable" populations for a fishery. AC also noted that the term "abundant" should be specifically defined in the NORMP. Larry noted that objectives for the NORMP still need to be developed and that is when the team will specify how success will be measured and defined. Craig noted that the goal is to achieve populations that recruit faster than they are dying and whose physical reef structure is accreting faster than it is being lost.

Larry went over the agency roles for the NORMP. Since the project had been delayed since 2006, USFWS, EPA, NOAA will send USACE an updated coordination letter.

<u>4. Master Plan Overview -</u>

Larry reviewed the roles of the agencies, USACE authority for this project, problems with oyster populations in the Bay, and the specific goals of the NORMP.

Mike Naylor asked what the numeric goal would be, such as a definition of a historical baseline number that would be achieved i.e. what is the ultimate metric? Angie noted that USACE did not want to pre-determine and limit the goal. The intent is for the process to identify the scale needed in a specific tributary to achieve a "sustainable" population. Rich recommended that people will often disagree on numbers so the goals should not be left too open or be too specific. Paula questioned the use of "natural condition" in the NORMP restoration goal. Does this speak to limit the use of alternate substrate? Angie said this term doesn't address substrate specifically, when the goal was written USACE did not have authority to use alternate substrates, now USACE does. Jeff suggested that one of the goals of the NORMP could be to develop a clear definition of various terms.

Rich asked what the USACE policy limitations are to monitoring and what has to be done to justify future needs past policy limitations. Claire noted that USACE will need to lay out plans and justification. Angie mentioned that Poplar Island has ongoing monitoring which is labeled as construction monitoring. Claire noted that USACE is limited to 2-4% of construction funds to be used for monitoring. Craig noted that the NORMP PMP includes adaptive management and monitoring. The NORMP will include justification for monitoring, particularly if expected costs exceed the 4% limit.

Rich asked if additional EIS's or EA's would be done to work in specific sites. Craig said that yes they would, the NORMP is not the final plan for all specific areas; there will be work and opportunities for agencies to be involved again. George asked about USACE authorization for building hatcheries. Claire noted that it is a possibility but there is not a lot of Federal interest to build hatcheries unless it is shown that it is necessary for restoration (not for a fishery).

Larry reviewed the NORMP study approach and strategy. Craig noted that both the VA Blue Ribbon Oyster Panel (May 2007), and the Maryland Oyster Advisory Commission (January 2009) recommendations would be carefully examined in developing the NORMP with the goal of developing oyster restoration strategies that support the recommendations of both groups. Claire noted that currently the program authorization is $50 million, and the NORMP could be the basis for requesting an increase in this program authorization from Congress.

There were various comments regarding the GIS strategy. Mike noted that one parameter that could be added for the GIS layers is oyster food (phytoplankton). He explained that the data would be tough to integrate because it has been collected by three different people using three different methods. He noted that Bay-wide, there has been a shift from green to blue green algae. This data may be better when sub-estuaries or tributaries are evaluated, in the 2nd tier EIS or EA. He also noted that there are limitations to water depth data for the Bay. Most of it was collected in the 1950's, prior to Hurricane Agnes, and may be inaccurate to what really exists in the field. Jeff suggested that USACE also may want to consider predation as criteria, such as mapping general areas where there are pests.

George asked if social factors include navigation channels, and Rich said they should. In Maryland it is tough to get permits to work in shallower water (under 8 feet) and navigation channels are 20 feet and above so the window is 8-20 feet. The NORMP could be used as a tool to justify working in shallower areas. Mike noted that the pycnocline depth should be evaluated. It is important to know dissolved oxygen (DO) concentrations in waters below the pycnocline. Larry noted that the team doesn't want to get wrapped around data gaps so much that the project can't move forward. Rich suggested that in the tier 1 level of this report the team could list data gaps and list the outcome of how the data gaps were handled. George asked if there are any good sources of sedimentation rates. The group consensus was that there wasn't, but the best substitute would be total suspended solids (TSS) data. Craig noted that placement, elevation, and position can impact how well a reef deals with sedimentation. Paula noted that NOAA research has found that historic reefs were often perpendicular to major currents to capture food sources and USACE should consider this in placing restoration projects. NOAA may be able to provide assistance in bottom mapping for projects at the tributary scale.

There was discussion on the use of alternate substrates. The general consensus was that there was more anecdotal than analytical evidence regarding their success but it was important to include as a component to the NORMP. Angie noted that one reef-building use could be to use these substrates as an elevating tool to get above the Bay bottom and then a veneer of shell could be placed on top of the substrates.

Rich noted that shell dissolution is a much bigger issue in VA than MD; sedimentation destroys reefs if the reef does not continue to grow. There was discussion on genetic rehabilitation of oysters as a strategy. It is believed that some disease resistance is developing in wild populations. Both Rich and Mike expect issues to arise between low and high salinity strategies within VA and MD. For example placing spat in high salinity is higher risk for mortality due to disease but oysters grow faster there. Rich noted that in the future, we could see hatchery-produced spat that is tailored to a specific region/tributary. There was discussion on the possibility of aquaculture increasing in MD because it produces a high number of larvae. Concurrent activity that would benefit the system (by other agencies other than USACE) would be beneficial. Craig noted that aquaculture takes commercial fishing pressure off the wild population as well.
Larry reviewed the NORMP schedule:

Final Programmatic NN EIS	June 2009
New scoping meetings	September 2009
GIS analysis	January - April 2009
Larval transport model analyses	January - May 2009
Hydrologic analyses	January - May 2009
Plan formulation/evaluation	May - November 2009
Report preparation	November - December 2009

Paula asked if predation control was going to be considered (e.g. fencing to deter cownose rays). Angie and Craig noted that new research will not be done but USACE will look at available information (USACE has evaluated commercial grade netting in the Lynnhaven River and it has been very successful). They requested that agencies send any applicable data to the NORMP that is available to them.

There was discussion on the contributions of agencies to the NORMP development. All agreed that agencies would attend necessary meetings and review the document. Rich noted that he could contact MGS/NOAA for an inventory of current bathymetric data. Jeff noted that NOAA may be able to facilitate meetings and review certain milestones. Barbara noted that EPA needs to evaluate resources to assess the level of participation they could have but she expects they will participate in agency meetings and review of the document. Larry indicated he would make a list of potential meetings and provide it to the agencies and they can judge whether they need to attend or not.

5. MDNR Update -

Mike gave the group an update on MDNR recent and planned activities for oyster restoration in the Bay:

- $1.5 million dollars to develop infrastructure and training for aquaculture
- $1.5 million dollars for 1000 acres of bar rehabilitation over next three years
- Hydro-mapping
- Dredging bars
- Reopening of Piney Point Hatchery
- 24-hour monitoring of selected oyster sanctuaries with cameras to deter poaching

Mike also noted that there is a bill now under consideration to permit non-private entities to lease the Maryland Bay bottom. It contains restrictions that would require leaseholders to submit a "use" plan and if there is no proof of use, the lease will be transferred to another individual (exception is demonstration leases). Mike provided information on increased efforts by the State to prevent illegal harvests of sanctuaries.

6. VMRC Update -

Jack gave the group an update on VMRC recent and planned activities for oyster restoration in the Bay:

- Increased sanctuaries
- Rotational harvest areas

- Developing $15 million dollar proposal for oyster restoration in response to NOAA's restoration request for proposals (RFP)
- Predation control
- Cages
- Develop commercial fishery for rays
- Blue crab disaster funding
- Encouraging waterman to switch from blue crab fishing to oystering or spat and shell production

Jack noted that there is support to develop a kill fishery for cownose rays and that there is not an interest in a State hatchery because the industry thinks it would be in competition with the State.

7. PRFC Update -

AC noted that they have not done any restoration activities in the last three years and they have no plans to do so until activities are identified that will provide a return for their investment.

8. NOAA Update -

Paula gave the group an update on NOAA's recent and planned activities for oyster restoration in the Bay.

- Community-based restoration projects
- Hatchery infrastructure support
- Research and monitoring
- Harvest reserve site rehabilitation

She noted that the recently passed Omnibus bill includes $4.6 million for oyster restoration activities in MD and VA.

9. USACE Update -

Craig gave the group an update on USACE recent and planned activities for oyster restoration in Virginia's portion of the Bay:

- ***Rappahannock River***
    - 97 acres public, 3 acres sanctuary (2000)
    - Baseline: 3 oysters/m^2
    - Restored: 20 oysters/m^2

- ***Tangier/Pocomoke Sound***
    - 150 acres public, 8 acres sanctuary (2002)
    - Baseline: 2 oysters/m^2
    - Restored: 23 oysters/m^2

- ***Great Wicomico River***
    - 30 acres high relief sanctuary; 55 acres low relief sanctuary (2004)
    - Baseline: 3 oysters/m^2

- Restored: High Relief Reefs: 1000 oysters/m^2,
- Low Relief Reefs: 250 oysters/m^2
- 185 million oysters total on restored reefs

- **Lynnhaven River**
  - 50 acres sanctuary (2007-2008)
  - Baseline: 0 oysters/m^2
  - Restored: TBD

Claire gave the group an update on USACE recent and planned activities for oyster restoration in Maryland's portion of the Bay:

- For the first 10 years of the project (1997-2006), USACE created new oyster bars in the Chester, Choptank, Magothy, Patuxent, and Severn Rivers, as well as seed bars in Kedges Strait and Eastern Bay.

- For the past 12 years (1997-2008), hatchery-produced spat has been placed by the Maryland oyster partners on most of these bars, including multi-year classes on the sanctuary bars; MDNR funded a large portion of this effort as an in-kind service. In addition, some of the spat placement costs were covered by NOAA funds.

- In FY09, the focus will be on creating 25-40 acres of new oyster bars using alternative substrate materials. The NEPA documentation for this effort is expected to be completed in May 2009, with construction in June-July 2009.

- Project monitoring of the restoration sites is ongoing; specifically, an assessment of the oyster populations and disease levels of the sanctuary bars has been initiated and is expected to be completed circa May 2009.

10. Summary – The following is a summary of key follow-up actions:

a. USACE will consider conflicting scientific journal articles (*oyster restoration has been successful on a local scale in some cases in the Chesapeake Bay* vs *it has* ***not*** *been successful*) and determine if what scientists are predicting in journals is occurring in real world application.

b. USACE will reissue a notice of intent (NOI) once the final non-native environmental impact statement (NN EIS) is released. The NOI will include information USACE is looking for from the scientific community and the process being undertaken.

c. USACE will define what restoration means in terms of scale and timeframe in the NORMP.

d. USACE will develop a clear definition of various oyster restoration terms in the NORMP.

e. USACE will include methods for follow-up monitoring to assess the success of restoration activities in the NORMP.

f. USACE will revisit NN-EIS discussions to refine the use of "self-sustaining" as the goal for oyster restoration in the NORMP (the goal of "self-sustaining" populations for oyster restoration was often in direct conflict with "sustainable" populations for a fishery during the NN-EIS development).

g. USACE will develop more specific objectives in the NORMP in coordination with the project sponsors and cooperating agencies that define abundance, self-sustaining, etc.

h. Angie will contact Mike to obtain phytoplankton data for GIS analysis.

i. USACE, in coordination with MDNR, will determine if phytoplankton data should be used for the programmatic-level analysis of the Chesapeake Bay that the NORMP is addressing or if this data would be better suited to analyze during the 2nd tier (EIS/EA level) when specific sub-estuaries and/or tributaries will be evaluated.

j. USACE will evaluate if predation should be used as a criterion for the GIS analysis.

k. USACE will include discussion on the need to possibly work in shallower waters (<8 feet) in the NORMP relative to the effects of the restoration project on navigation.

l. NOAA, EPA, MDNR, VMRC and USFWS will send any applicable data to the NORMP to USACE.

m. USFWS, EPA, NOAA will send USACE updated coordination letters.

n. Rich will contact MGS/NOAA for their inventory of current bathymetric data.

o. NOAA, EPA, USFWS will achieve minimum requirements of cooperating agencies (agency meetings, and document review). All agencies will evaluate their resources to assess the level of further participation they could commit too.

p. USACE will invite agencies to the plan formulation meetings so they can determine whether their attendance is necessary.

q. USACE will include data gaps encountered during the development of the NORMP and will list the outcome of how the data gaps were handled.

Anna Compton,

CENAB-PL-P

F-2: AGENCY COORDINATION MEETING SUMMARY DEC 14, 2009

MEMORANDUM FOR RECORD

SUBJECT: Chesapeake Bay Oyster Recovery Project, MD and VA, Native Oyster Restoration Master Plan, Agency Coordination Meeting

1. On 14 December 2009, the third agency coordination meeting for the Chesapeake Bay Oyster Recovery Project, MD and VA, Native Oyster Restoration Master Plan (NORMP), was held at the office of the Potomac River Fisheries Commission (PRFC) in Colonial Beach, Virginia. The following participated:

Angie Sowers	USACE-Baltimore	angela.sowers@usace.army.mil
Anna Compton	USACE-Baltimore	anna.m.compton@usace.army.mil
Bill Goldsborough	Chesapeake Bay Foundation	bgoldsborough@cbf.org
Bruce Vogt	NOAA	Bruce.vogt@noaa.gov
Claire O'Neill	USACE-Baltimore	claire.d.oneill@usace.army.mil
Craig Seltzer	USACE-Norfolk	Craig.l.seltzer@usace.army.mil
Dave Schulte	USACE-Norfolk	David.m.schulte@usace.army.mil
Ellen Cosby	PRFC	Ellen.prfc@verizon.net
Eric Campbell (by telephone)	MD DNR	Ecampbell@dnr.state.md.us
George Ruddy	USFWS	George_ruddy@fws.gov
Greg Steele	USACE-Norfolk	Gregory.c.steele@usace.army.mil
Jeff Shenot	NOAA Fisheries Habitat restoration	Jeff.shenot@noaa.gov
Jeff Strahan	USACE-Norfolk	Jeffery.P.Strahan@usace.army.mil
Larry Oliver	USACE-New England	Lawrence.r.oliver@usace.army.mil
Mark Bryer	The Nature Conservancy	Mbryer@tnc.org
Rich Takacs	NOAA Restoration Center	Rich.takacs@noaa.gov
Rom Lipcius	VIMS (representing VMRC)	Rom@vims.edu
Stephanie Reynolds	Chesapeake Bay Foundation	sreynolds@cbf.org

2. Introductions and Purpose -
Larry opened the meeting and had everyone introduce themselves. He noted that the purpose of this meeting was to continue project coordination of the NORMP with the cooperating agencies and that the focus would be on discussing the initial plan formulation results and path forward.

3. Plan Formulation Overview -
Larry explained that he would review the NORMP team's approach to restoration scale, initial results of the NORMP and study schedule. Larry reviewed the strategy for native oyster restoration that the NORMP team has been working on to make sure that the group was in

agreement with the approach. The NORMP team has been using a GIS layering approach to help evaluate the suitability of tributaries for oyster restoration. The NORMP will include monitoring and adaptive management due to the fact that we do not have all the answers to successful restoration at this time. Larry went over the restoration goal for the NORMP which is ecosystem restoration, though if an ancillary effect was that the restoration contributes to the oyster fishery that would be a welcome benefit consistent with the project goal. He emphasized that the NORMP would not define specific projects for implementation, but instead would lay out an approach to restore oysters throughout Bay.

Craig noted that the team will take advantage of the research from the *Final Programmatic Environmental (EIS) for Oyster Restoration in Chesapeake Including use of a Native or Nonnative* (August 2009) and will build upon recommendations for the preferred alternative from that EIS which included enhancing oyster restoration, harvest moratoriums, and expanding aquaculture. USACE would have limited interest in aquaculture because of its minimal contribution to ecological services. The USACE mission is ecosystem restoration and this goal would be the priority. The VA Blue Ribbon Oyster Panel recommendations and the MD Oyster Advisory Commission (OAC) recommendations lined up well with the non-native oyster EIS preferred alternative. More recently MD Governor O'Malley laid out a plan for native oyster restoration which includes expanding sanctuary sizes from 9 to 24% in MD waters as soon as possible, and to 40% in the long-term. All of these recommendations lay a good foundation for the NORMP. Rich asked what everyone's thoughts were (given the Chesapeake Bay Executive Order) on expanding language in the NORMP to be a Federal agency rather than a USACE-only plan. The E.O. charges Federal agencies with conducting unified, joint, efforts regarding native oyster restoration. All native oyster restoration efforts undertaken by Federal agencies should be in-line with one another based on this E.O. Should language in the NORMP be expanded beyond just USACE to all Federal agencies? Craig noted that Federal agencies have different authorities given to them which dictate the kind of work that the agency participates in. For example USACE is not a research agency; the focus is construction, and developing implementable projects. The USACE NORMP could be used as a foundation for other Federal agencies to draft subsequent companion documents to focus on each agency's particular interests and mission.

Claire noted that if time permits other Federal agencies could develop documents to attach to the NORMP as appendices with a summary in the main text of the NORMP. Rich noted that he does not foresee any companion documents being drafted to avoid duplicative efforts. Craig noted that the NORMP will not allow the construction of specific projects; but rather is a means to that end. Subsequent and follow-on decision documents will allow USACE to plan specific projects, with project-specific schedules, designs, and funding requirements. Future Federal funding is contingent upon USACE identifying justifiable projects where ecological benefits outweigh Federal costs.

Rich noted that NOAA will have 2010/2011 money available for oyster restoration projects (construction), but may need a short-term plan in order to utilize this funding. NOAA is looking for how to jump on board rather than do a companion document (plan). Larry thinks that the group will see our methods as broad enough that others will be able to apply it for their own agency's use. Jeff Shenot explained that NOAA has to have a plan together for the E.O. in the short-term (May timeframe) because that is when the E.O. strategy reports will be finalized. The strategy report should not hold anyone up, and could be incorporated/attached to the NORMP. Larry noted that Angie is working on a matrix to demonstrate the compatibility of the various oyster restoration plans out there to show where the agencies are similar, and where they separate. Larry noted that USACE can summarize agency goals in the NORMP. Angie requested that participants send goals for their agencies to include in this matrix.

Bill noted that from the non-governmental organization (NGO) perspective, they are looking for a coordinating mechanism that includes all agencies and NGOs for oyster restoration. Larry noted that the NORMP will be focused on USACE work; however, the goals could be used by all. Mark asked that since the main output of the NORMP will be evaluating/prioritizing tributaries, would USACE evaluate current oyster populations and consider them when ranking tributaries due to the fact that it is more cost-effective to do work where oysters already exist. Craig noted that what is known about current populations in the Bay will be considered, but it is important to keep in mind that the current populations are very depressed in all tributaries. He added that the team will be taking full advantage of work done to this point, and that it would be a huge economic commitment to restore all tributaries at once so prioritization is essential. Tier 1 sites (best tributaries in prioritization) will be selected using the screening criteria (biological and physical), that create constraints to restoration. In order to achieve long-term success, it is going to take numerous oyster restoration projects in the areas that hold the most potential for success. Larry noted that oyster habitat will not be expanded upstream to where they have not existed in the past.

Craig noted that the team has also been working to identify the appropriate scale required for a restoration project in a given tributary that would be large enough to achieve a self-sustaining population. Ultimately USACE is looking to determine the appropriate scale that will achieve successful restoration. Oyster restoration at the projected scale has only been attempted once in the Chesapeake Bay (Great Wicomico). Certain parameters will enhance or restrain success including physical and biological factors. Some constraints include things like navigation channels, dissolved oxygen (DO), salinity, soft bottom, etc. Once these acres are removed, the acres that are left are where restoration can occur in a given tributary. The formula for restorable acreage is:

Total tributary area - Acreage restrained = Total restorable acreage.

If a tributary is so constrained that there is no way possible that oyster reefs can be built at the scale needed to meet a sustainable population then work will not be done in that tributary right away (i.e., it will not be a Tier 1 site). In the future, these tributaries can be looked at to see if some of the constraints can be resolved to allow for oyster restoration.

Rich noted that the historic maps with Yates and Baylor ground data are known to be gross exaggerations of historic oyster populations. The current practice is to use bay bottom mapping when looking for places to do oyster restoration. Larry noted that the "substrate capable of supporting shell" data was not comprehensive enough to be used as absolute criteria.

3.1 DO and Salinity Evaluation

Angie noted that the NORMP team worked with Versar to compile data sources, for salinity and DO. Growing season and bottom layer data was used and was divided into two salinity zones: 5-12 and greater than 12. Rom commented that in choosing April-October for DO averages it may be skewed higher because this average will not cover dips in June and July for DO that are typically seen. He suggested that the team evaluate average growing season DO compared to average summer DO (summer should have the lowest dips). The team should make sure using growing season data does not mask unsuitable summer areas. Angie noted that USACE will look back at the data to see if there are any concerns. The group agreed that the NORMP should include singular maps for suitable DO, salinity, etc. Mark asked what the raster cell size was. The team will get back to him on this.

Jeff Shenot noted that it should be recognized that areas that are unsuitable because of a stressor, could have those stressors managed to become suitable for restoration in the future. Can a data layer be added that identifies manageable stressors compared to issues of the organism such as disease?

Rom asked if the NORMP team plans to validate results of the GIS analysis. He noticed areas in the Rappahannock for example, that have good oyster populations, though the maps presented do not portray these areas. Larry noted that there will be validation of the maps and data to see what is making an area "red" (i.e., unsuitable) to the extent possible using available data. Craig noted that it will be important to identify the driving force behind these red areas. The NORMP team would not do field work but if data is available, even anecdotal, this could refine the data set used in the GIS analysis. The Chesapeake Bay Program (CBP) monitoring data used for some of the data layers is not as refined (lacking data points in some areas) as would be ideal for this analysis but it is the best available. Rich noted that some reefs exist in areas that defy all logic (i.e., unsuitable conditions). These areas should not be targeted for restoration (with resources focused here), given the scale required for oyster restoration success. The broad-scale analysis in the NORMP will point to areas that have greater potential for success in future efforts; it won't necessarily reflect small scale conditions that support existing beds.

Rom asked how the NORMP team decided on 5 mg/L (milligrams/liter) as the cut-off for DO. Many organisms can survive at 2-3 mg/L. Angie noted that 5 mg/L was used for the screening because it was a recommendation from the 2004 Oyster Management Plan and is an average value. The NORMP team looked at DO averages, with the knowledge that minimums will exist and DO will fluctuate in the system. Mark noted that areas that do not have higher DO may support oysters, but not finfish (which require a higher level of DO) so restoration in these areas would not achieve as many ecological benefits as restoration in areas with an average DO of 5 mg/L.

3.2 Hydrodynamics

Angie noted that the NORMP team recognized that hydrodynamics is important to look at in a system. The NORMP team took a dual approach for addressing hydrodynamics in large and small tributaries. Large tributaries are those that have well-established estuarine (gravitational) circulation which is induced by significant freshwater flow. Small tributaries are those that, for the most part, do not have strong estuarine circulation so it is assumed that flushing is tidally induced. For small tributaries tidal flushing time is calculated for each tributary using surface area, depth, and volume at high and low tide with tide tables and predicted tidal current velocities to calculate an adjusted tidal flushing time for each small tributary. For large tributaries a larval transport model (LTM) was used, which provided an estimate of how much larvae are retained in the system.

Based on data, results were broken into groups, the larger the number, the greater the retentiveness of the system (less flushing). Green is the most retentive system and red is the least retentive. George noted that low flushing may be good for retentiveness, but may reduce water quality and currents for oysters. Oysters may not thrive as well in low current systems. Using low flushing is a good thing because it makes the system retentive, but this might not be good as far as habitat goes and water quality. Angie noted that the retentive data layer will be layered with the water quality data layer to provide the full picture of the tributary. There was discussion on flushing and that it is good for food circulation but bad for oyster retentiveness. George suggested that the team consider the interactions of trap estuary characteristics, currents, and food circulation for oysters. Larry noted that the GIS analysis showed that much of the eastern shore, was green (suitable) for absolute criteria, but mostly red for retentiveness. Rich added that Doug Wilson of NOAA may be able to provide some data (wind-driven currents) for a smaller scale than what the NORMP team is currently using. Rich will get the team in touch with Doug. Discussion followed on how to appropriately evaluate the hydrodynamics of a tributary, in that scale is a big factor, and it is important to utilize high resolution models in small systems to have high confidence in the results.

Jeff Shenot noted that the percent of imperviousness of a watershed causes pulses of freshwater input and made the point that there could be a correlation between the "red" tributaries having a low amount of imperviousness. Larry clarified the "red" areas in the retentiveness maps, are not necessarily areas that should be avoided altogether, but rather are areas that should be addressed later down the road (as oyster restoration projects begin to be built and reefs are established in trap estuaries, it will be desirable to establish reefs that export larvae to one another). George suggested using data on spat sets to determine the retentiveness of a system. Someone pointed out that spatset is dependent on existing oyster populations and may not be a good indicator of retentiveness. Angie noted that the NORMP team is currently dealing with trying to find comparable information for MD and VA. The hydrodynamic model was the best view of the hydrodynamics of the system with the time and funding available. Since the NORMP is a living document, it will use the best available information to date and can be supplemented with updated information in the future.

Rom noted that a more fundamental issue is that a retentive system does not have high connectivity; the goal should be to have an interconnected system allowing for oyster metapopulations throughout the Bay. The criterion of being self-sustaining, retentive vs. non-retentive is too simplistic. Rom had concern that sites will be thrown out based on non-retentiveness. Craig explained that sites would not be thrown out based on this factor. However, the priority is to establish several self-sustaining populations in tributaries before creating connectivity between tributaries.

Mark noted that there needs to be success in small tributaries in the short term, in order to continue to get funds. It appears an (unwritten) goal of USACE is to focus on a tributary or two over the next 5-10 years. Craig and Claire discussed the possibility of having parallel plans for construction in case funds are provided by Congress to do work in the Piankatank (Norfolk District) and other Maryland tributaries (Baltimore District). The Baltimore District already has the authority to work in the Magothy, Severn, Patuxent, Nanticoke, Choptank, and Chester Rivers (tributaries designated as oyster recovery areas in the 1995 Oyster Roundtable Plan), as well as Kedges Strait and Eastern Bay.

3.3 LTM

Angie reviewed the results of the LTM. She noted that green areas show high self-recruitment and added that the model includes both live and dead particles in its simulations. Larry added that in the beginning stages of oyster restoration the goal is to have self-recruiting reefs that will establish themselves. Rom noted that in addition to percentages of self-recruitment the team should also consider the number of particles being produced. In response to a question about the time scale of the master plan, Angie noted that the NORMP is a 10-year plan in terms of funding. The normal evaluation period for Corps projects is 50 years. Craig added that it has been estimated that it would require $50 million a year to restore oysters in the Bay, and that there is no set point for updating the NORMP; it would be updated periodically as a living document.

3.4 Scale

Craig described the approach to estimating the appropriate scale required for restoration in a given tributary. The first step is to estimate the historic population size in the tributary. When the Baylor surveys were done in VA, the focus was not looking at viable oyster grounds; it was looking to preserve areas for a public fishery. The team compared the Baylor survey to another historic survey in VA, the Moore survey (which looked at viable reefs in James River), and used GIS overlays to determine that only 47% of the Baylor ground had viable oyster habitat. The 47% will be extrapolated to Baylor grounds in other VA tributaries in the Bay to estimate the amount of historical, viable oyster habitat in each tributary. The need for this extrapolation is due to the fact that accurate historical maps of oyster reefs are not available. Dave explained that the Baylor grounds were aimed at preserving grounds for the public fishery and were not necessarily used to identify viable oyster beds. However, the Baylor survey was not all inclusive and there were already signs that some reefs were removed by the time of the Baylor survey. Rom asked if the NORMP team was going to use current oyster populations to offset the needed acreage amount required to reach the established restoration targets. Dave noted that the NORMP will do this to the greatest extent possible given current limited knowledge of oyster populations. With a multiphase construction plan, if restoration takes off and perpetuates itself, there may not be a need to do the last phases of construction because the reef may build itself. George asked if the team was targeting a population density. The NORMP will target biomass and metapopulation persistence to determine what the minimum amount of accretion required to allow a reef to maintain itself and grow over time.

Maryland has a comparable survey to the VA Moore survey called the Winslow survey. Eric will contact Kelly Greenhawk, to get the geo-referenced Winslow surveys to the NORMP team. Angie will contact the UVA author, McCormick-Ray, who may also have the Winslow maps because she did work similar to the James/Moore survey in the Pocomoke in MD. Discussion followed on the problems with extrapolating these estimates (e.g., 47% from the James River) to the entire bay and whether or not there are any other data points available. Rich noted that bottom mapping and bank profiles are available but these would be a poor estimation because the "historic" conditions were already impacted at the time of the surveys. Dave commented that the team could try to estimate a rate of loss (of oyster habitat) but that estimate would not be consistent across all tributaries because of different fishing pressures.

Craig explained that Marine Protected Areas (MPA's) range from 20 to 70% of a species' habitat range to allow a species to be restored. According to the scientific literature, finfish need more habitat than a sessile organism like oysters to be successful. In the Great Wicomico for example, oyster restoration has been successful thus far and 40% of the historical acreage was restored. Mark noted that his agency may be able to provide some insight on MPA numbers that the staff have read about in literature. Based on the example of the Great Wicomico and the range of MPA sizes from the literature, the team recommended the goal of 40% of the calculated historic reef area. Rom added that 40% is in line with MPA, and said it was an agreeable number that was risk adverse. Dave explained that the NORMP will need to explain that the approach for restoration is a cautionary one; for the cost and time investment USACE does not want to fail because too small of a percentage of historic habitat was restored. He emphasized that tiny sanctuaries do not work based on lessons learned, it is better to overdo (acres of restoration) it than under do it. Rom added that the NORMP should clarify that it is a cautionary approach to restoration.

Rich asked how the document would address closures of oyster reefs for harvesting – would closures occur all at once or as projects are constructed. Larry responded that closures would occur as projects are constructed. Once a project partnership agreement is signed by the agencies, then the amount of acreage needed to be closed would be dealt with at that time. MPA has a specific definition and the term will not be used in the NORMP although the restored reefs will be similar to MPA's.

Mark asked if the 40% is representative of a self-sustaining population or ecosystem services. This number would likely be different. Larry commented that the NORMP team needs to give more thought to defining ecosystem benefits outside of just a self-sustaining population. Craig noted that the primary objective is a self-sustaining population; ecological services will be ancillary, but a self-sustaining population is needed first. Dave noted that reef footprints should expand over time once oysters reach the point of being self-sustaining, therefore habitat will be gained over time (i.e., more ecological services). Mark noted that this will help with the cost-benefit analysis and suggested including all these ancillary benefits in the cost-effectiveness analysis. Rom noted that there is good literature that provides a lot of information on the kinds of ecological services that oyster reefs provide including finfish production, secondary production (currency), and larval production (within region). Finfish production can be captured on a per acre basis and have a simple number associated with it. Also during placement

clams/worms will be negatively impacted but the reefs will eventually provide more habitats for benthic invertebrates so that is a positive impact.
Mark indicated that he would check with other shellfish restoration goals to see what scale others are experiencing for restoration. Angie has looked into the scale of previous oyster restoration projects in the Bay and noted that MD Sea Grant Program conducted an effort looking at the scale of past oyster restoration efforts and the past efforts came to approximately 1% of historic Bay-wide populations.

Angie discussed the results of the LTM analysis in determining where oyster larvae would accumulate in a given tributary. She emphasized that this analysis does not include any biological limitations, it was solely looking to answer whether or a not a particle would settle in a given location or not. There was discussion on the maps, and it was recommended that the NORMP team validate the results by reviewing MD DNR fall survey data.

3.5 Alternate Substrates

Larry reviewed the alternate substrates (for oyster reef construction) that will be evaluated in the NORMP. He noted that slag is not there. Rich asked if the team was considering clam shell. It is inexpensive and could be a good base layer for the reefs.

3.6 Cost Estimate

Jeff Strahan reviewed the preliminary cost estimates that have been worked up for oyster restoration at the scale the NORMP lays out. The cost estimate includes varying designs, substrates, sizes, and locations and includes transportation and material costs. He noted that the document would not have a traditional cost-effective incremental cost analysis; this will be done when specific sites are evaluated for restoration at the tributary level down the road. The cost estimate that has been worked up will allow for a discussion on varying costs to expect at a given location. Mark asked if the NORMP team is evaluating the breakdown of material over the lifespan of the reef and limitation of source material. Jeff Strahan said that the team was looking at the scarcity of oyster shell as a substrate but that shell dissolution and reshelling of the oyster reefs had not yet been considered. It could be considered. Craig added that the NORMP would also discuss the advantages of using long-lasting materials in reef building as a core with materials more preferential to oysters on top. Jeff Shenot added that alternate substrates are a poaching deterrent.

3.7 Prioritization of individual tributaries

Craig reviewed the individual tributary planning that will be laid out in the NORMP. The NORMP will consider the location of restoration sites at the individual tributary level in follow-on documents to NORMP. Water quality, sedimentation rates, currents, food availability, recruitment, growth, survival, project scale, interconnectedness, relationship to fisheries, leases, resources, and social issues would be evaluated at the individual tributary level in these follow-on documents. Greg noted that in order to have a return on investment there needs to be a level of environmental return on economic costs (i.e., environmental benefits). Stephanie asked if the NORMP was considering existing functioning reefs in the scoring and if this would rank a tributary higher in prioritization. Craig said that yes it would, any remnant population will benefit restoration. If habitat can be built that does not need as much population augmentation in the form of broodstock, spat-on-shell, etc., that will represent a cost savings.

3.8 Genetic Rehabilitation

Craig reviewed the genetic rehabilitation strategy that will be laid out in the NORMP. The goal is to document disease-resistance development in the wild population, evaluate the potential to accelerate disease-resistance development by stocking reefs with disease-tolerant wild broodstock and/or spat-on-shell, and document pros and cons of using selectively bred disease-resistant oysters (e.g., CROSbred, DEBY lines). Rich noted that DEBY oysters are bred to live to market size. Rom added that most recent genetic recommendations are to use wild stock that has grown close to the tributary.

3.9 Sanctuaries

There was discussion on the impacts of building sanctuaries throughout the bay. In regards to the relationship between sanctuaries and the commercial oyster fishery, Craig said there was anecdotal evidence that oyster aquaculture lease holders in the Great Wicomico are seeing better return on investments due to the proximity to the restored sanctuary reefs there. Larry noted that there is very little submerged aquatic vegetation (SAV) where viable oyster habitat is located and no restoration will occur on top of SAV beds. Rich agreed with the NORMP team’s conclusions regarding SAV and noted that there is often a close nexus between SAV and oysters. George asked if the impacted clam habitat would be considered in the NORMP. Craig said that benthic surveys would be done at the individual tributary project level.

4.0. Summary/Conclusions –

Larry reviewed the current schedule for the NORMP:

- Final Programmatic Oyster EIS Record of Decision August 2009
- NORMP Notice of Intent September 2009
- Cooperating Agency Meeting, Initial Formulation December 2009
- Cooperating Agency Meeting, Alternative Consensus March 2010
- Cooperating Agency Meeting, Alternative Priorities June 2010
- Cooperating Agency Meeting, Report Content August 2010
- NORMP Public Release Summer 2011

Larry suggested web meetings for future agency coordination meetings and the group was agreeable to this.

Rich asked when the tributary-based companion documents would be out to allow for actual construction. Craig said that the NORMP really will not hold up individual projects because USACE already has authority to construct projects in some areas and (as mentioned previously) is working on others during the preparation of NORMP. Claire added that the NORMP will expand USACE authorization and funding to do work in the future.

Bruce noted that the Chesapeake Bay E.O. strategy is to restore 20 tributaries by 2020 (restore to their historic oyster abundance). NOAA would like to collaborate on identifying tributaries and plans to achieve this goal. There was discussion on how to work out the details of this goal since tributaries are not named and the specific scale of restoration is not specified. Due to the fact that the Federal agencies have different missions, NOAA will need to provide a plan to be attached to the NORMP to show that the agencies goals align to meet similar oyster restoration goals.

Claire noted that all oyster restoration in the Bay cannot be done all at once due to limited resources. Things like spat, contractors, and substrates are all limited. There will be significant challenges to overcome to achieve such a rapid pace of construction/restoration (20 tributaries in 10 years).

There was discussion on how the cooperating agencies felt about the NORMP approach thus far. George noted that he agrees with the plan conceptually but will need to see the nuts and bolts to see how it will work out. At this point he was unsure about how the team should apply some of the data (hydrodynamics, etc). Rich noted that he did not see any fundamental flaws; as a planning tool the NORMP is good. He projects that the bulk of the NOAA work will deal with sanctuaries; this aligns well with the NORMP but NOAA will also include aquaculture work. Rich asked for clarification if the NORMP is an encompassing plan including the states as well. Larry noted that it could be encompassing plan if all agree to it, and the NORMP could identify each agency and what oyster restoration tasks they will participate in. Jeff Shenot added that another incentive for other Federal agencies to participate in the NORMP is that it makes it easier to incorporate analyses going on now for future actions. Bruce was comfortable with the approach laid out in the NORMP thus far, but wants to make sure the NORMP has a common goal for oyster restoration work, aligns with the Chesapeake Bay E.O. goals, and is clear that it is an inter-agency process. Rom noted that the NORMP is in line with the E.O., but is not addressing the E.O. in totality; perhaps other agencies could try to fill in the gaps?

Rom (speaking for VMRC) noted that VMRC is supportive of oyster restoration, though money is limited. Any VMRC involvement in a project would need to be voted on a project-by-project basis. Mark noted that the NGO perspective is that agencies are working together towards a bigger goal; he sees that it is beneficial that agencies are coming together to do oyster restoration work. Bill would like to see collaboration and the best use of efforts/funds towards a coordinated goal to maximize effectiveness. This may be the last chance at securing significant funds to achieve oyster restoration goals. Bill added that it has been recognized that successful oyster restoration cannot be accomplished individually; therefore the E.O. calls for a comprehensive strategy amongst all. There was discussion on the NORMP being the vessel to coordinate efforts and provide support, and leverage, and a funding mechanism for future oyster restoration efforts.

Rom asked if enforcement will be part of the NORMP or will it be the responsibility of MD and VA. Is there a GIS layer that could show areas that would be more easily policed? Claire noted that MD and VA action is required here. States will need to provide input and increase enforcement to deter poaching on any established oyster sanctuaries. Sanctuaries that are adjacent to harvest areas do raise problems. Rom noted that in VA, VMRC has worked with private land owner/lease owners to deter poaching. Eric noted that MD DNR does have plans to increase enforcement measures for intended oyster sanctuaries such as radar installation and night vision cameras and supports closing larger areas to allow for ease of policing. Bill noted that reef design can also help with poaching. CBF and NOAA are getting more involved with using reef balls in areas with high poaching risks due to the fact that reef balls deter poaching. Rom added that Europeans could be looked to for lessons learned on successful anti-poaching efforts.

Claire asked Mark if MD OAC is coming out with any other information that would be beneficial to the NORMP. Mark did not think so at this time. Mark asked if the NORMP has a goal for the number of tributaries restored in the Bay in a certain number of years. Larry explained that the NORMP has a broad goal of a self-sustaining population of oysters in the Bay; no tributary specific goals are laid out.

5.0. <u>Action Items</u> –

- EPA and NOAA will send USACE updated coordination letters.
- Angie will distribute a matrix demonstrating the compatibility of the various state and Federal agency oyster restoration goals and objectives (including the Chesapeake Bay Executive Order) to meeting participants. Cooperating agencies should send Angie their respective agency's goals to incorporate into the matrix.
- The NORMP team will evaluate average growing season DO compared to average summer DO to ensure that utilizing the growing season data does not mask unsuitable summer areas.
- The NORMP team will add singular maps for the absolute criteria (DO, salinity, water depth, historic reef upstream limits).
- The NORMP team will let Mark know what the raster cell size is for the GIS data.
- The master plan will address the effects of stressors on restoration potential and discuss how restoration potential can be increased by reducing stressors.
- Rich will get the team in touch with Doug Wilson of NOAA to get some current data.
- Eric will contact Kelly Greenhawk, to get the geo-referenced Winslow surveys for MD to the NORMP team.
- Angie will contact the UVA author, McCormick-Ray regarding Winslow survey information.
- USACE will validate the GIS layers to the extent possible by comparing existing information to GIS analysis predictions made thus far based on the absolute criteria, hydrodynamic and LTM modeling results. A summary discussion of each tributary ranking will be included in the NORMP to capture any adjustments made to tributary scoring based on this validation process. Where possible, the reason for an area being identified as "unsuitable" will be explained/summarized.
- USACE will email the NORMP presentation to meeting attendees for further comment.
- USACE will send the Versar and University of Maryland reports to the cooperating agencies and the sponsors.
- USACE will lay out in the NORMP how existing oyster population contribution to nearby newly constructed reefs will be weighted in tributary prioritization.
- USACE will lay out in the NORMP how interactions between trap estuaries, currents and food availability for oysters were considered.

- USACE will lay out in the NORMP how interactions between oyster populations in different tributaries (i.e., metapopulations) were considered.
- USACE will lay out in the NORMP why oyster retention rather than spatfall is given priority in the NORMP.
- USACE will add slag as an alternate substrate to be evaluated in the NORMP.
- USACE will lay out in the NORMP's economic analysis how the deterioration of shell affects its long-term costs relative to other substrates.
- The following need to be given some consideration: What is the minimum amount of accretion needed to allow a reef to maintain itself and grow over time? Can GIS help to identify areas that can be more easily policed for poaching? Are "unsuitable" areas resulting from hydrodynamics related to more heavily developed (greater imperviousness) watersheds? What can be learned from European anti-poaching efforts?
- Mark will request available MPA size information and literature from TNC colleagues as it relates to the sanctuaries that will be discussed in the NORMP.
- Mark will investigate the scale of oyster restoration projects that TNC has knowledge of.
- USACE will incorporate the benefits of ecological services into cost estimate as well as the loss in habitat/species from covering an area with shell for oyster restoration.

Anna Compton,
CENAB-PL-P

F-3: AGENCY COORDINATION MEETING SUMMARY MAY 11, 2010

MEMORANDUM FOR RECORD

SUBJECT: Chesapeake Bay Oyster Recovery Project, MD and VA, Native Oyster Restoration Master Plan, Agency Coordination Meeting

1. On 11 May 2010, the fourth agency coordination meeting for the Chesapeake Bay Oyster Recovery Project, MD and VA, Native Oyster Restoration Master Plan (NORMP), was held via webinar. The following participated:

Allison Colden	VIMS	acolden@vims.edu
Angie Sowers	USACE-Baltimore	angela.sowers@usace.army.mil
Anna Compton	USACE-Baltimore	anna.m.compton@usace.army.mil
Bill Goldsborough	Chesapeake Bay Foundation	bgoldsborough@cbf.org
Claire O'Neill	USACE-Baltimore	claire.d.oneill@usace.army.mil
Craig Seltzer	USACE-Norfolk	Craig.l.seltzer@usace.army.mil
Ellen Cosby	PRFC	Ellen.prfc@verizon.net
Eric Weissberger	MD DNR	EWeissberger@dnr.state.md.us
George Ruddy	USFWS	George_ruddy@fws.gov
Jeff Strahan	USACE-Norfolk	Jeffery.P.Strahan@usace.army.mil
John Catena	NOAA	john.catena@noaa.gov.
Larry Oliver	USACE-New England	Lawrence.r.oliver@usace.army.mil
Mark Bryer	The Nature Conservancy	Mbryer@tnc.org
Peter Bergstrom	NOAA	Peter.Bergstrom@noaa.gov
Rom Lipcius	VIMS (representing VMRC)	Rom@vims.edu
Russ Burke	VIMS	russ@vims.edu
Stephanie Reynolds	Chesapeake Bay Foundation	SWestby@cbf.org

2. Introductions and Purpose – Larry opened the meeting and had everyone introduce themselves. He noted that the purpose of this meeting was to continue project coordination of the NORMP with the cooperating agencies and that the focus would be to discuss and obtain a consensus on goals and objectives and hydrodynamic information. Also the white papers would be summarized briefly, however there will be a follow-up meeting (not yet scheduled) to discuss those in more detail.

3. Recap of December 2009 Meeting – Larry noted that at the last meeting the Chesapeake Bay Executive Order (E.O.) 13508 was discussed and the possible use of the NORMP as a multi-agency plan to execute this E.O. The group had determined that the NORMP was consistent with the E.O., though the NORMP goals and objectives are catered specifically to what USACE can participate with regarding oyster restoration. There was also discussion on the GIS layering approach and initial results used in the NORMP, the hydrodynamic/larval transport modeling

results, how historic oyster habitat was calculated for the 40% target for restoration area, alternate substrates, cost estimating, and genetic rehabilitation.

Larry noted that there were a lot of comments on the modeling results at the last meeting. Specifically, there was concern that certain tributaries (e.g. Lynnhaven) did not appear to have high larval retentiveness according to the calculations performed by University of Maryland, but were known to have high larval retentiveness based on field observations. In light of these comments USACE revised the hydrodynamic approach taking into account other sources of larval retentiveness (instead of just the calculations) and revised tributary rankings for hydrodynamics. Details of these revisions will be discussed later on.

4. Goals and Objectives – Larry went over the goals and objectives USACE has developed for the NORMP. The goal for today was to get feedback from attendees and obtain a consensus on text.

Larry noted that Angie had worked up a spreadsheet of bay-wide oyster plans that have been developed in the past to compare the goals and objectives of these plans with the NORMP. This spreadsheet had been sent out to attendees. There was consensus that in general, NORMP goals and objectives are consistent with these oyster plans (i.e. not contradictory).

The NORMP short-term objectives were discussed first. John noted that the NORMP goals do not say anything about area/ scale. In the E.O. process NOAA was pushed very hard to come up with a number for restored oyster acres to include in the goals. He asked whether a specific number was discussed in the development of the NORMP goals. Larry noted that USACE has not come up with a specific number and would not normally specify a specific number goal because that would limit alternatives. Mark said that the wording in the NORMP goals is "throughout the Chesapeake Bay," and asked whether "throughout the Chesapeake Bay" should be further defined. Craig explained that the NORMP will provide a means to evaluate and prioritize where work will occur, and suggest the scale necessary on a tributary level, it will not provide a certain amount of acres in a certain time period; however it will facilitate moving in that direction. Larry mentioned that at this level the goal (as opposed to objectives) should be relatively broad with the intention of getting more specific in objectives not goals. At this planning level USACE does not want to specify a certain number of acres. Mark asked if there should be further clarification in the NORMP goal for restored oyster acreage. He asked whether the two agencies (USACE and NOAA) feel like this restoration goal in the NORMP is in conflict with what the EO says: the NORMP goal is a broad restoration goal (i.e. not quantitative) while the EO goals set a number of tributaries to be restored in a certain amount of time. John did not see the language being in conflict; the tributary approach of the NORMP is very much consistent with the E.O. Angie noted that a demographic model was not done for the NORMP and it is important to not over extend past current knowledge with regards to the how specific the goals are in amount of acres restored.

Larry continued into the discussion of the objectives noting that the NORMP goals and objectives were revised to account for the fact that in lower salinity waters it will take longer to achieve self-sustainability (low salinity does not have significant larval recruitment), so lower salinity waters (less than 12 ppt) do not have a short-term objective of self-sustainability while the high salinity (greater than 12 ppt) does. Peter questioned if some low salinity waters could ever become self-sustaining, even in the long-term. For example, his experience in the Magothy River has shown that oysters spawn there approximately once every 10 years. Additionally due to climatic shifts, salinity is much lower than it used to be in the Bay due to more fresh water inputs. Larry explained that the thought was that there used to be self-sustaining oysters populations in low salinity waters in the past, so the NORMP goal is to recover some portion of that population. Bill noted that the there is still work to be done to understand spat set patterns in low salinity waters and how to appropriately mange oysters to increase broodstock in these locations.

Craig said that USACE is taking a multi-faceted approach to recovering oyster populations in low salinity by thinking about scale, broodstock, disease resistance development, and correct habitat elevations. Through careful hydrodynamic and metapopulation dynamics evaluations in the follow-on studies to NORMP, there is also the potential to see significant recovery in the lower salinities by strategically evaluating opportunities to connect restoration work in higher salinities with those in the lower salinity reaches.

Bill asked why USACE did not break salinity into three zones (high, mid, low) instead of just two (high and low). He noted that in mid-salinity zones the other balancing factor is disease. In the lower bay, where there is high salinity, there is evidence of increased tolerance for disease; however this is not the case in mid-salinity zones. Therefore if there was a drought and salinity was increased in the mid-salinity zones there could be high disease mortality. The mid-salinity zone will probably require its own strategy, manipulation, and management. Craig explained that in the individual tributary documents that will follow-on after the NORMP this issue will be addressed; USACE was trying to keep the evaluation in the NORMP at a higher, more conceptual level. Eric noted that the OMP takes a three salinity zone approach to its management strategy, which is available if this group wants to adopt. Craig said that this document will be an appendix to include in the NORMP. The group generally agreed with the salinity paragraph without modifications.

The group reviewed and discussed the specific objectives of the NORMP. Larry pointed out the high salinity objectives include the term “self-sustaining” in long and short term objectives while low salinity does not. Mark asked about the low-salinity objective “the development of multi-year class structure on reefs (short-term) and “production of sufficient shell to support future generations (short-term)” and whether acreage or areal extent will be considered as a measureable indicator. It was determined that “increased abundance (reef area and oyster densities)” would be added to the objective to clarify this. Rom noted that the term “abundance” encapsulates density and area.

In regards to the objective “restore resiliency of native oyster populations” measured by: “varying survivorship and recolonization of impacted areas within a tributary following climate events (i.e., droughts and freshets),” Rom pointed out that the definition of resistance is an oyster’s ability to overcome disease, while resilience, is its ability to recover after some disturbance, and asked whether this objective was getting at both? Larry stated that resistance and resiliency are linked. In the face of a climatic event, the goal is to have a population that can bounce back. Rom noted that to be consistent with ecological literature “resilience” should replace “resiliency.” Additionally, time to recovery is a metric used to measure resilience so the term “recovery” should be used in the objective. Peter asked if temperature should be added since higher temperatures increase susceptibility to pollution. Larry noted that droughts and freshets are just an example and temperature changes are also included.

John asked what “natural climate variations” means in the objective. Does the term “natural” need to be included? For example the issue of climate change is not a “natural” phenomenon and that is part of what this objective is addressing. The consensus was that “natural and anthropogenic environmental variations” would be a more fitting term.

There was discussion on the reef community objective “Restore native oyster populations in key areas/tributaries throughout the historic range of oysters in the Chesapeake Bay with reef form similar to undegraded oyster reefs.” There was discussion on whether or not any undegraded reefs exist today, and what exactly is meant by the term form? There are no good measures of historical reef form. The consensus was to change “form” to “characteristics”.

There was discussion on the “Ecological services” objective specifically in regards to the stated measurability factor which includes “increased species diversity” and “water filtration.” Mark asked if the goal is to achieve productivity and diversity. Rom suggested adding “an increase in secondary production and species diversity” compared to baseline conditions. Mark asked if anything regarding sediment should be added here and Peter asked about water clarity. Rom mentioned that these factors depend on salinity zone; species in lower salinity increase water quality substantially. Water clarity could be added to measurability, but it should be recognized that this won’t happen across the board.

In regards to the fisheries management objective which includes “export larvae outside the sanctuary boundaries to support a sustainable oyster fishery” Eric cautioned against using this language about creating a sustainable fishery. The consensus was to change “support a sustainable oyster fishery” language to “provide larval subsidies to potential harvest grounds.” This more clearly states the intent of the NORMP goals instead which is providing larvae, not sustaining the oyster fishery.

The long-term objective of the NORMP was discussed next. Many of the changes made in the short term objectives were also changed in the long term objective. Specifically: “natural climate variation: changed to “natural and anthropogenic environmental variations” and “Resilience” changed to “resilient”.
Eric suggested monitoring for detectable disease resistance. Craig noted that one of the disease strategies being developed in the NORMP is using broodstock that has demonstrated a level of disease resistance via direct adult broodstock application or their progeny (i.e., spat-on-shell) to augment the population on constructed reefs. Rom suggested adding “resistance to predation” to the goals as well.

The group agreed to all the goals and objectives as revised through the discussion. Larry noted that he will revise the goals and objectives based on comments and send out a new version and that these goals and objectives would be placed on a Corps website as the interagency approved goals and objectives.

5. GIS Layering Update - Larry reviewed the absolute criteria used in the GIS layering process to prioritize tributaries for oyster restoration in the NORMP. The absolute criteria include:

- Growing season salinity: >5 ppt
- Summer dissolved oxygen: >5 mg/L
- Water depth: < 20 feet
- Historic reef upstream extents

At the last meeting the group requested that USACE add singular maps for the absolute criteria (DO, salinity, water depth, historic reef upstream limits). Larry noted that these maps are stilling being refined and will be sent out at a later date.

6. Tributary Hydrodynamics - Larry noted that the next topic was to discuss the hydrodynamics excel sheet developed by the team and how it was filled out.

Angie noted that the NORMP team recognized that hydrodynamics is important to look at in a system. The NORMP team took a dual approach for addressing hydrodynamics in large and small tributaries. For small tributaries tidal flushing time was calculated for each tributary using surface area, depth, and volume at high and low tide with tide tables and predicted tidal current velocities to calculate an adjusted tidal flushing time for each small tributary. For large tributaries a larval transport model (LTM) was used, which provided an estimate of how much larvae are retained in the system. Angie explained that results of this hydrodynamic analysis were presented at the last cooperating agency meeting. Comments were that the small tributary analysis did not appear to hold up well and the team should not rely on residence calculations alone. Also the calculations did not take into account the geometry of each tributary. It was recommended that the NORMP team validate the results by reviewing other data sources and develop a summary discussion of each tributary ranking to capture any adjustments made to tributary ranking based on this validation process. Where possible, the reason for an area being identified as "unsuitable" will be explained/summarized.

Angie said that she reviewed the data and revised the tributary rankings based on this review. Data sources she reviewed include: small Tributary Flushing Times, Scientific Literature, Larval Transport Modeling (Self-recruitment metric of large tributaries), Larval Transport Modeling (self-recruitment of sub-basins), Best Bar Identification by Maryland Department of Natural Resources and Historical Spat Set Data. She noted that other potential data sources are the VA Oyster Atlas and Larval Transport Modeling (Particle Accumulation Zones). Angie said that the ranking now considers shape (geometry) of the tributaries as well. For example, if a tributary is long and narrow or has lots of branches it is more likely to have retentive properties. She requested that the group let her know of any other references/data sources that discuss the hydrodynamics of tributaries in the Bay.

Angie noted that all of this data was compiled into a matrix and a qualitative rating was developed for each tributary of High, Medium High, Medium, Medium Low, and Low with respect to retentive properties. Data that was given the most confidence was monitoring data and scientific literature followed by modeling results.

Rom noted that this matrix was a major improvement to what was shown at the last meeting.

Larry asked that the group look over the Hydrodynamic white paper, map, and the matrix and provide comments to USACE. Rom said he would run the table by Shen and Wang (modelers at VIMS) as well.

7. White Paper Status Summary- Larry provided a brief review of each of the white papers, which lay out the NORMP strategy for various oyster restoration topics including: Scale, Disease, Populations – bay-scape setting, Populations - individual reefs, Physiochemical factors, Hydrodynamics, and Reproduction. Reproduction is the only paper that remains to be sent out for review and comment. The purpose of this discussion is to set the stage for the next cooperating agency meeting (which will focus on comments to white papers). Larry noted that if a white paper does not receive a lot of comments it will not be focused on at the upcoming meeting. Anna noted that all comments for all white papers will be due by May 31st.

8. Next Steps- Anna will coordinate a date with the group for the next meeting; it will be sometime in June. Larry noted that the more info provided to USACE to rank these tributaries regarding hydrodynamics and absolute criteria the more accurate the rankings will be.
Larry reviewed the current schedule for the NORMP:

- Final Programmatic Oyster EIS Record of Decision August 2009
- NORMP Notice of Intent September 2009
- Cooperating Agency Meeting, Initial Formulation December 2009
- Cooperating Agency Meeting, Focus Locations May 2010
- Cooperating Agency Meeting, White Papers June 2010
- Draft Report to Cooperating Agencies August 2010
- Cooperating Agency Meeting, Report Content September 2010
- NORMP Public Release Summer 2011

9. Action Items –

- The NORMP team will add singular maps for the absolute criteria (DO, salinity, water depth, historic reef upstream limits).
- Larry will revise the goals and objectives based on comments and send out a new version.
- Cooperating agencies will review Hydrodynamic white paper, map, and the matrix and provide comments to USACE by May 31st.
- Rom will provide the hydrodynamics matrix to Shen and Wang (modelers at VIMS) to provide comment.
- Cooperating agencies will review all white papers and provide comments to USACE by May 31st.
- USACE will complete reproduction white paper and will send out to cooperating agencies for review.

Anna Compton,
Biologist
CENAB-PL-P

F-4: AGENCY COORDINATION MEETING SUMMARY JUNE 24, 2010

MEMORANDUM FOR RECORD

SUBJECT: Chesapeake Bay Oyster Recovery Project, MD and VA, Native Oyster Restoration Master Plan, Agency Coordination Meeting

1. On 24 June 2010, the fifth agency coordination meeting for the Chesapeake Bay Oyster Recovery Project, MD and VA, Native Oyster Restoration Master Plan (NORMP), was held via webinar. The following participated:

Angie Sowers	USACE-Baltimore	angela.sowers@usace.army.mil
Anna Compton	USACE-Baltimore	anna.m.compton@usace.army.mil
Claire O'Neill	USACE-Baltimore	claire.d.oneill@usace.army.mil
Craig Seltzer	USACE-Norfolk	Craig.l.seltzer@usace.army.mil
Eric Weissberger	MD DNR	EWeissberger@dnr.state.md.us
George Ruddy	USFWS	George_ruddy@fws.gov
Jeff Strahan	USACE-Norfolk	Jeffery.P.Strahan@usace.army.mil
Jack Travelstead	VMRC	jack.travelstead@mrc.virginia.gov
Larry Oliver	USACE-New England	Lawrence.r.oliver@usace.army.mil
Andy Lacatell	The Nature Conservancy	
Peter Bergstrom	NOAA	Peter.Bergstrom@noaa.gov

1. Introductions and Purpose - Larry opened the meeting and had everyone introduce themselves. He noted that the purpose of this meeting was to continue project coordination of the NORMP with the cooperating agencies and that the focus would be to discuss each of the white paper topics, summarize comments made to the white papers through the review process, and to obtain consensus or define areas of disagreement. Larry noted that USACE will integrate the white papers into the draft NORMP report along with other factors such as costs.

2. Review of May 2010 meeting - Larry noted that at the last meeting goals and objectives were discussed and revised. He explained that the goals and objectives have reached a good consensus and are linked back to monitoring criteria to show that they could be monitored. The tributary hydrodynamics table was reviewed and the white paper topics were discussed at the last meeting as well.

3. White Paper topics-Scale - Before discussing the Scale paper Craig noted that the NORMP will serve as a guide to oyster restoration as opposed to directing exactly what should be done. No implementation plans will come out of the master plan. The goal is to optimize ecological benefits as well as create self-sustaining populations of oysters.

Craig explained that the scale white paper is looking to answer the question "At what scale must oyster reefs be developed (i.e., how many acres of habitat) in various areas/tributaries of the Bay in order to achieve self-sustaining oyster populations that support the NORMP goal?" One of the comments received was regarding how USACE is justifying the 40% target. Craig noted that in

Maryland the spatial extent of historic bars is the Yates surveys and in VA the Baylor surveys. Craig noted that these surveys identify political boundaries. USACE estimated how much actual reef existed within these political boundaries (MD-48%; VA-43%). USACE then applied a marine protected area (MPA) percentage out of literature (40%). A MPA is a geographic area designated to protect a species or habitat. This percentage was selected and applied to provide an estimate or relative amount of acres that need to be restored in a given tributary. MPA's typically range from 20-70% protection of a species historical habitat.

Craig noted that no definitive information is available on the scale of restoration for oysters and a reasonable estimate is required for relative scope and costs. Large scale sanctuaries will be needed to be successful and projects built in the past have been too small. The 40% target is expected to vary in specific tributary plans. Field studies, modeling, and monitoring and adaptive management should be used to adjust scale in the tributary specific plans.

One of the justifications for the 40% target was the Great Wicomico (GW) project (restored 40% of the population) which is the only current example of restoration that is still thriving after 6 years. Future restoration projects may vary in scale in high salinity vs. (larger scale) in lower salinity.

George asked how the NORMP will propose implementing and sequencing projects. Is the plan to restore 40% of historic acreage tributary by tributary or would some restoration occur in a tributary and then in another tributary and then going back to complete the previous tributary. Craig noted that the plan would be to select a VA tributary for restoration that the Norfolk district would take the lead on as well as a MD tributary for Baltimore District to take the lead on. These restoration activities would occur at the same time and restoration would occur in phases. The most efficient process is to do one tributary at a time due to the fact that USACE "decision documents" will need to be developed and approved in order to go to construction. George asked how much time will be needed to assess if the restoration in a tributary is at the appropriate scale. Craig said that monitoring will begin 1 year after spat on shell placement on reefs. Shell string methods can be used to look at recruitment. Often tributaries are habitat limited (not recruitment). After a year or two, recruitment can be assessed to determine if more structure is needed. Monitoring elements will be the same for all tributaries and degradation monitoring will validate projections on scale. George noted that in MD recruitment is variable from year to year and he was uncertain if scale could be assessed in a short timeframe (e.g. what if it is a low recruitment year). Angie noted that the NORMP "Tier 1" tribs will have good retention based on the hydrodynamics evaluation. She added that 40% is a large number but the goal is to restore a species, so major investments will be needed to get the desired results. However this percent is not even half of what was there historically.

4. Disease – Craig went over the contents of the disease white paper. The paper discusses the disease to salinity relationship, how to create sustainable populations in the face of disease, low salinity vs. a high salinity strategy, using disease resistant parent broodstock for spat-on-shell production throughout the Bay, and using wild disease resistant broodstock for population augmentation on restored reefs, within a similar salinity regime. The major comments on this white paper were concerns over the risk of the transportation of wild diseased stock, if disease resistance can be maintained and/or developed in low salinity waters, avoiding genetic

bottlenecking, incorporating the 2007 Disease Workshop recommendations and incorporating the known restrictions on transplanting diseased stock.

The comments were addressed by stating that in low salinity waters massive die-offs during droughts must be addressed in order to develop self-sustaining populations; confronting disease should be considered rather than avoidance; hatchery spat-on-shell should be produced from disease resistant wild broodstock; accelerating disease resistance development in low salinity areas by using hatchery produced spat-on-shell derived from disease resistant parent broodstock should be considered; and genetic bottlenecking should not be an issue if wild oyster strains are used.

The challenge is that the goal is to develop self-sustaining populations (i.e. self-maintain and require very little maintenance). Oysters that are only exposed to disease during rare climate extremes do not develop disease resistance and are killed when they are exposed to disease. This is a critical issue. The strategy of restoration efforts in the past in low salinity was to avoid disease. The NORMP is suggesting that disease be dealt with directly. In order to avoid the possibility of genetic bottle-necking, the same broodstock should not be used over and over again. This would be implemented by using new wild broodstock for each hatchery stocking event.

George noted that the incubator reefs concept is acceptable as long as seed is transferred to reefs within the same salinity regime. Craig noted that the idea of transferring seed directly from the wild (instead of wild to hatchery back to wild) in different salinity regimes was dropped.

5. <u>Bayscape setting - population</u> - Angie reviewed the contents of this white paper. She noted that the Baylor and Yates surveys were adjusted and used to estimate historic size.
The NORMP recommends providing reef networks within an average distance of 9 km based on Dr. North's larval transport modeling. Finally specific locations will be determined in individual tributary studies considering individual tributary dispersal distances. Angie noted that there were no comments made to this paper.

6. <u>Populations - individual reefs</u> - Angie reviewed the contents of this white paper. The paper focused on bar morphology, height, and heterogeneity. The NORMP recommends that restored bars be built to a 1 ft minimum with variation to create heterogeneity and spaces within reefs. She noted that the size of the reef (acreage) will depend on historic size, available suitable bottom, and available hard substrate. For alternate substrates the preference will be to place a clean oyster shell veneer at least 15 cm thick over an alternate substrate core, if shell is available. Regarding orientation to flow, northern tributary reefs historically are parallel to currents while southern tributaries are perpendicular to currents; therefore the NORMP recommends this same strategy. The future tributary specific plans will lay out the appropriate orientation of the reefs. Additionally reefs should be placed in water depths of less than 20 feet. Angie noted that there were no comments made to this paper.

7. <u>Physiochemical</u> - Angie reviewed the contents of this white paper. The NORMP recommends that restoration occur in waters with salinity greater than 5 ppt. Plans will be developed for two salinity zones: Zone 1 (5-12 ppt) and Zone 2 (>12 ppt). Regarding dissolved

oxygen (DO), bars will not be restored in waters that have an average summer DO of less than 5 mg/L. The salinity and DO criteria meet appropriate habitat quality and oyster survival requirements.

Comments to this paper were in regards to the 5 ppt salinity criteria as the chosen salinity tolerance even though oyster reproduction does not occur at 5 ppt (waters >8 ppt support reproduction). Angie noted that this comment was addressed by adding to the NORMP that individual tributary plans will take into consideration that greater than 8 ppt is required for oyster reproduction but greater than 5 ppt supports growth of oysters. Angie noted that the team is developing a GIS layer which will identify areas that are between 5-8 ppt. She said that there may be areas in the Eastern Bay, Chester, Severn, and Magothy. The team will look at the extent of area that falls between 5-8 ppt and there will be discussion in the NORMP that areas between 5-8 ppt should not have the majority of construction. Angie noted that the map of the areas that fall between 5-8 ppt can be shared with the group once completed. Eric Weissberger suggested that there could be strategies for 3 salinity zones instead of only two to include a zone between 5-8 ppt. Angie noted that if it turns out that the area between 5-8 ppt is large we will consider adding this as a third zone.

Peter Bergstrom asked if the mean salinity was used in the salinity evaluation or whether the analysis allowed for the consideration of freshets. Angie noted that bottom and surface growing season averages were used in the evaluations. Also the team is looking back at data to see the variation in salinity to determine which sites are stable or more variable. Peter noted that the bottom salinity does not change as much as the surface. Maps in the NORMP will include mean bottom and surface salinity and individual maps for dry, wet, and average years.

8. Hydrodynamics - Angie reviewed the contents of this white paper. The hydrodynamic rating is a qualitative ranking based on documented retention as well as modeling. Documentation comes from scientific literature, best bar identification by Maryland Department of Natural Resources, historical spat set data and current restoration activities. The modeling component includes larval transport modeling of self-recruitment in large tributaries and sub-basins, small tributary flushing time, and particle accumulation zones.

The major comments to this paper were whether the effects of salinity on recruitment as it pertains to trap estuary desirability were investigated, whether low salinity trap estuaries are sources or sinks, and the discrepancy between retention ratings and spat set records.

The comments were addressed by noting that the importance of both retention and recruitment in re-establishing populations are recognized in the NORMP. Recruitment will be factored into the hydrodynamic evaluation by including best bars identified by MD, and the team is still looking for a VA dataset to incorporate. Additionally the team will compare hydrodynamic ratings with historic recruitment and salinity zone. Tributaries within the same salinity zone (low to low salinity and high to high salinity) will be compared (Merritt 1977 (MD spat set records 1939-1977), and VA VIMS data).

Jack Travelstead said he could look into the VA spat set surveys that go back for decades which may include some of the VA spat set date needed for this evaluation.

9. Reproduction - Larry reviewed the contents of this white paper. He noted that since this paper was not sent out until this week there have been no agency comments submitted yet. For low to moderate salinity zones (<12 ppt salinity) the NORMP recommends providing substrate as needed and stocking spat on shell at 4 - 5 million spat per acre. Adult disease resistant wild stock should be used to produce the spat-on-shell (SOS) in hatcheries to pass on disease resistance and restocking should occur 2 to 3 years following initial planting to provide a multi-age population. Monitoring should be conducted to assess natural recruitment, population characteristics, and condition to determine the need for additional stocking.

For high salinity zones (>12 ppt salinity) the NORMP recommends providing substrate as needed (where natural recruitment is sufficient seeding may not be required). High salinity waters with depleted stocks may need seeding if sufficient natural spatset is not occurring as predicted based on spatfall survey data. Large natural oysters harvested from areas with demonstrated disease tolerance should be stocked and aggregated to enhance fertilization success. Monitoring (pre and post construction) should occur to assess natural recruitment, density and condition and determine need for stocking. If monitoring reveals that natural recruitment is not occurring and substrate degradation is occurring, consider adding new material and/or restocking should occur at 4 to 5 million spat/acre. Large adult wild stock should be used to produce the SOS in hatcheries. Wild-SOS from areas (e.g. Great Wicomico River) where large adult parent broodstock demonstrates some disease resistance w/similar salinity should be used. Monitoring should be conducted to assess natural recruitment, population characteristics, and condition to determine the need for additional stocking.

George asked if the NORMP would provide recommendations on the size of spat to avoid predation. Craig said that the NORMP recommends spat 20-40 mm. However the larger the spat the more costly so cost/benefits will need to be evaluated. Eric noted that it is a lot of effort to grow spat to that size and they would occupy space in the hatchery and asked how long it would take them to get to that size. Peter noted that there are problems with mortality in hatchery as well. Angie said that possibly a method could be developed to get the spat to the larger size without being in a hatchery (i.e. bags in the wild). Eric noted that DNR does this with cages however the scale suggested in the NORMP is much larger.

10. Schedule – Larry reviewed the current schedule for the NORMP. He noted that the team is developing a draft report which will go into our more formal USACE review process before the public review process. August 2010 is when the cooperating agencies would see actual recommendations on the process.

Final Programmatic EIS-	July ‘09
NORMP NOI-	Sep ‘09
Coop Agency Meet, Initial Formulation-	Dec ‘09
Coop Agency Meet, Focus Locations-	May ‘10
Coop Agency Meet, White Papers-	Jun ‘10
Draft Report to CA’s-	Aug ‘10

Note: follow-up meetings of the Corps team indicated that September 2010 is a more likely date and the draft report will include only the plan formulation sections (e.g. not include affected environment and environmental consequences, etc.)

Coop Agency Meet, Report Content- Sep '10
NORMP Public Release- Summer '11

11. Action Items

- USACE will send the cooperating agencies a map of the oyster restoration areas that have salinity levels between 5-8 ppt.

- If areas between 5-8 ppt salinity are large we will consider adding this as a third zone for restoration strategy development in coordination with the sponsors.

- Jack Travelstead will provide USACE with VA spat set surveys.

- Cooperating agencies will review reproduction white paper and provide comments to USACE.

Anna Compton,
Biologist
CENAB-PL-P

APPENDIX G: Detailed Cost Projections and Calculations

Maryland Tributary Cost Estimate Worksheets

Magothy River

Broad Creek

Monie Bay

Magothy River

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 3.6M spat/ac)									
option 1 (25 acre site):									
limestone	CY	40333	$ 47.50	$ 1,915,833.33		$ -		$ -	
Mob/Demob	HR	14		$ -	$ 172.98	$ 2,421.72	$ 367.43	$ 5,144.02	
barge delivery	HR	284		$ -	$ 172.98	$ 49,126.32	$ 336.62	$ 95,600.08	
limestone placement	CY	40333		$ -	$ 1.16	$ 46,786.67	$ 2.09	$ 84,296.67	
			MATERIAL SUBTOTAL	$ 1,915,833.33	***LABOR SUBTOTAL***	$ 98,334.71	***EQUIP SUBTOTAL***	$ 185,040.77	
			SALES TAX (MATERIALS) 5%	$ 95,791.67	***Labor Insurance 32%***	$ 31,467.11			
			SUBTOTALS	$ 2,011,625.00		$ 129,801.81		$ 185,040.77	
			TOTAL COST	$ 2,326,467.58					
			CONTIGENCY 20%	$ 465,293.52					
			OVERHEAD 10%	$ 232,646.76					
			PROFIT 8%	$ 241,952.63					
			TOTAL COST						$ 3,266,360
spat	EA	90000000	$ 0.010	$ 900,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	10		$ -	$ 172.98	$ 1,729.80	$ 151.41	$ 1,514.10	
spat planting	EA	90000000		$ -	$ 0.001	$ 84,330.00		$ -	
			MATERIAL SUBTOTAL	$ 900,000.00	***LABOR SUBTOTAL***	$ 87,616.62	***EQUIP SUBTOTAL***	$ 2,583.57	
			SALES TAX (MATERIALS) 5%	$ 45,000.00	***Labor Insurance 32%***	$ 28,037.32			
			SUBTOTALS	$ 945,000.00		$ 115,653.94		$ 2,583.57	
			TOTAL COST	$ 1,063,237.51					
			CONTIGENCY 20%	$ 212,647.50					
			OVERHEAD 10%	$ 106,323.75					
			PROFIT 8%	$ 110,576.70					
			TOTAL COST						$ 1,492,785

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
limestone	CY	80667	$ 47.50	$ 3,831,666.67		$ -		$ -	
Mob/Demob	HR	14		$ -	$ 172.98	$ 2,421.72	$ 367.43	$ 5,144.02	
barge delivery	HR	567		$ -	$ 172.98	$ 98,079.66	$ 336.62	$ 190,863.54	
limestone placement	CY	80667		$ -	$ 1.16	$ 93,573.33	$ 2.09	$ 168,593.33	
			MATERIAL SUBTOTAL	$ 3,831,666.67	***LABOR SUBTOTAL***	$ 194,074.71	***EQUIP SUBTOTAL***	$ 364,600.89	
			SALES TAX (MATERIALS) 5%	$ 191,583.33	***Labor Insurance 32%***	$ 62,103.91			
			SUBTOTALS	$ 4,023,250.00		$ 256,178.62		$ 364,600.89	
			TOTAL COST	$ 4,644,029.51					
			CONTIGENCY 20%	$ 928,805.90					
			OVERHEAD 10%	$ 464,402.95					
			PROFIT 8%	$ 482,979.07					
			TOTAL COST						$ 6,520,217
spat	EA	180000000	$ 0.010	$ 1,800,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	10		$ -	$ 172.98	$ 1,729.80	$ 151.41	$ 1,514.10	
spat planting	EA	180000000		$ -	$ 0.001	$ 168,660.00		$ -	
			MATERIAL SUBTOTAL	$ 1,800,000.00	***LABOR SUBTOTAL***	$ 171,946.62	***EQUIP SUBTOTAL***	$ 2,583.57	
			SALES TAX (MATERIALS) 5%	$ 90,000.00	***Labor Insurance 32%***	$ 55,022.92			
			SUBTOTALS	$ 1,890,000.00		$ 226,969.54		$ 2,583.57	
			TOTAL COST	$ 2,119,553.11					
			CONTIGENCY 20%	$ 423,910.62					
			OVERHEAD 10%	$ 211,955.31					
			PROFIT 8%	$ 220,433.52					
			TOTAL COST						$ 2,975,853

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
limestone	CY	161333	$ 47.50	$ 7,663,333.33		$ -		$ -	
Mob/Demob	HR	14		$ -	$ 172.98	$ 2,421.72	$ 367.43	$ 5,144.02	
barge delivery	HR	1135		$ -	$ 172.98	$ 196,332.30	$ 336.62	$ 382,063.70	
limestone placement	CY	161333		$ -	$ 1.16	$ 187,146.67	$ 2.09	$ 337,186.67	
			MATERIAL SUBTOTAL	$ 7,663,333.33	***LABOR SUBTOTAL***	$ 385,900.69	***EQUIP SUBTOTAL***	$ 724,394.39	
			SALES TAX (MATERIALS) 5%	$ 383,166.67	***Labor Insurance 32%***	$ 123,488.22			
			SUBTOTALS	$ 8,046,500.00		$ 509,388.91		$ 724,394.39	
			TOTAL COST	$ 9,280,283.29					
			CONTIGENCY 20%	$ 1,856,056.66					
			OVERHEAD 10%	$ 928,028.33					
			PROFIT 8%	$ 965,149.46					
			TOTAL COST						$ 13,029,518
spat	EA	360000000	$ 0.010	$ 3,600,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	10		$ -	$ 172.98	$ 1,729.80	$ 151.41	$ 1,514.10	
spat planting	EA	360000000		$ -	$ 0.001	$ 337,320.00		$ -	
			MATERIAL SUBTOTAL	$ 3,600,000.00	***LABOR SUBTOTAL***	$ 340,606.62	***EQUIP SUBTOTAL***	$ 2,583.57	
			SALES TAX (MATERIALS) 5%	$ 180,000.00	***Labor Insurance 32%***	$ 108,994.12			
			SUBTOTALS	$ 3,780,000.00		$ 449,600.74		$ 2,583.57	
			TOTAL COST	$ 4,232,184.31					
			CONTIGENCY 20%	$ 846,436.86					
			OVERHEAD 10%	$ 423,218.43					
			PROFIT 8%	$ 440,147.17					
			TOTAL COST						$ 5,941,987

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 4.5M spat/ac)									
option 1 (25 acre site):									
limestone	CY	40333	$ 47.50	$ 1,915,833.33		$ -		$ -	
Mob/Demob	HR	14		$ -	$ 172.98	$ 2,421.72	$ 367.43	$ 5,144.02	
barge delivery	HR	284		$ -	$ 172.98	$ 49,126.32	$ 336.62	$ 95,600.08	
limestone placement	CY	40333		$ -	$ 1.16	$ 46,786.67	$ 2.09	$ 84,296.67	
			MATERIAL SUBTOTAL	$ 1,915,833.33	***LABOR SUBTOTAL***	$ 98,334.71	***EQUIP SUBTOTAL***	$ 185,040.77	
			SALES TAX (MATERIALS) 5%	$ 95,791.67	***Labor Insurance 32%***	$ 31,467.11			
			SUBTOTALS	$ 2,011,625.00		$ 129,801.81		$ 185,040.77	
			TOTAL COST	$ 2,326,467.58					
			CONTIGENCY 20%	$ 465,293.52					
			OVERHEAD 10%	$ 232,646.76					
			PROFIT 8%	$ 241,952.63					
			TOTAL COST						$ 3,266,360
spat	EA	112500000	$ 0.010	$ 1,125,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	10		$ -	$ 172.98	$ 1,729.80	$ 151.41	$ 1,514.10	
spat planting	EA	112500000		$ -	$ 0.001	$ 105,412.50		$ -	
			MATERIAL SUBTOTAL	$ 1,125,000.00	***LABOR SUBTOTAL***	$ 108,699.12	***EQUIP SUBTOTAL***	$ 2,583.57	
			SALES TAX (MATERIALS) 5%	$ 56,250.00	***Labor Insurance 32%***	$ 34,783.72			
			SUBTOTALS	$ 1,181,250.00		$ 143,482.84		$ 2,583.57	
			TOTAL COST	$ 1,327,316.41					
			CONTIGENCY 20%	$ 265,463.28					
			OVERHEAD 10%	$ 132,731.64					
			PROFIT 8%	$ 138,040.91					
			TOTAL COST						$ 1,863,552

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
limestone	CY	80667	$ 47.50	$ 3,831,666.67		$ -		$ -	
Mob/Demob	HR	14		$ -	$ 172.98	$ 2,421.72	$ 367.43	$ 5,144.02	
barge delivery	HR	567		$ -	$ 172.98	$ 98,079.66	$ 336.62	$ 190,863.54	
limestone placement	CY	80667		$ -	$ 1.16	$ 93,573.33	$ 2.09	$ 168,593.33	
			MATERIAL SUBTOTAL	$ 3,831,666.67	***LABOR SUBTOTAL***	$ 194,074.71	***EQUIP SUBTOTAL***	$ 364,600.89	
			SALES TAX (MATERIALS) 5%	$ 191,583.33	***Labor Insurance 32%***	$ 62,103.91			
			SUBTOTALS	$ 4,023,250.00		$ 256,178.62		$ 364,600.89	
			TOTAL COST	$ 4,644,029.51					
			CONTIGENCY 20%	$ 928,805.90					
			OVERHEAD 10%	$ 464,402.95					
			PROFIT 8%	$ 482,979.07					
			TOTAL COST						$ 6,520,217
spat	EA	225000000	$ 0.010	$ 2,250,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	10		$ -	$ 172.98	$ 1,729.80	$ 151.41	$ 1,514.10	
spat planting	EA	225000000		$ -	$ 0.001	$ 210,825.00		$ -	
			MATERIAL SUBTOTAL	$ 2,250,000.00	***LABOR SUBTOTAL***	$ 214,111.62	***EQUIP SUBTOTAL***	$ 2,583.57	
			SALES TAX (MATERIALS) 5%	$ 112,500.00	***Labor Insurance 32%***	$ 68,515.72			
			SUBTOTALS	$ 2,362,500.00		$ 282,627.34		$ 2,583.57	
			TOTAL COST	$ 2,647,710.91					
			CONTIGENCY 20%	$ 529,542.18					
			OVERHEAD 10%	$ 264,771.09					
			PROFIT 8%	$ 275,361.93					
			TOTAL COST						$ 3,717,386

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
limestone	CY	161333	$ 47.50	$ 7,663,333.33		$ -		$ -	
Mob/Demob	HR	14		$ -	$ 172.98	$ 2,421.72	$ 367.43	$ 5,144.02	
barge delivery	HR	1135		$ -	$ 172.98	$ 196,332.30	$ 336.62	$ 382,063.70	
limestone placement	CY	161333		$ -	$ 1.16	$ 187,146.67	$ 2.09	$ 337,186.67	
			MATERIAL SUBTOTAL	$ 7,663,333.33	***LABOR SUBTOTAL***	$ 385,900.69	***EQUIP SUBTOTAL***	$ 724,394.39	
			SALES TAX (MATERIALS) 5%	$ 383,166.67	***Labor Insurance 32%***	$ 123,488.22			
			SUBTOTALS	$ 8,046,500.00		$ 509,388.91		$ 724,394.39	
			TOTAL COST	$ 9,280,283.29					
			CONTIGENCY 20%	$ 1,856,056.66					
			OVERHEAD 10%	$ 928,028.33					
			PROFIT 8%	$ 965,149.46					
			TOTAL COST						$ 13,029,518
spat	EA	450000000	$ 0.010	$ 4,500,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	10		$ -	$ 172.98	$ 1,729.80	$ 151.41	$ 1,514.10	
spat planting	EA	450000000		$ -	$ 0.001	$ 421,650.00		$ -	
			MATERIAL SUBTOTAL	$ 4,500,000.00	***LABOR SUBTOTAL***	$ 424,936.62	***EQUIP SUBTOTAL***	$ 2,583.57	
			SALES TAX (MATERIALS) 5%	$ 225,000.00	***Labor Insurance 32%***	$ 135,979.72			
			SUBTOTALS	$ 4,725,000.00		$ 560,916.34		$ 2,583.57	
			TOTAL COST	$ 5,288,499.91					
			CONTIGENCY 20%	$ 1,057,699.98					
			OVERHEAD 10%	$ 528,849.99					
			PROFIT 8%	$ 550,003.99					
			TOTAL COST						$ 7,425,054

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 6.75M spat/ac)									
option 1 (25 acre site):									
limestone	CY	40333	$ 47.50	$ 1,915,833.33		$ -		$ -	
Mob/Demob	HR	14		$ -	$ 172.98	$ 2,421.72	$ 367.43	$ 5,144.02	
barge delivery	HR	284		$ -	$ 172.98	$ 49,126.32	$ 336.62	$ 95,600.08	
limestone placement	CY	40333		$ -	$ 1.16	$ 46,786.67	$ 2.09	$ 84,296.67	
			MATERIAL SUBTOTAL	$ 1,915,833.33	***LABOR SUBTOTAL***	$ 98,334.71	***EQUIP SUBTOTAL***	$ 185,040.77	
			SALES TAX (MATERIALS) 5%	$ 95,791.67	***Labor Insurance 32%***	$ 31,467.11			
			SUBTOTALS	$ 2,011,625.00		$ 129,801.81		$ 185,040.77	
			TOTAL COST	$ 2,326,467.58					
			CONTIGENCY 20%	$ 465,293.52					
			OVERHEAD 10%	$ 232,646.76					
			PROFIT 8%	$ 241,952.63					
			TOTAL COST						$ 3,266,360
spat	EA	168750000	$ 0.010	$ 1,687,500.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	10		$ -	$ 172.98	$ 1,729.80	$ 151.41	$ 1,514.10	
spat planting	EA	168750000		$ -	$ 0.001	$ 158,118.75		$ -	
			MATERIAL SUBTOTAL	$ 1,687,500.00	***LABOR SUBTOTAL***	$ 161,405.37	***EQUIP SUBTOTAL***	$ 2,583.57	
			SALES TAX (MATERIALS) 5%	$ 84,375.00	***Labor Insurance 32%***	$ 51,649.72			
			SUBTOTALS	$ 1,771,875.00		$ 213,055.09		$ 2,583.57	
			TOTAL COST	$ 1,987,513.66					
			CONTIGENCY 20%	$ 397,502.73					
			OVERHEAD 10%	$ 198,751.37					
			PROFIT 8%	$ 206,701.42					
			TOTAL COST						$ 2,790,469

DESCRIPTION	*UOM*	*QTY*	*MATERIAL UNIT COST*	*TOTAL MATERIAL*	*LABOR UNIT COST LABOR*	*TOTAL LABOR*	*EQUIP UNIT COST*	*TOTAL EQUIP*	
option 2 (50 acre site):									
limestone	CY	80667	$ 47.50	$ 3,831,666.67		$ -		$ -	
Mob/Demob	HR	14		$ -	$ 172.98	$ 2,421.72	$ 367.43	$ 5,144.02	
barge delivery	HR	567		$ -	$ 172.98	$ 98,079.66	$ 336.62	$ 190,863.54	
limestone placement	CY	80667		$ -	$ 1.16	$ 93,573.33	$ 2.09	$ 168,593.33	
			MATERIAL SUBTOTAL	$ 3,831,666.67	***LABOR SUBTOTAL***	$ 194,074.71	***EQUIP SUBTOTAL***	$ 364,600.89	
			SALES TAX (MATERIALS) 5%	$ 191,583.33	***Labor Insurance 32%***	$ 62,103.91			
			SUBTOTALS	$ 4,023,250.00		$ 256,178.62		$ 364,600.89	
			TOTAL COST	$ 4,644,029.51					
			CONTIGENCY 20%	$ 928,805.90					
			OVERHEAD 10%	$ 464,402.95					
			PROFIT 8%	$ 482,979.07					
			TOTAL COST						$ 6,520,217
spat	EA	337500000	$ 0.010	$ 3,375,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	10		$ -	$ 172.98	$ 1,729.80	$ 151.41	$ 1,514.10	
spat planting	EA	337500000		$ -	$ 0.001	$ 316,237.50		$ -	
			MATERIAL SUBTOTAL	$ 3,375,000.00	***LABOR SUBTOTAL***	$ 319,524.12	***EQUIP SUBTOTAL***	$ 2,583.57	
			SALES TAX (MATERIALS) 5%	$ 168,750.00	***Labor Insurance 32%***	$ 102,247.72			
			SUBTOTALS	$ 3,543,750.00		$ 421,771.84		$ 2,583.57	
			TOTAL COST	$ 3,968,105.41					
			CONTIGENCY 20%	$ 793,621.08					
			OVERHEAD 10%	$ 396,810.54					
			PROFIT 8%	$ 412,682.96					
			TOTAL COST						$ 5,571,220

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
limestone	CY	161333	$ 47.50	$ 7,663,333.33		$ -		$ -	
Mob/Demob	HR	14		$ -	$ 172.98	$ 2,421.72	$ 367.43	$ 5,144.02	
barge delivery	HR	1135		$ -	$ 172.98	$ 196,332.30	$ 336.62	$ 382,063.70	
limestone placement	CY	161333		$ -	$ 1.16	$ 187,146.67	$ 2.09	$ 337,186.67	
			MATERIAL SUBTOTAL	$ 7,663,333.33	***LABOR SUBTOTAL***	$ 385,900.69	***EQUIP SUBTOTAL***	$ 724,394.39	
			SALES TAX (MATERIALS) 5%	$ 383,166.67	***Labor Insurance 32%***	$ 123,488.22			
			SUBTOTALS	$ 8,046,500.00		$ 509,388.91		$ 724,394.39	
			TOTAL COST	$ 9,280,283.29					
			CONTIGENCY 20%	$ 1,856,056.66					
			OVERHEAD 10%	$ 928,028.33					
			PROFIT 8%	$ 965,149.46					
			TOTAL COST						$ 13,029,518
spat	EA	675000000	$ 0.010	$ 6,750,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	10		$ -	$ 172.98	$ 1,729.80	$ 151.41	$ 1,514.10	
spat planting	EA	675000000		$ -	$ 0.001	$ 632,475.00		$ -	
			MATERIAL SUBTOTAL	$ 6,750,000.00	***LABOR SUBTOTAL***	$ 635,761.62	***EQUIP SUBTOTAL***	$ 2,583.57	
			SALES TAX (MATERIALS) 5%	$ 337,500.00	***Labor Insurance 32%***	$ 203,443.72			
			SUBTOTALS	$ 7,087,500.00		$ 839,205.34		$ 2,583.57	
			TOTAL COST	$ 7,929,288.91					
			CONTIGENCY 20%	$ 1,585,857.78					
			OVERHEAD 10%	$ 792,928.89					
			PROFIT 8%	$ 824,646.05					
			TOTAL COST						$ 11,132,722

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 3.6M spat/ac)									
option 1 (25 acre site):									
granite	CY	40333.3333	$ 48.00	$ 1,936,000.00		$ -		$ -	
Mob/Demob	HR	14		$ -	$ 172.98	$ 2,421.72	$ 367.43	$ 5,144.02	
barge delivery	HR	192		$ -	$ 172.98	$ 33,212.16	$ 336.62	$ 64,631.04	
granite placement	CY	40333.3333		$ -	$ 1.16	$ 46,786.67	$ 2.09	$ 84,296.67	
			MATERIAL SUBTOTAL	$ 1,936,000.00	***LABOR SUBTOTAL***	$ 82,420.55	***EQUIP SUBTOTAL***	$ 154,071.73	
			SALES TAX (MATERIALS) 5%	$ 96,800.00	***Labor Insurance 32%***	$ 26,374.57			
			SUBTOTALS	$ 2,032,800.00		$ 108,795.12		$ 154,071.73	
			TOTAL COST	$ 2,295,666.85					
			CONTIGENCY 20%	$ 459,133.37					
			OVERHEAD 10%	$ 229,566.68					
			PROFIT 8%	$ 238,749.35					
			TOTAL COST						$ 3,223,116
spat	EA	90000000	$ 0.010	$ 900,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	10		$ -	$ 172.98	$ 1,729.80	$ 151.41	$ 1,514.10	
spat planting	EA	90000000		$ -	$ 0.001	$ 84,330.00		$ -	
			MATERIAL SUBTOTAL	$ 900,000.00	***LABOR SUBTOTAL***	$ 87,616.62	***EQUIP SUBTOTAL***	$ 2,583.57	
			SALES TAX (MATERIALS) 5%	$ 45,000.00	***Labor Insurance 32%***	$ 28,037.32			
			SUBTOTALS	$ 945,000.00		$ 115,653.94		$ 2,583.57	
			TOTAL COST	$ 1,063,237.51					
			CONTIGENCY 20%	$ 212,647.50					
			OVERHEAD 10%	$ 106,323.75					
			PROFIT 8%	$ 110,576.70					
			TOTAL COST						$ 1,492,785

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
granite	CY	80666.6667	$ 48.00	$ 3,872,000.00		$ -		$ -	
Mob/Demob	HR	14		$ -	$ 172.98	$ 2,421.72	$ 367.43	$ 5,144.02	
barge delivery	HR	383		$ -	$ 172.98	$ 66,251.34	$ 336.62	$ 128,925.46	
granite placement	CY	80666.6667		$ -	$ 1.16	$ 93,573.33	$ 2.09	$ 168,593.33	
			MATERIAL SUBTOTAL	$ 3,872,000.00	***LABOR SUBTOTAL***	$ 162,246.39	***EQUIP SUBTOTAL***	$ 302,662.81	
			SALES TAX (MATERIALS) 5%	$ 193,600.00	***Labor Insurance 32%***	$ 51,918.85			
			SUBTOTALS	$ 4,065,600.00		$ 214,165.24		$ 302,662.81	
			TOTAL COST	$ 4,582,428.05					
			CONTIGENCY 20%	$ 916,485.61					
			OVERHEAD 10%	$ 458,242.81					
			PROFIT 8%	$ 476,572.52					
			TOTAL COST						$ 6,433,729
spat	EA	180000000	$ 0.010	$ 1,800,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	10		$ -	$ 172.98	$ 1,729.80	$ 151.41	$ 1,514.10	
spat planting	EA	180000000		$ -	$ 0.001	$ 168,660.00		$ -	
			MATERIAL SUBTOTAL	$ 1,800,000.00	***LABOR SUBTOTAL***	$ 171,946.62	***EQUIP SUBTOTAL***	$ 2,583.57	
			SALES TAX (MATERIALS) 5%	$ 90,000.00	***Labor Insurance 32%***	$ 55,022.92			
			SUBTOTALS	$ 1,890,000.00		$ 226,969.54		$ 2,583.57	
			TOTAL COST	$ 2,119,553.11					
			CONTIGENCY 20%	$ 423,910.62					
			OVERHEAD 10%	$ 211,955.31					
			PROFIT 8%	$ 220,433.52					
			TOTAL COST						$ 2,975,853

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
granite	CY	161333.333	$ 48.00	$ 7,744,000.00		$ -		$ -	
Mob/Demob	HR	14		$ -	$ 172.98	$ 2,421.72	$ 367.43	$ 5,144.02	
barge delivery	HR	767		$ -	$ 172.98	$ 132,675.66	$ 336.62	$ 258,187.54	
granite placement	CY	161333.333		$ -	$ 1.16	$ 187,146.67	$ 2.09	$ 337,186.67	
			MATERIAL SUBTOTAL	$ 7,744,000.00	***LABOR SUBTOTAL***	$ 322,244.05	***EQUIP SUBTOTAL***	$ 600,518.23	
			SALES TAX (MATERIALS) 5%	$ 387,200.00	***Labor Insurance 32%***	$ 103,118.09			
			SUBTOTALS	$ 8,131,200.00		$ 425,362.14		$ 600,518.23	
			TOTAL COST	$ 9,157,080.37					
			CONTIGENCY 20%	$ 1,831,416.07					
			OVERHEAD 10%	$ 915,708.04					
			PROFIT 8%	$ 952,336.36					
			TOTAL COST						$ 12,856,541
spat	EA	360000000	$ 0.010	$ 3,600,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	10		$ -	$ 172.98	$ 1,729.80	$ 151.41	$ 1,514.10	
spat planting	EA	360000000		$ -	$ 0.001	$ 337,320.00		$ -	
			MATERIAL SUBTOTAL	$ 3,600,000.00	***LABOR SUBTOTAL***	$ 340,606.62	***EQUIP SUBTOTAL***	$ 2,583.57	
			SALES TAX (MATERIALS) 5%	$ 180,000.00	***Labor Insurance 32%***	$ 108,994.12			
			SUBTOTALS	$ 3,780,000.00		$ 449,600.74		$ 2,583.57	
			TOTAL COST	$ 4,232,184.31					
			CONTIGENCY 20%	$ 846,436.86					
			OVERHEAD 10%	$ 423,218.43					
			PROFIT 8%	$ 440,147.17					
			TOTAL COST						$ 5,941,987

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 4.5M spat/ac)									
option 1 (25 acre site):									
granite	CY	40333.3333	$ 48.00	$ 1,936,000.00		$ -		$ -	
Mob/Demob	HR	14		$ -	$ 172.98	$ 2,421.72	$ 367.43	$ 5,144.02	
barge delivery	HR	192		$ -	$ 172.98	$ 33,212.16	$ 336.62	$ 64,631.04	
granite placement	CY	40333.3333		$ -	$ 1.16	$ 46,786.67	$ 2.09	$ 84,296.67	
			MATERIAL SUBTOTAL	$ 1,936,000.00	***LABOR SUBTOTAL***	$ 82,420.55	***EQUIP SUBTOTAL***	$ 154,071.73	
			SALES TAX (MATERIALS) 5%	$ 96,800.00	***Labor Insurance 32%***	$ 26,374.57			
			SUBTOTALS	$ 2,032,800.00		$ 108,795.12		$ 154,071.73	
			TOTAL COST	$ 2,295,666.85					
			CONTIGENCY 20%	$ 459,133.37					
			OVERHEAD 10%	$ 229,566.68					
			PROFIT 8%	$ 238,749.35					
			TOTAL COST						$ 3,223,116
spat	EA	112500000	$ 0.010	$ 1,125,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	10		$ -	$ 172.98	$ 1,729.80	$ 151.41	$ 1,514.10	
spat planting	EA	112500000		$ -	$ 0.001	$ 105,412.50		$ -	
			MATERIAL SUBTOTAL	$ 1,125,000.00	***LABOR SUBTOTAL***	$ 108,699.12	***EQUIP SUBTOTAL***	$ 2,583.57	
			SALES TAX (MATERIALS) 5%	$ 56,250.00	***Labor Insurance 32%***	$ 34,783.72			
			SUBTOTALS	$ 1,181,250.00		$ 143,482.84		$ 2,583.57	
			TOTAL COST	$ 1,327,316.41					
			CONTIGENCY 20%	$ 265,463.28					
			OVERHEAD 10%	$ 132,731.64					
			PROFIT 8%	$ 138,040.91					
			TOTAL COST						$ 1,863,552

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
granite	CY	80666.6667	$ 48.00	$ 3,872,000.00		$ -		$ -	
Mob/Demob	HR	14		$ -	$ 172.98	$ 2,421.72	$ 367.43	$ 5,144.02	
barge delivery	HR	383		$ -	$ 172.98	$ 66,251.34	$ 336.62	$ 128,925.46	
granite placement	CY	80666.6667		$ -	$ 1.16	$ 93,573.33	$ 2.09	$ 168,593.33	
			MATERIAL SUBTOTAL	$ 3,872,000.00	***LABOR SUBTOTAL***	$ 162,246.39	***EQUIP SUBTOTAL***	$ 302,662.81	
			SALES TAX (MATERIALS) 5%	$ 193,600.00	***Labor Insurance 32%***	$ 51,918.85			
			SUBTOTALS	$ 4,065,600.00		$ 214,165.24		$ 302,662.81	
			TOTAL COST	$ 4,582,428.05					
			CONTIGENCY 20%	$ 916,485.61					
			OVERHEAD 10%	$ 458,242.81					
			PROFIT 8%	$ 476,572.52					
			TOTAL COST						$ 6,433,729
spat	EA	225000000	$ 0.010	$ 2,250,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	10		$ -	$ 172.98	$ 1,729.80	$ 151.41	$ 1,514.10	
spat planting	EA	225000000		$ -	$ 0.001	$ 210,825.00		$ -	
			MATERIAL SUBTOTAL	$ 2,250,000.00	***LABOR SUBTOTAL***	$ 214,111.62	***EQUIP SUBTOTAL***	$ 2,583.57	
			SALES TAX (MATERIALS) 5%	$ 112,500.00	***Labor Insurance 32%***	$ 68,515.72			
			SUBTOTALS	$ 2,362,500.00		$ 282,627.34		$ 2,583.57	
			TOTAL COST	$ 2,647,710.91					
			CONTIGENCY 20%	$ 529,542.18					
			OVERHEAD 10%	$ 264,771.09					
			PROFIT 8%	$ 275,361.93					
			TOTAL COST						$ 3,717,386

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
granite	CY	161333.333	$ 48.00	$ 7,744,000.00		$ -		$ -	
Mob/Demob	HR	14		$ -	$ 172.98	$ 2,421.72	$ 367.43	$ 5,144.02	
barge delivery	HR	767		$ -	$ 172.98	$ 132,675.66	$ 336.62	$ 258,187.54	
granite placement	CY	161333.333		$ -	$ 1.16	$ 187,146.67	$ 2.09	$ 337,186.67	
			MATERIAL SUBTOTAL	$ 7,744,000.00	***LABOR SUBTOTAL***	$ 322,244.05	***EQUIP SUBTOTAL***	$ 600,518.23	
			SALES TAX (MATERIALS) 5%	$ 387,200.00	***Labor Insurance 32%***	$ 103,118.09			
			SUBTOTALS	$ 8,131,200.00		$ 425,362.14		$ 600,518.23	
			TOTAL COST	$ 9,157,080.37					
			CONTIGENCY 20%	$ 1,831,416.07					
			OVERHEAD 10%	$ 915,708.04					
			PROFIT 8%	$ 952,336.36					
			TOTAL COST						$ 12,856,541
spat	EA	450000000	$ 0.010	$ 4,500,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	10		$ -	$ 172.98	$ 1,729.80	$ 151.41	$ 1,514.10	
spat planting	EA	450000000		$ -	$ 0.001	$ 421,650.00		$ -	
			MATERIAL SUBTOTAL	$ 4,500,000.00	***LABOR SUBTOTAL***	$ 424,936.62	***EQUIP SUBTOTAL***	$ 2,583.57	
			SALES TAX (MATERIALS) 5%	$ 225,000.00	***Labor Insurance 32%***	$ 135,979.72			
			SUBTOTALS	$ 4,725,000.00		$ 560,916.34		$ 2,583.57	
			TOTAL COST	$ 5,288,499.91					
			CONTIGENCY 20%	$ 1,057,699.98					
			OVERHEAD 10%	$ 528,849.99					
			PROFIT 8%	$ 550,003.99					
			TOTAL COST						$ 7,425,054

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 6.75M spat/ac)									
option 1 (25 acre site):									
granite	CY	40333.3333	$ 48.00	$ 1,936,000.00		$ -		$ -	
Mob/Demob	HR	14		$ -	$ 172.98	$ 2,421.72	$ 367.43	$ 5,144.02	
barge delivery	HR	192		$ -	$ 172.98	$ 33,212.16	$ 336.62	$ 64,631.04	
granite placement	CY	40333.3333		$ -	$ 1.16	$ 46,786.67	$ 2.09	$ 84,296.67	
			MATERIAL SUBTOTAL	$ 1,936,000.00	***LABOR SUBTOTAL***	$ 82,420.55	***EQUIP SUBTOTAL***	$ 154,071.73	
			SALES TAX (MATERIALS) 5%	$ 96,800.00	***Labor Insurance 32%***	$ 26,374.57			
			SUBTOTALS	$ 2,032,800.00		$ 108,795.12		$ 154,071.73	
			TOTAL COST	$ 2,295,666.85					
			CONTIGENCY 20%	$ 459,133.37					
			OVERHEAD 10%	$ 229,566.68					
			PROFIT 8%	$ 238,749.35					
			TOTAL COST						$ 3,223,116
spat	EA	168750000	$ 0.010	$ 1,687,500.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	10		$ -	$ 172.98	$ 1,729.80	$ 151.41	$ 1,514.10	
spat planting	EA	168750000		$ -	$ 0.001	$ 158,118.75		$ -	
			MATERIAL SUBTOTAL	$ 1,687,500.00	***LABOR SUBTOTAL***	$ 161,405.37	***EQUIP SUBTOTAL***	$ 2,583.57	
			SALES TAX (MATERIALS) 5%	$ 84,375.00	***Labor Insurance 32%***	$ 51,649.72			
			SUBTOTALS	$ 1,771,875.00		$ 213,055.09		$ 2,583.57	
			TOTAL COST	$ 1,987,513.66					
			CONTIGENCY 20%	$ 397,502.73					
			OVERHEAD 10%	$ 198,751.37					
			PROFIT 8%	$ 206,701.42					
			TOTAL COST						$ 2,790,469

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
granite	CY	80666.6667	$ 48.00	$ 3,872,000.00		$ -		$ -	
Mob/Demob	HR	14		$ -	$ 172.98	$ 2,421.72	$ 367.43	$ 5,144.02	
barge delivery	HR	383		$ -	$ 172.98	$ 66,251.34	$ 336.62	$ 128,925.46	
granite placement	CY	80666.6667		$ -	$ 1.16	$ 93,573.33	$ 2.09	$ 168,593.33	
			MATERIAL SUBTOTAL	$ 3,872,000.00	***LABOR SUBTOTAL***	$ 162,246.39	***EQUIP SUBTOTAL***	$ 302,662.81	
			SALES TAX (MATERIALS) 5%	$ 193,600.00	***Labor Insurance 32%***	$ 51,918.85			
			SUBTOTALS	$ 4,065,600.00		$ 214,165.24		$ 302,662.81	
			TOTAL COST	$ 4,582,428.05					
			CONTIGENCY 20%	$ 916,485.61					
			OVERHEAD 10%	$ 458,242.81					
			PROFIT 8%	$ 476,572.52					
			TOTAL COST						$ 6,433,729
spat	EA	337500000	$ 0.010	$ 3,375,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	10		$ -	$ 172.98	$ 1,729.80	$ 151.41	$ 1,514.10	
spat planting	EA	337500000		$ -	$ 0.001	$ 316,237.50		$ -	
			MATERIAL SUBTOTAL	$ 3,375,000.00	***LABOR SUBTOTAL***	$ 319,524.12	***EQUIP SUBTOTAL***	$ 2,583.57	
			SALES TAX (MATERIALS) 5%	$ 168,750.00	***Labor Insurance 32%***	$ 102,247.72			
			SUBTOTALS	$ 3,543,750.00		$ 421,771.84		$ 2,583.57	
			TOTAL COST	$ 3,968,105.41					
			CONTIGENCY 20%	$ 793,621.08					
			OVERHEAD 10%	$ 396,810.54					
			PROFIT 8%	$ 412,682.96					
			TOTAL COST						$ 5,571,220

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
granite	CY	161333.333	$ 48.00	$ 7,744,000.00		$ -		$ -	
Mob/Demob	HR	14		$ -	$ 172.98	$ 2,421.72	$ 367.43	$ 5,144.02	
barge delivery	HR	767		$ -	$ 172.98	$ 132,675.66	$ 336.62	$ 258,187.54	
granite placement	CY	161333.333		$ -	$ 1.16	$ 187,146.67	$ 2.09	$ 337,186.67	
			MATERIAL SUBTOTAL	$ 7,744,000.00	***LABOR SUBTOTAL***	$ 322,244.05	***EQUIP SUBTOTAL***	$ 600,518.23	
			SALES TAX (MATERIALS) 5%	$ 387,200.00	***Labor Insurance 32%***	$ 103,118.09			
			SUBTOTALS	$ 8,131,200.00		$ 425,362.14		$ 600,518.23	
			TOTAL COST	$ 9,157,080.37					
			CONTIGENCY 20%	$ 1,831,416.07					
			OVERHEAD 10%	$ 915,708.04					
			PROFIT 8%	$ 952,336.36					
			TOTAL COST						$ 12,856,541
spat	EA	675000000	$ 0.010	$ 6,750,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	10		$ -	$ 172.98	$ 1,729.80	$ 151.41	$ 1,514.10	
spat planting	EA	675000000		$ -	$ 0.001	$ 632,475.00		$ -	
			MATERIAL SUBTOTAL	$ 6,750,000.00	***LABOR SUBTOTAL***	$ 635,761.62	***EQUIP SUBTOTAL***	$ 2,583.57	
			SALES TAX (MATERIALS) 5%	$ 337,500.00	***Labor Insurance 32%***	$ 203,443.72			
			SUBTOTALS	$ 7,087,500.00		$ 839,205.34		$ 2,583.57	
			TOTAL COST	$ 7,929,288.91					
			CONTIGENCY 20%	$ 1,585,857.78					
			OVERHEAD 10%	$ 792,928.89					
			PROFIT 8%	$ 824,646.05					
			TOTAL COST						$ 11,132,722

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 3.6M spat/ac)									
option 1 (25 acre site):									
concrete	CY	40333.3333	$ 30.00	$ 1,210,000.00		$ -		$ -	
Mob/Demob	HR	14		$ -	$ 172.98	$ 2,421.72	$ 367.43	$ 5,144.02	
barge delivery	HR	153		$ -	$ 172.98	$ 26,465.94	$ 336.62	$ 51,502.86	
concrete placement	CY	40333.3333		$ -	$ 0.92	$ 37,106.67	$ 1.67	$ 67,356.67	
			MATERIAL SUBTOTAL	$ 1,210,000.00	***LABOR SUBTOTAL***	$ 65,994.33	***EQUIP SUBTOTAL***	$ 124,003.55	
			SALES TAX (MATERIALS) 5%	$ 60,500.00	***Labor Insurance 32%***	$ 21,118.18			
			SUBTOTALS	$ 1,270,500.00		$ 87,112.51		$ 124,003.55	
			TOTAL COST	$ 1,481,616.06					
			CONTIGENCY 20%	$ 296,323.21					
			OVERHEAD 10%	$ 148,161.61					
			PROFIT 8%	$ 154,088.07					
			TOTAL COST						$ 2,080,189
spat	EA	90000000	$ 0.010	$ 900,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	10		$ -	$ 172.98	$ 1,729.80	$ 151.41	$ 1,514.10	
spat planting	EA	90000000		$ -	$ 0.001	$ 84,330.00		$ -	
			MATERIAL SUBTOTAL	$ 900,000.00	***LABOR SUBTOTAL***	$ 87,616.62	***EQUIP SUBTOTAL***	$ 2,583.57	
			SALES TAX (MATERIALS) 5%	$ 45,000.00	***Labor Insurance 32%***	$ 28,037.32			
			SUBTOTALS	$ 945,000.00		$ 115,653.94		$ 2,583.57	
			TOTAL COST	$ 1,063,237.51					
			CONTIGENCY 20%	$ 212,647.50					
			OVERHEAD 10%	$ 106,323.75					
			PROFIT 8%	$ 110,576.70					
			TOTAL COST						$ 1,492,785

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
concrete	CY	80666.6667	$ 30.00	$ 2,420,000.00		$ -		$ -	
Mob/Demob	HR	14		$ -	$ 172.98	$ 2,421.72	$ 367.43	$ 5,144.02	
barge delivery	HR	307		$ -	$ 172.98	$ 53,104.86	$ 336.62	$ 103,342.34	
concrete placement	CY	80666.6667		$ -	$ 0.92	$ 74,213.33	$ 1.67	$ 134,713.33	
			MATERIAL SUBTOTAL	$ 2,420,000.00	***LABOR SUBTOTAL***	$ 129,739.91	***EQUIP SUBTOTAL***	$ 243,199.69	
			SALES TAX (MATERIALS) 5%	$ 121,000.00	***Labor Insurance 32%***	$ 41,516.77			
			SUBTOTALS	$ 2,541,000.00		$ 171,256.69		$ 243,199.69	
			TOTAL COST	$ 2,955,456.38					
			CONTIGENCY 20%	$ 591,091.28					
			OVERHEAD 10%	$ 295,545.64					
			PROFIT 8%	$ 307,367.46					
			TOTAL COST						$ 4,149,461
spat	EA	180000000	$ 0.010	$ 1,800,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	10		$ -	$ 172.98	$ 1,729.80	$ 151.41	$ 1,514.10	
spat planting	EA	180000000		$ -	$ 0.001	$ 168,660.00		$ -	
			MATERIAL SUBTOTAL	$ 1,800,000.00	***LABOR SUBTOTAL***	$ 171,946.62	***EQUIP SUBTOTAL***	$ 2,583.57	
			SALES TAX (MATERIALS) 5%	$ 90,000.00	***Labor Insurance 32%***	$ 55,022.92			
			SUBTOTALS	$ 1,890,000.00		$ 226,969.54		$ 2,583.57	
			TOTAL COST	$ 2,119,553.11					
			CONTIGENCY 20%	$ 423,910.62					
			OVERHEAD 10%	$ 211,955.31					
			PROFIT 8%	$ 220,433.52					
			TOTAL COST						$ 2,975,853

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
concrete	CY	161333.333	$ 30.00	$ 4,840,000.00		$ -		$ -	
Mob/Demob	HR	14		$ -	$ 172.98	$ 2,421.72	$ 367.43	$ 5,144.02	
barge delivery	HR	613		$ -	$ 172.98	$ 106,036.74	$ 336.62	$ 206,348.06	
concrete placement	CY	161333.333		$ -	$ 0.92	$ 148,426.67	$ 1.67	$ 269,426.67	
			MATERIAL SUBTOTAL	$ 4,840,000.00	***LABOR SUBTOTAL***	$ 256,885.13	***EQUIP SUBTOTAL***	$ 480,918.75	
			SALES TAX (MATERIALS) 5%	$ 242,000.00	***Labor Insurance 32%***	$ 82,203.24			
			SUBTOTALS	$ 5,082,000.00		$ 339,088.37		$ 480,918.75	
			TOTAL COST	$ 5,902,007.11					
			CONTIGENCY 20%	$ 1,180,401.42					
			OVERHEAD 10%	$ 590,200.71					
			PROFIT 8%	$ 613,808.74					
			TOTAL COST						$ 8,286,418
spat	EA	360000000	$ 0.010	$ 3,600,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	10		$ -	$ 172.98	$ 1,729.80	$ 151.41	$ 1,514.10	
spat planting	EA	360000000		$ -	$ 0.001	$ 337,320.00		$ -	
			MATERIAL SUBTOTAL	$ 3,600,000.00	***LABOR SUBTOTAL***	$ 340,606.62	***EQUIP SUBTOTAL***	$ 2,583.57	
			SALES TAX (MATERIALS) 5%	$ 180,000.00	***Labor Insurance 32%***	$ 108,994.12			
			SUBTOTALS	$ 3,780,000.00		$ 449,600.74		$ 2,583.57	
			TOTAL COST	$ 4,232,184.31					
			CONTIGENCY 20%	$ 846,436.86					
			OVERHEAD 10%	$ 423,218.43					
			PROFIT 8%	$ 440,147.17					
			TOTAL COST						$ 5,941,987

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 4.5M spat/ac)									
option 1 (25 acre site):									
concrete	CY	40333.3333	$ 30.00	$ 1,210,000.00		$ -		$ -	
Mob/Demob	HR	14		$ -	$ 172.98	$ 2,421.72	$ 367.43	$ 5,144.02	
barge delivery	HR	153		$ -	$ 172.98	$ 26,465.94	$ 336.62	$ 51,502.86	
concrete placement	CY	40333.3333		$ -	$ 0.92	$ 37,106.67	$ 1.67	$ 67,356.67	
			MATERIAL SUBTOTAL	$ 1,210,000.00	***LABOR SUBTOTAL***	$ 65,994.33	***EQUIP SUBTOTAL***	$ 124,003.55	
			SALES TAX (MATERIALS) 5%	$ 60,500.00	***Labor Insurance 32%***	$ 21,118.18			
			SUBTOTALS	$ 1,270,500.00		$ 87,112.51		$ 124,003.55	
			TOTAL COST	$ 1,481,616.06					
			CONTIGENCY 20%	$ 296,323.21					
			OVERHEAD 10%	$ 148,161.61					
			PROFIT 8%	$ 154,088.07					
			TOTAL COST						$ 2,080,189
spat	EA	112500000	$ 0.010	$ 1,125,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	10		$ -	$ 172.98	$ 1,729.80	$ 151.41	$ 1,514.10	
spat planting	EA	112500000		$ -	$ 0.001	$ 105,412.50		$ -	
			MATERIAL SUBTOTAL	$ 1,125,000.00	***LABOR SUBTOTAL***	$ 108,699.12	***EQUIP SUBTOTAL***	$ 2,583.57	
			SALES TAX (MATERIALS) 5%	$ 56,250.00	***Labor Insurance 32%***	$ 34,783.72			
			SUBTOTALS	$ 1,181,250.00		$ 143,482.84		$ 2,583.57	
			TOTAL COST	$ 1,327,316.41					
			CONTIGENCY 20%	$ 265,463.28					
			OVERHEAD 10%	$ 132,731.64					
			PROFIT 8%	$ 138,040.91					
			TOTAL COST						$ 1,863,552

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
concrete	CY	80666.6667	$ 30.00	$ 2,420,000.00		$ -		$ -	
Mob/Demob	HR	14		$ -	$ 172.98	$ 2,421.72	$ 367.43	$ 5,144.02	
barge delivery	HR	307		$ -	$ 172.98	$ 53,104.86	$ 336.62	$ 103,342.34	
concrete placement	CY	80666.6667		$ -	$ 0.92	$ 74,213.33	$ 1.67	$ 134,713.33	
			MATERIAL SUBTOTAL	$ 2,420,000.00	***LABOR SUBTOTAL***	$ 129,739.91	***EQUIP SUBTOTAL***	$ 243,199.69	
			SALES TAX (MATERIALS) 5%	$ 121,000.00	***Labor Insurance 32%***	$ 41,516.77			
			SUBTOTALS	$ 2,541,000.00		$ 171,256.69		$ 243,199.69	
			TOTAL COST	$ 2,955,456.38					
			CONTIGENCY 20%	$ 591,091.28					
			OVERHEAD 10%	$ 295,545.64					
			PROFIT 8%	$ 307,367.46					
			TOTAL COST						$ 4,149,461
spat	EA	225000000	$ 0.010	$ 2,250,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	10		$ -	$ 172.98	$ 1,729.80	$ 151.41	$ 1,514.10	
spat planting	EA	225000000		$ -	$ 0.001	$ 210,825.00		$ -	
			MATERIAL SUBTOTAL	$ 2,250,000.00	***LABOR SUBTOTAL***	$ 214,111.62	***EQUIP SUBTOTAL***	$ 2,583.57	
			SALES TAX (MATERIALS) 5%	$ 112,500.00	***Labor Insurance 32%***	$ 68,515.72			
			SUBTOTALS	$ 2,362,500.00		$ 282,627.34		$ 2,583.57	
			TOTAL COST	$ 2,647,710.91					
			CONTIGENCY 20%	$ 529,542.18					
			OVERHEAD 10%	$ 264,771.09					
			PROFIT 8%	$ 275,361.93					
			TOTAL COST						$ 3,717,386

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
concrete	CY	161333.333	$ 30.00	$ 4,840,000.00		$ -		$ -	
Mob/Demob	HR	14		$ -	$ 172.98	$ 2,421.72	$ 367.43	$ 5,144.02	
barge delivery	HR	613		$ -	$ 172.98	$ 106,036.74	$ 336.62	$ 206,348.06	
concrete placement	CY	161333.333		$ -	$ 0.92	$ 148,426.67	$ 1.67	$ 269,426.67	
			MATERIAL SUBTOTAL	$ 4,840,000.00	***LABOR SUBTOTAL***	$ 256,885.13	***EQUIP SUBTOTAL***	$ 480,918.75	
			SALES TAX (MATERIALS) 5%	$ 242,000.00	***Labor Insurance 32%***	$ 82,203.24			
			SUBTOTALS	$ 5,082,000.00		$ 339,088.37		$ 480,918.75	
			TOTAL COST	$ 5,902,007.11					
			CONTIGENCY 20%	$ 1,180,401.42					
			OVERHEAD 10%	$ 590,200.71					
			PROFIT 8%	$ 613,808.74					
			TOTAL COST						$ 8,286,418
spat	EA	450000000	$ 0.010	$ 4,500,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	10		$ -	$ 172.98	$ 1,729.80	$ 151.41	$ 1,514.10	
spat planting	EA	450000000		$ -	$ 0.001	$ 421,650.00		$ -	
			MATERIAL SUBTOTAL	$ 4,500,000.00	***LABOR SUBTOTAL***	$ 424,936.62	***EQUIP SUBTOTAL***	$ 2,583.57	
			SALES TAX (MATERIALS) 5%	$ 225,000.00	***Labor Insurance 32%***	$ 135,979.72			
			SUBTOTALS	$ 4,725,000.00		$ 560,916.34		$ 2,583.57	
			TOTAL COST	$ 5,288,499.91					
			CONTIGENCY 20%	$ 1,057,699.98					
			OVERHEAD 10%	$ 528,849.99					
			PROFIT 8%	$ 550,003.99					
			TOTAL COST						$ 7,425,054

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 6.75M spat/ac)									
option 1 (25 acre site):									
concrete	CY	40333.3333	$ 30.00	$ 1,210,000.00		$ -		$ -	
Mob/Demob	HR	14		$ -	$ 172.98	$ 2,421.72	$ 367.43	$ 5,144.02	
barge delivery	HR	153		$ -	$ 172.98	$ 26,465.94	$ 336.62	$ 51,502.86	
concrete placement	CY	40333.3333		$ -	$ 0.92	$ 37,106.67	$ 1.67	$ 67,356.67	
			MATERIAL SUBTOTAL	$ 1,210,000.00	***LABOR SUBTOTAL***	$ 65,994.33	***EQUIP SUBTOTAL***	$ 124,003.55	
			SALES TAX (MATERIALS) 5%	$ 60,500.00	***Labor Insurance 32%***	$ 21,118.18			
			SUBTOTALS	$ 1,270,500.00		$ 87,112.51		$ 124,003.55	
			TOTAL COST	$ 1,481,616.06					
			CONTIGENCY 20%	$ 296,323.21					
			OVERHEAD 10%	$ 148,161.61					
			PROFIT 8%	$ 154,088.07					
			TOTAL COST						$ 2,080,189
spat	EA	168750000	$ 0.010	$ 1,687,500.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	10		$ -	$ 172.98	$ 1,729.80	$ 151.41	$ 1,514.10	
spat planting	EA	168750000		$ -	$ 0.001	$ 158,118.75		$ -	
			MATERIAL SUBTOTAL	$ 1,687,500.00	***LABOR SUBTOTAL***	$ 161,405.37	***EQUIP SUBTOTAL***	$ 2,583.57	
			SALES TAX (MATERIALS) 5%	$ 84,375.00	***Labor Insurance 32%***	$ 51,649.72			
			SUBTOTALS	$ 1,771,875.00		$ 213,055.09		$ 2,583.57	
			TOTAL COST	$ 1,987,513.66					
			CONTIGENCY 20%	$ 397,502.73					
			OVERHEAD 10%	$ 198,751.37					
			PROFIT 8%	$ 206,701.42					
			TOTAL COST						$ 2,790,469

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
concrete	CY	80666.6667	$ 30.00	$ 2,420,000.00		$ -		$ -	
Mob/Demob	HR	14		$ -	$ 172.98	$ 2,421.72	$ 367.43	$ 5,144.02	
barge delivery	HR	307		$ -	$ 172.98	$ 53,104.86	$ 336.62	$ 103,342.34	
concrete placement	CY	80666.6667		$ -	$ 0.92	$ 74,213.33	$ 1.67	$ 134,713.33	
			MATERIAL SUBTOTAL	$ 2,420,000.00	***LABOR SUBTOTAL***	$ 129,739.91	***EQUIP SUBTOTAL***	$ 243,199.69	
			SALES TAX (MATERIALS) 5%	$ 121,000.00	***Labor Insurance 32%***	$ 41,516.77			
			SUBTOTALS	$ 2,541,000.00		$ 171,256.69		$ 243,199.69	
			TOTAL COST	$ 2,955,456.38					
			CONTIGENCY 20%	$ 591,091.28					
			OVERHEAD 10%	$ 295,545.64					
			PROFIT 8%	$ 307,367.46					
			TOTAL COST						$ 4,149,461
spat	EA	337500000	$ 0.010	$ 3,375,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	10		$ -	$ 172.98	$ 1,729.80	$ 151.41	$ 1,514.10	
spat planting	EA	337500000		$ -	$ 0.001	$ 316,237.50		$ -	
			MATERIAL SUBTOTAL	$ 3,375,000.00	***LABOR SUBTOTAL***	$ 319,524.12	***EQUIP SUBTOTAL***	$ 2,583.57	
			SALES TAX (MATERIALS) 5%	$ 168,750.00	***Labor Insurance 32%***	$ 102,247.72			
			SUBTOTALS	$ 3,543,750.00		$ 421,771.84		$ 2,583.57	
			TOTAL COST	$ 3,968,105.41					
			CONTIGENCY 20%	$ 793,621.08					
			OVERHEAD 10%	$ 396,810.54					
			PROFIT 8%	$ 412,682.96					
			TOTAL COST						$ 5,571,220

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
concrete	CY	161333.333	$ 30.00	$ 4,840,000.00		$ -		$ -	
Mob/Demob	HR	14		$ -	$ 172.98	$ 2,421.72	$ 367.43	$ 5,144.02	
barge delivery	HR	613		$ -	$ 172.98	$ 106,036.74	$ 336.62	$ 206,348.06	
concrete placement	CY	161333.333		$ -	$ 0.92	$ 148,426.67	$ 1.67	$ 269,426.67	
			MATERIAL SUBTOTAL	$ 4,840,000.00	***LABOR SUBTOTAL***	$ 256,885.13	***EQUIP SUBTOTAL***	$ 480,918.75	
			SALES TAX (MATERIALS) 5%	$ 242,000.00	***Labor Insurance 32%***	$ 82,203.24			
			SUBTOTALS	$ 5,082,000.00		$ 339,088.37		$ 480,918.75	
			TOTAL COST	$ 5,902,007.11					
			CONTIGENCY 20%	$ 1,180,401.42					
			OVERHEAD 10%	$ 590,200.71					
			PROFIT 8%	$ 613,808.74					
			TOTAL COST						$ 8,286,418
spat	EA	675000000	$ 0.010	$ 6,750,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	10		$ -	$ 172.98	$ 1,729.80	$ 151.41	$ 1,514.10	
spat planting	EA	675000000		$ -	$ 0.001	$ 632,475.00		$ -	
			MATERIAL SUBTOTAL	$ 6,750,000.00	***LABOR SUBTOTAL***	$ 635,761.62	***EQUIP SUBTOTAL***	$ 2,583.57	
			SALES TAX (MATERIALS) 5%	$ 337,500.00	***Labor Insurance 32%***	$ 203,443.72			
			SUBTOTALS	$ 7,087,500.00		$ 839,205.34		$ 2,583.57	
			TOTAL COST	$ 7,929,288.91					
			CONTIGENCY 20%	$ 1,585,857.78					
			OVERHEAD 10%	$ 792,928.89					
			PROFIT 8%	$ 824,646.05					
			TOTAL COST						$ 11,132,721.63

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 3.6M spat/ac)									
option 1 (25 acre site):									
oyster shell dredging	CY	40333.3333	$ 15.85	$ 639,283.33		$ -		$ -	
Mob/Demob	HR	22		$ -	$ 172.98	$ 3,805.56	$ 367.43	$ 8,083.46	
barge delivery	HR	128		$ -	$ 172.98	$ 22,141.44	$ 336.62	$ 43,087.36	
oyster placement	CY	40333.3333		$ -	$ 6.27	$ 252,890.00		$ -	
			MATERIAL SUBTOTAL	$ 639,283.33	***LABOR SUBTOTAL***	$ 278,837.00	***EQUIP SUBTOTAL***	$ 51,170.82	
			SALES TAX (MATERIALS) 5%	$ 31,964.17	***Labor Insurance 32%***	$ 89,227.84			
			SUBTOTALS	$ 671,247.50		$ 368,064.84		$ 51,170.82	
			TOTAL COST	$ 1,090,483.16					
			CONTIGENCY 20%	$ 218,096.63					
			OVERHEAD 10%	$ 109,048.32					
			PROFIT 8%	$ 113,410.25					
			TOTAL COST						$ 1,531,038
spat	EA	90000000	$ 0.010	$ 900,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	10		$ -	$ 172.98	$ 1,729.80	$ 151.41	$ 1,514.10	
spat planting	EA	10		$ -	$ 0.001	$ 0.01		$ -	
Turbidity control	LF	4200	$ 0.69	$ 2,898.00	$ 0.15	$ 630.00	$ 0.39	$ 1,638.00	
			MATERIAL SUBTOTAL	$ 902,898.00	***LABOR SUBTOTAL***	$ 3,916.63	***EQUIP SUBTOTAL***	$ 4,221.57	
			SALES TAX (MATERIALS) 5%	$ 45,144.90	***Labor Insurance 32%***	$ 1,253.32			
			SUBTOTALS	$ 948,042.90		$ 5,169.95		$ 4,221.57	
			TOTAL COST	$ 957,434.42					
			CONTIGENCY 20%	$ 191,486.88					
			OVERHEAD 10%	$ 95,743.44					
			PROFIT 8%	$ 99,573.18					
			TOTAL COST						$ 1,344,238

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
oyster shell dredging	CY	80666.6667	$ 15.85	$ 1,278,566.67		$ -		$ -	
Mob/Demob	HR	22		$ -	$ 172.98	$ 3,805.56	$ 367.43	$ 8,083.46	
barge delivery	HR	256		$ -	$ 172.98	$ 44,282.88	$ 336.62	$ 86,174.72	
oyster placement	CY	80666.6667		$ -	$ 6.27	$ 505,780.00		$ -	
			MATERIAL SUBTOTAL	$ 1,278,566.67	***LABOR SUBTOTAL***	$ 553,868.44	***EQUIP SUBTOTAL***	$ 94,258.18	
			SALES TAX (MATERIALS) 5%	$ 63,928.33	***Labor Insurance 32%***	$ 177,237.90			
			SUBTOTALS	$ 1,342,495.00		$ 731,106.34		$ 94,258.18	
			TOTAL COST	$ 2,167,859.52					
			CONTIGENCY 20%	$ 433,571.90					
			OVERHEAD 10%	$ 216,785.95					
			PROFIT 8%	$ 225,457.39					
			TOTAL COST						$ 3,043,675
spat	EA	180000000	$ 0.010	$ 1,800,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	10		$ -	$ 172.98	$ 1,729.80	$ 151.41	$ 1,514.10	
spat planting	EA	180000000		$ -	$ 0.001	$ 168,660.00		$ -	
Turbidity control	LF	5900	$ 0.69	$ 4,071.00	$ 0.15	$ 885.00	$ 0.39	$ 2,301.00	
			MATERIAL SUBTOTAL	$ 1,804,071.00	***LABOR SUBTOTAL***	$ 172,831.62	***EQUIP SUBTOTAL***	$ 4,884.57	
			SALES TAX (MATERIALS) 5%	$ 90,203.55	***Labor Insurance 32%***	$ 55,306.12			
			SUBTOTALS	$ 1,894,274.55		$ 228,137.74		$ 4,884.57	
			TOTAL COST	$ 2,127,296.86					
			CONTIGENCY 20%	$ 425,459.37					
			OVERHEAD 10%	$ 212,729.69					
			PROFIT 8%	$ 221,238.87					
			TOTAL COST						$ 2,986,725

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
oyster shell dredging	CY	161333.333	$ 15.85	$ 2,557,133.33		$ -		$ -	
Mob/Demob	HR	22		$ -	$ 172.98	$ 3,805.56	$ 367.43	$ 8,083.46	
barge delivery	HR	511		$ -	$ 172.98	$ 88,392.78	$ 336.62	$ 172,012.82	
oyster placement	CY	161333.333		$ -	$ 6.27	$ 1,011,560.00		$ -	
			MATERIAL SUBTOTAL	$ 2,557,133.33	***LABOR SUBTOTAL***	$ 1,103,758.34	***EQUIP SUBTOTAL***	$ 180,096.28	
			SALES TAX (MATERIALS) 5%	$ 127,856.67	***Labor Insurance 32%***	$ 353,202.67			
			SUBTOTALS	$ 2,684,990.00		$ 1,456,961.01		$ 180,096.28	
			TOTAL COST	$ 4,322,047.29					
			CONTIGENCY 20%	$ 864,409.46					
			OVERHEAD 10%	$ 432,204.73					
			PROFIT 8%	$ 449,492.92					
			TOTAL COST						$ 6,068,154
spat	EA	360000000	$ 0.010	$ 3,600,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	10		$ -	$ 172.98	$ 1,729.80	$ 151.41	$ 1,514.10	
spat planting	EA	360000000		$ -	$ 0.001	$ 337,320.00		$ -	
Turbidity control	LF	8350	$ 0.69	$ 5,761.50	$ 0.15	$ 1,252.50	$ 0.39	$ 3,256.50	
			MATERIAL SUBTOTAL	$ 3,605,761.50	***LABOR SUBTOTAL***	$ 341,859.12	***EQUIP SUBTOTAL***	$ 5,840.07	
			SALES TAX (MATERIALS) 5%	$ 180,288.08	***Labor Insurance 32%***	$ 109,394.92			
			SUBTOTALS	$ 3,786,049.58		$ 451,254.04		$ 5,840.07	
			TOTAL COST	$ 4,243,143.68					
			CONTIGENCY 20%	$ 848,628.74					
			OVERHEAD 10%	$ 424,314.37					
			PROFIT 8%	$ 441,286.94					
			TOTAL COST						$ 5,957,374

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 4.5M spat/ac)									
option 1 (25 acre site):									
oyster shell dredging	CY	40333.3333	$ 15.85	$ 639,283.33		$ -		$ -	
Mob/Demob	HR	22		$ -	$ 172.98	$ 3,805.56	$ 367.43	$ 8,083.46	
barge delivery	HR	128		$ -	$ 172.98	$ 22,141.44	$ 336.62	$ 43,087.36	
oyster placement	CY	40333.3333		$ -	$ 6.27	$ 252,890.00		$ -	
			MATERIAL SUBTOTAL	$ 639,283.33	***LABOR SUBTOTAL***	$ 278,837.00	***EQUIP SUBTOTAL***	$ 51,170.82	
			SALES TAX (MATERIALS) 5%	$ 31,964.17	***Labor Insurance 32%***	$ 89,227.84			
			SUBTOTALS	$ 671,247.50		$ 368,064.84		$ 51,170.82	
			TOTAL COST	$ 1,090,483.16					
			CONTIGENCY 20%	$ 218,096.63					
			OVERHEAD 10%	$ 109,048.32					
			PROFIT 8%	$ 113,410.25					
			TOTAL COST						$ 1,531,038
spat	EA	112500000	$ 0.010	$ 1,125,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	10		$ -	$ 172.98	$ 1,729.80	$ 151.41	$ 1,514.10	
spat planting	EA	112500000		$ -	$ 0.001	$ 105,412.50		$ -	
Turbidity control	LF	4200	$ 0.69	$ 2,898.00	$ 0.15	$ 630.00	$ 0.39	$ 1,638.00	
			MATERIAL SUBTOTAL	$ 1,127,898.00	***LABOR SUBTOTAL***	$ 109,329.12	***EQUIP SUBTOTAL***	$ 4,221.57	
			SALES TAX (MATERIALS) 5%	$ 56,394.90	***Labor Insurance 32%***	$ 34,985.32			
			SUBTOTALS	$ 1,184,292.90		$ 144,314.44		$ 4,221.57	
			TOTAL COST	$ 1,332,828.91					
			CONTIGENCY 20%	$ 266,565.78					
			OVERHEAD 10%	$ 133,282.89					
			PROFIT 8%	$ 138,614.21					
			TOTAL COST						$ 1,871,292

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
oyster shell dredging	CY	80666.6667	$ 15.85	$ 1,278,566.67		$ -		$ -	
Mob/Demob	HR	22		$ -	$ 172.98	$ 3,805.56	$ 367.43	$ 8,083.46	
barge delivery	HR	256		$ -	$ 172.98	$ 44,282.88	$ 336.62	$ 86,174.72	
oyster placement	CY	80666.6667		$ -	$ 6.27	$ 505,780.00		$ -	
			MATERIAL SUBTOTAL	$ 1,278,566.67	***LABOR SUBTOTAL***	$ 553,868.44	***EQUIP SUBTOTAL***	$ 94,258.18	
			SALES TAX (MATERIALS) 5%	$ 63,928.33	***Labor Insurance 32%***	$ 177,237.90			
			SUBTOTALS	$ 1,342,495.00		$ 731,106.34		$ 94,258.18	
			TOTAL COST	$ 2,167,859.52					
			CONTIGENCY 20%	$ 433,571.90					
			OVERHEAD 10%	$ 216,785.95					
			PROFIT 8%	$ 225,457.39					
			TOTAL COST						$ 3,043,675
spat	EA	225000000	$ 0.010	$ 2,250,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	10		$ -	$ 172.98	$ 1,729.80	$ 151.41	$ 1,514.10	
spat planting	EA	225000000		$ -	$ 0.001	$ 210,825.00		$ -	
Turbidity control	LF	5900	$ 0.69	$ 4,071.00	$ 0.15	$ 885.00	$ 0.39	$ 2,301.00	
			MATERIAL SUBTOTAL	$ 2,254,071.00	***LABOR SUBTOTAL***	$ 214,996.62	***EQUIP SUBTOTAL***	$ 4,884.57	
			SALES TAX (MATERIALS) 5%	$ 112,703.55	***Labor Insurance 32%***	$ 68,798.92			
			SUBTOTALS	$ 2,366,774.55		$ 283,795.54		$ 4,884.57	
			TOTAL COST	$ 2,655,454.66					
			CONTIGENCY 20%	$ 531,090.93					
			OVERHEAD 10%	$ 265,545.47					
			PROFIT 8%	$ 276,167.28					
			TOTAL COST						$ 3,728,258

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
oyster shell dredging	CY	161333.333	$ 15.85	$ 2,557,133.33		$ -		$ -	
Mob/Demob	HR	22		$ -	$ 172.98	$ 3,805.56	$ 367.43	$ 8,083.46	
barge delivery	HR	511		$ -	$ 172.98	$ 88,392.78	$ 336.62	$ 172,012.82	
oyster placement	CY	161333.333		$ -	$ 6.27	$ 1,011,560.00		$ -	
			MATERIAL SUBTOTAL	$ 2,557,133.33	***LABOR SUBTOTAL***	$ 1,103,758.34	***EQUIP SUBTOTAL***	$ 180,096.28	
			SALES TAX (MATERIALS) 5%	$ 127,856.67	***Labor Insurance 32%***	$ 353,202.67			
			SUBTOTALS	$ 2,684,990.00		$ 1,456,961.01		$ 180,096.28	
			TOTAL COST	$ 4,322,047.29					
			CONTIGENCY 20%	$ 864,409.46					
			OVERHEAD 10%	$ 432,204.73					
			PROFIT 8%	$ 449,492.92					
			TOTAL COST						$ 6,068,154
spat	EA	450000000	$ 0.010	$ 4,500,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	10		$ -	$ 172.98	$ 1,729.80	$ 151.41	$ 1,514.10	
spat planting	EA	450000000		$ -	$ 0.001	$ 421,650.00		$ -	
Turbidity control	LF	8350	$ 0.69	$ 5,761.50	$ 0.15	$ 1,252.50	$ 0.39	$ 3,256.50	
			MATERIAL SUBTOTAL	$ 4,505,761.50	***LABOR SUBTOTAL***	$ 426,189.12	***EQUIP SUBTOTAL***	$ 5,840.07	
			SALES TAX (MATERIALS) 5%	$ 225,288.08	***Labor Insurance 32%***	$ 136,380.52			
			SUBTOTALS	$ 4,731,049.58		$ 562,569.64		$ 5,840.07	
			TOTAL COST	$ 5,299,459.28					
			CONTIGENCY 20%	$ 1,059,891.86					
			OVERHEAD 10%	$ 529,945.93					
			PROFIT 8%	$ 551,143.77					
			TOTAL COST						$ 7,440,441

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 6.75M spat/ac)									
option 1 (25 acre site):									
oyster shell dredging	CY	40333.3333	$ 15.85	$ 639,283.33		$ -		$ -	
Mob/Demob	HR	22		$ -	$ 172.98	$ 3,805.56	$ 367.43	$ 8,083.46	
barge delivery	HR	128		$ -	$ 172.98	$ 22,141.44	$ 336.62	$ 43,087.36	
oyster placement	CY	40333.3333		$ -	$ 6.27	$ 252,890.00		$ -	
			MATERIAL SUBTOTAL	$ 639,283.33	***LABOR SUBTOTAL***	$ 278,837.00	***EQUIP SUBTOTAL***	$ 51,170.82	
			SALES TAX (MATERIALS) 5%	$ 31,964.17	***Labor Insurance 32%***	$ 89,227.84			
			SUBTOTALS	$ 671,247.50		$ 368,064.84		$ 51,170.82	
			TOTAL COST	$ 1,090,483.16					
			CONTIGENCY 20%	$ 218,096.63					
			OVERHEAD 10%	$ 109,048.32					
			PROFIT 8%	$ 113,410.25					
			TOTAL COST						$ 1,531,038
spat	EA	168750000	$ 0.010	$ 1,687,500.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	10		$ -	$ 172.98	$ 1,729.80	$ 151.41	$ 1,514.10	
spat planting	EA	168750000		$ -	$ 0.001	$ 158,118.75		$ -	
Turbidity control	LF	4200	$ 0.69	$ 2,898.00	$ 0.15	$ 630.00	$ 0.39	$ 1,638.00	
			MATERIAL SUBTOTAL	$ 1,690,398.00	***LABOR SUBTOTAL***	$ 162,035.37	***EQUIP SUBTOTAL***	$ 4,221.57	
			SALES TAX (MATERIALS) 5%	$ 84,519.90	***Labor Insurance 32%***	$ 51,851.32			
			SUBTOTALS	$ 1,774,917.90		$ 213,886.69		$ 4,221.57	
			TOTAL COST	$ 1,993,026.16					
			CONTIGENCY 20%	$ 398,605.23					
			OVERHEAD 10%	$ 199,302.62					
			PROFIT 8%	$ 207,274.72					
			TOTAL COST						$ 2,798,209

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
oyster shell dredging	CY	80666.6667	$ 15.85	$ 1,278,566.67		$ -		$ -	
Mob/Demob	HR	22		$ -	$ 172.98	$ 3,805.56	$ 367.43	$ 8,083.46	
barge delivery	HR	256		$ -	$ 172.98	$ 44,282.88	$ 336.62	$ 86,174.72	
oyster placement	CY	80666.6667		$ -	$ 6.27	$ 505,780.00		$ -	
			MATERIAL SUBTOTAL	$ 1,278,566.67	***LABOR SUBTOTAL***	$ 553,868.44	***EQUIP SUBTOTAL***	$ 94,258.18	
			SALES TAX (MATERIALS) 5%	$ 63,928.33	***Labor Insurance 32%***	$ 177,237.90			
			SUBTOTALS	$ 1,342,495.00		$ 731,106.34		$ 94,258.18	
			TOTAL COST	$ 2,167,859.52					
			CONTIGENCY 20%	$ 433,571.90					
			OVERHEAD 10%	$ 216,785.95					
			PROFIT 8%	$ 225,457.39					
			TOTAL COST						$ 3,043,675
spat	EA	337500000	$ 0.010	$ 3,375,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	10		$ -	$ 172.98	$ 1,729.80	$ 151.41	$ 1,514.10	
spat planting	EA	337500000		$ -	$ 0.001	$ 316,237.50		$ -	
Turbidity control	LF	5900	$ 0.69	$ 4,071.00	$ 0.15	$ 885.00	$ 0.39	$ 2,301.00	
			MATERIAL SUBTOTAL	$ 3,379,071.00	***LABOR SUBTOTAL***	$ 320,409.12	***EQUIP SUBTOTAL***	$ 4,884.57	
			(MATERIALS) 5%	$ 168,953.55	***Insurance 32%***	$ 102,530.92			
			SUBTOTALS	$ 3,548,024.55		$ 422,940.04		$ 4,884.57	
			TOTAL COST	$ 3,975,849.16					
			CONTIGENCY 20%	$ 795,169.83					
			OVERHEAD 10%	$ 397,584.92					
			PROFIT 8%	$ 413,488.31					
			TOTAL COST						$ 5,582,092

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
oyster shell dredging	CY	161333.333	$ 15.85	$ 2,557,133.33		$ -		$ -	
Mob/Demob	HR	22		$ -	$ 172.98	$ 3,805.56	$ 367.43	$ 8,083.46	
barge delivery	HR	511		$ -	$ 172.98	$ 88,392.78	$ 336.62	$ 172,012.82	
oyster placement	CY	161333.333		$ -	$ 6.27	$ 1,011,560.00		$ -	
			MATERIAL SUBTOTAL	$ 2,557,133.33	***LABOR SUBTOTAL***	$ 1,103,758.34	***EQUIP SUBTOTAL***	$ 180,096.28	
			SALES TAX (MATERIALS) 5%	$ 127,856.67	***Labor Insurance 32%***	$ 353,202.67			
			SUBTOTALS	$ 2,684,990.00		$ 1,456,961.01		$ 180,096.28	
			TOTAL COST	$ 4,322,047.29					
			CONTIGENCY 20%	$ 864,409.46					
			OVERHEAD 10%	$ 432,204.73					
			PROFIT 8%	$ 449,492.92					
			TOTAL COST						$ 6,068,154
spat	EA	675000000	$ 0.010	$ 6,750,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	10		$ -	$ 172.98	$ 1,729.80	$ 151.41	$ 1,514.10	
spat planting	EA	675000000		$ -	$ 0.001	$ 632,475.00		$ -	
Turbidity control	LF	8350	$ 0.69	$ 5,761.50	$ 0.15	$ 1,252.50	$ 0.39	$ 3,256.50	
			MATERIAL SUBTOTAL	$ 6,755,761.50	***LABOR SUBTOTAL***	$ 637,014.12	***EQUIP SUBTOTAL***	$ 5,840.07	
			SALES TAX (MATERIALS) 5%	$ 337,788.08	***Labor Insurance 32%***	$ 203,844.52			
			SUBTOTALS	$ 7,093,549.58		$ 840,858.64		$ 5,840.07	
			TOTAL COST	$ 7,940,248.28					
			CONTIGENCY 20%	$ 1,588,049.66					
			OVERHEAD 10%	$ 794,024.83					
			PROFIT 8%	$ 825,785.82					
			TOTAL COST						$ 11,148,109

Broad Creek

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 3.6M spat/ac)									
option 1 (25 acre site):									
limestone	CY	40333.333	$ 47.50	$ 1,915,833.33		$ -		$ -	
Mob/Demob	HR	22		$ -	$ 172.98	$ 3,805.56	$ 367.43	$ 8,083.46	
barge delivery	HR	464		$ -	$ 172.98	$ 80,262.72	$ 336.62	$ 156,191.68	
limestone placement	CY	40333.333		$ -	$ 1.16	$ 46,786.67	$ 2.09	$ 84,296.67	
			MATERIAL SUBTOTAL	$ 1,915,833.33	***LABOR SUBTOTAL***	$ 130,854.95	***EQUIP SUBTOTAL***	$ 248,571.81	
			SALES TAX (MATERIALS) 5%	$ 95,791.67	***Labor Insurance 32%***	$ 41,873.58			
			SUBTOTALS	$ 2,011,625.00		$ 172,728.53		$ 248,571.81	
			TOTAL COST	$ 2,432,925.34					
			CONTIGENCY 20%	$ 486,585.07					
			OVERHEAD 10%	$ 243,292.53					
			PROFIT 8%	$ 253,024.23					
			TOTAL COST						$ 3,415,827
spat	EA	90000000	$ 0.010	$ 900,000.00		$ -		$ -	
Mob/Demob	HR	13			$ 172.98	$ 2,248.74	$ 118.83	$ 1,544.79	
barge delivery	HR	3		$ -	$ 172.98	$ 518.94	$ 151.41	$ 454.23	
spat planting	EA	90000000		$ -	$ 0.001	$ 84,330.00		$ -	
			MATERIAL SUBTOTAL	$ 900,000.00	***LABOR SUBTOTAL***	$ 87,097.68	***EQUIP SUBTOTAL***	$ 1,999.02	
			SALES TAX (MATERIALS) 5%	$ 45,000.00	***Labor Insurance 32%***	$ 27,871.26			
			SUBTOTALS	$ 945,000.00		$ 114,968.94		$ 1,999.02	
			TOTAL COST	$ 1,061,967.96					
			CONTIGENCY 20%	$ 212,393.59					
			OVERHEAD 10%	$ 106,196.80					
			PROFIT 8%	$ 110,444.67					
			TOTAL COST						$ 1,491,003

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
limestone	CY	80666.667	$ 47.50	$ 3,831,666.67		$ -		$ -	
Mob/Demob	HR	22		$ -	$ 172.98	$ 3,805.56	$ 367.43	$ 8,083.46	
barge delivery	HR	928		$ -	$ 172.98	$ 160,525.44	$ 336.62	$ 312,383.36	
limestone placement	CY	80666.667		$ -	$ 1.16	$ 93,573.33	$ 2.09	$ 168,593.33	
			MATERIAL SUBTOTAL	$ 3,831,666.67	***LABOR SUBTOTAL***	$ 257,904.33	***EQUIP SUBTOTAL***	$ 489,060.15	
			SALES TAX (MATERIALS) 5%	$ 191,583.33	***Labor Insurance 32%***	$ 82,529.39			
			SUBTOTALS	$ 4,023,250.00		$ 340,433.72		$ 489,060.15	
			TOTAL COST	$ 4,852,743.87					
			CONTIGENCY 20%	$ 970,548.77					
			OVERHEAD 10%	$ 485,274.39					
			PROFIT 8%	$ 504,685.36					
			TOTAL COST						$ 6,813,252
spat	EA	180000000	$ 0.010	$ 1,800,000.00		$ -		$ -	
Mob/Demob	HR	13			$ 172.98	$ 2,248.74	$ 118.83	$ 1,544.79	
barge delivery	HR	3		$ -	$ 172.98	$ 518.94	$ 151.41	$ 454.23	
spat planting	EA	180000000		$ -	$ 0.001	$ 168,660.00		$ -	
			MATERIAL SUBTOTAL	$ 1,800,000.00	***LABOR SUBTOTAL***	$ 171,427.68	***EQUIP SUBTOTAL***	$ 1,999.02	
			SALES TAX (MATERIALS) 5%	$ 90,000.00	***Labor Insurance 32%***	$ 54,856.86			
			SUBTOTALS	$ 1,890,000.00		$ 226,284.54		$ 1,999.02	
			TOTAL COST	$ 2,118,283.56					
			CONTIGENCY 20%	$ 423,656.71					
			OVERHEAD 10%	$ 211,828.36					
			PROFIT 8%	$ 220,301.49					
			TOTAL COST						$ 2,974,070

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
limestone	CY	161333.33	$ 47.50	$ 7,663,333.33		$ -		$ -	
Mob/Demob	HR	22		$ -	$ 172.98	$ 3,805.56	$ 367.43	$ 8,083.46	
barge delivery	HR	1856		$ -	$ 172.98	$ 321,050.88	$ 336.62	$ 624,766.72	
limestone placement	CY	161333.33		$ -	$ 1.16	$ 187,146.67	$ 2.09	$ 337,186.67	
			MATERIAL SUBTOTAL	$ 7,663,333.33	***LABOR SUBTOTAL***	$ 512,003.11	***EQUIP SUBTOTAL***	$ 970,036.85	
			SALES TAX (MATERIALS) 5%	$ 383,166.67	***Labor Insurance 32%***	$ 163,840.99			
			SUBTOTALS	$ 8,046,500.00		$ 675,844.10		$ 970,036.85	
			TOTAL COST	$ 9,692,380.95					
			CONTIGENCY 20%	$ 1,938,476.19					
			OVERHEAD 10%	$ 969,238.09					
			PROFIT 8%	$ 1,008,007.62					
			TOTAL COST						$ 13,608,103
spat	EA	360000000	$ 0.010	$ 3,600,000.00		$ -		$ -	
Mob/Demob	HR	13			$ 172.98	$ 2,248.74	$ 118.83	$ 1,544.79	
barge delivery	HR	3		$ -	$ 172.98	$ 518.94	$ 151.41	$ 454.23	
spat planting	EA	360000000		$ -	$ 0.001	$ 337,320.00		$ -	
			MATERIAL SUBTOTAL	$ 3,600,000.00	***LABOR SUBTOTAL***	$ 340,087.68	***EQUIP SUBTOTAL***	$ 1,999.02	
			SALES TAX (MATERIALS) 5%	$ 180,000.00	***Labor Insurance 32%***	$ 108,828.06			
			SUBTOTALS	$ 3,780,000.00		$ 448,915.74		$ 1,999.02	
			TOTAL COST	$ 4,230,914.76					
			CONTIGENCY 20%	$ 846,182.95					
			OVERHEAD 10%	$ 423,091.48					
			PROFIT 8%	$ 440,015.13					
			TOTAL COST						$ 5,940,204

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 4.5M spat/ac)									
option 1 (25 acre site):									
limestone	CY	40333.333	$ 47.50	$ 1,915,833.33		$ -		$ -	
Mob/Demob	HR	22		$ -	$ 172.98	$ 3,805.56	$ 367.43	$ 8,083.46	
barge delivery	HR	464		$ -	$ 172.98	$ 80,262.72	$ 336.62	$ 156,191.68	
limestone placement	CY	40333.333		$ -	$ 1.16	$ 46,786.67	$ 2.09	$ 84,296.67	
			MATERIAL SUBTOTAL	$ 1,915,833.33	***LABOR SUBTOTAL***	$ 130,854.95	***EQUIP SUBTOTAL***	$ 248,571.81	
			SALES TAX (MATERIALS) 5%	$ 95,791.67	***Labor Insurance 32%***	$ 41,873.58			
			SUBTOTALS	$ 2,011,625.00		$ 172,728.53		$ 248,571.81	
			TOTAL COST	$ 2,432,925.34					
			CONTIGENCY 20%	$ 486,585.07					
			OVERHEAD 10%	$ 243,292.53					
			PROFIT 8%	$ 253,024.23					
			TOTAL COST						$ 3,415,827
spat	EA	112500000	$ 0.010	$ 1,125,000.00		$ -		$ -	
Mob/Demob	HR	13			$ 172.98	$ 2,248.74	$ 118.83	$ 1,544.79	
barge delivery	HR	3		$ -	$ 172.98	$ 518.94	$ 151.41	$ 454.23	
spat planting	EA	112500000		$ -	$ 0.001	$ 105,412.50		$ -	
			MATERIAL SUBTOTAL	$ 1,125,000.00	***LABOR SUBTOTAL***	$ 108,180.18	***EQUIP SUBTOTAL***	$ 1,999.02	
			SALES TAX (MATERIALS) 5%	$ 56,250.00	***Labor Insurance 32%***	$ 34,617.66			
			SUBTOTALS	$ 1,181,250.00		$ 142,797.84		$ 1,999.02	
			TOTAL COST	$ 1,326,046.86					
			CONTIGENCY 20%	$ 265,209.37					
			OVERHEAD 10%	$ 132,604.69					
			PROFIT 8%	$ 137,908.87					
			TOTAL COST						$ 1,861,770

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
limestone	CY	80666.667	$ 47.50	$ 3,831,666.67		$ -		$ -	
Mob/Demob	HR	22		$ -	$ 172.98	$ 3,805.56	$ 367.43	$ 8,083.46	
barge delivery	HR	928		$ -	$ 172.98	$ 160,525.44	$ 336.62	$ 312,383.36	
limestone placement	CY	80666.667		$ -	$ 1.16	$ 93,573.33	$ 2.09	$ 168,593.33	
			MATERIAL SUBTOTAL	$ 3,831,666.67	***LABOR SUBTOTAL***	$ 257,904.33	***EQUIP SUBTOTAL***	$ 489,060.15	
			SALES TAX (MATERIALS) 5%	$ 191,583.33	***Labor Insurance 32%***	$ 82,529.39			
			SUBTOTALS	$ 4,023,250.00		$ 340,433.72		$ 489,060.15	
			TOTAL COST	$ 4,852,743.87					
			CONTIGENCY 20%	$ 970,548.77					
			OVERHEAD 10%	$ 485,274.39					
			PROFIT 8%	$ 504,685.36					
			TOTAL COST						$ 6,813,252
spat	EA	225000000	$ 0.010	$ 2,250,000.00		$ -		$ -	
Mob/Demob	HR	13			$ 172.98	$ 2,248.74	$ 118.83	$ 1,544.79	
barge delivery	HR	3		$ -	$ 172.98	$ 518.94	$ 151.41	$ 454.23	
spat planting	EA	225000000		$ -	$ 0.001	$ 210,825.00		$ -	
			MATERIAL SUBTOTAL	$ 2,250,000.00	***LABOR SUBTOTAL***	$ 213,592.68	***EQUIP SUBTOTAL***	$ 1,999.02	
			SALES TAX (MATERIALS) 5%	$ 112,500.00	***Labor Insurance 32%***	$ 68,349.66			
			SUBTOTALS	$ 2,362,500.00		$ 281,942.34		$ 1,999.02	
			TOTAL COST	$ 2,646,441.36					
			CONTIGENCY 20%	$ 529,288.27					
			OVERHEAD 10%	$ 264,644.14					
			PROFIT 8%	$ 275,229.90					
			TOTAL COST						$ 3,715,604

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
limestone	CY	161333.33	$ 47.50	$ 7,663,333.33		$ -		$ -	
Mob/Demob	HR	22		$ -	$ 172.98	$ 3,805.56	$ 367.43	$ 8,083.46	
barge delivery	HR	1856		$ -	$ 172.98	$ 321,050.88	$ 336.62	$ 624,766.72	
limestone placement	CY	161333.33		$ -	$ 1.16	$ 187,146.67	$ 2.09	$ 337,186.67	
			MATERIAL SUBTOTAL	$ 7,663,333.33	***LABOR SUBTOTAL***	$ 512,003.11	***EQUIP SUBTOTAL***	$ 970,036.85	
			SALES TAX (MATERIALS) 5%	$ 383,166.67	***Labor Insurance 32%***	$ 163,840.99			
			SUBTOTALS	$ 8,046,500.00		$ 675,844.10		$ 970,036.85	
			TOTAL COST	$ 9,692,380.95					
			CONTIGENCY 20%	$ 1,938,476.19					
			OVERHEAD 10%	$ 969,238.09					
			PROFIT 8%	$ 1,008,007.62					
			TOTAL COST						$ 13,608,103
spat	EA	450000000	$ 0.010	$ 4,500,000.00		$ -		$ -	
Mob/Demob	HR	13			$ 172.98	$ 2,248.74	$ 118.83	$ 1,544.79	
barge delivery	HR	3		$ -	$ 172.98	$ 518.94	$ 151.41	$ 454.23	
spat planting	EA	450000000		$ -	$ 0.001	$ 421,650.00		$ -	
			MATERIAL SUBTOTAL	$ 4,500,000.00	***LABOR SUBTOTAL***	$ 424,417.68	***EQUIP SUBTOTAL***	$ 1,999.02	
			SALES TAX (MATERIALS) 5%	$ 225,000.00	***Labor Insurance 32%***	$ 135,813.66			
			SUBTOTALS	$ 4,725,000.00		$ 560,231.34		$ 1,999.02	
			TOTAL COST	$ 5,287,230.36					
			CONTIGENCY 20%	$ 1,057,446.07					
			OVERHEAD 10%	$ 528,723.04					
			PROFIT 8%	$ 549,871.96					
			TOTAL COST						$ 7,423,271

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 6.75M spat/ac)									
option 1 (25 acre site):									
limestone	CY	40333.333	$ 47.50	$ 1,915,833.33		$ -		$ -	
Mob/Demob	HR	22		$ -	$ 172.98	$ 3,805.56	$ 367.43	$ 8,083.46	
barge delivery	HR	464		$ -	$ 172.98	$ 80,262.72	$ 336.62	$ 156,191.68	
limestone placement	CY	40333.333		$ -	$ 1.16	$ 46,786.67	$ 2.09	$ 84,296.67	
			MATERIAL SUBTOTAL	$ 1,915,833.33	***LABOR SUBTOTAL***	$ 130,854.95	***EQUIP SUBTOTAL***	$ 248,571.81	
			SALES TAX (MATERIALS) 5%	$ 95,791.67	***Labor Insurance 32%***	$ 41,873.58			
			SUBTOTALS	$ 2,011,625.00		$ 172,728.53		$ 248,571.81	
			TOTAL COST	$ 2,432,925.34					
			CONTIGENCY 20%	$ 486,585.07					
			OVERHEAD 10%	$ 243,292.53					
			PROFIT 8%	$ 253,024.23					
			TOTAL COST						$ 3,415,827
spat	EA	168750000	$ 0.010	$ 1,687,500.00		$ -		$ -	
Mob/Demob	HR	13			$ 172.98	$ 2,248.74	$ 118.83	$ 1,544.79	
barge delivery	HR	3		$ -	$ 172.98	$ 518.94	$ 151.41	$ 454.23	
spat planting	EA	168750000		$ -	$ 0.001	$ 158,118.75		$ -	
			MATERIAL SUBTOTAL	$ 1,687,500.00	***LABOR SUBTOTAL***	$ 160,886.43	***EQUIP SUBTOTAL***	$ 1,999.02	
			SALES TAX (MATERIALS) 5%	$ 84,375.00	***Labor Insurance 32%***	$ 51,483.66			
			SUBTOTALS	$ 1,771,875.00		$ 212,370.09		$ 1,999.02	
			TOTAL COST	$ 1,986,244.11					
			CONTIGENCY 20%	$ 397,248.82					
			OVERHEAD 10%	$ 198,624.41					
			PROFIT 8%	$ 206,569.39					
			TOTAL COST						$ 2,788,687

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
limestone	CY	80666.667	$ 47.50	$ 3,831,666.67		$ -		$ -	
Mob/Demob	HR	22		$ -	$ 172.98	$ 3,805.56	$ 367.43	$ 8,083.46	
barge delivery	HR	928		$ -	$ 172.98	$ 160,525.44	$ 336.62	$ 312,383.36	
limestone placement	CY	80666.667		$ -	$ 1.16	$ 93,573.33	$ 2.09	$ 168,593.33	
			MATERIAL SUBTOTAL	$ 3,831,666.67	***LABOR SUBTOTAL***	$ 257,904.33	***EQUIP SUBTOTAL***	$ 489,060.15	
			SALES TAX (MATERIALS) 5%	$ 191,583.33	***Labor Insurance 32%***	$ 82,529.39			
			SUBTOTALS	$ 4,023,250.00		$ 340,433.72		$ 489,060.15	
			TOTAL COST	$ 4,852,743.87					
			CONTIGENCY 20%	$ 970,548.77					
			OVERHEAD 10%	$ 485,274.39					
			PROFIT 8%	$ 504,685.36					
			TOTAL COST						$ 6,813,252
spat	EA	337500000	$ 0.010	$ 3,375,000.00		$ -		$ -	
Mob/Demob	HR	13			$ 172.98	$ 2,248.74	$ 118.83	$ 1,544.79	
barge delivery	HR	3		$ -	$ 172.98	$ 518.94	$ 151.41	$ 454.23	
spat planting	EA	337500000		$ -	$ 0.001	$ 316,237.50		$ -	
			MATERIAL SUBTOTAL	$ 3,375,000.00	***LABOR SUBTOTAL***	$ 319,005.18	***EQUIP SUBTOTAL***	$ 1,999.02	
			SALES TAX (MATERIALS) 5%	$ 168,750.00	***Labor Insurance 32%***	$ 102,081.66			
			SUBTOTALS	$ 3,543,750.00		$ 421,086.84		$ 1,999.02	
			TOTAL COST	$ 3,966,835.86					
			CONTIGENCY 20%	$ 793,367.17					
			OVERHEAD 10%	$ 396,683.59					
			PROFIT 8%	$ 412,550.93					
			TOTAL COST						$ 5,569,438

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
limestone	CY	161333.33	$ 47.50	$ 7,663,333.33		$ -		$ -	
Mob/Demob	HR	22		$ -	$ 172.98	$ 3,805.56	$ 367.43	$ 8,083.46	
barge delivery	HR	1856		$ -	$ 172.98	$ 321,050.88	$ 336.62	$ 624,766.72	
limestone placement	CY	161333.33		$ -	$ 1.16	$ 187,146.67	$ 2.09	$ 337,186.67	
			MATERIAL SUBTOTAL	$ 7,663,333.33	***LABOR SUBTOTAL***	$ 512,003.11	***EQUIP SUBTOTAL***	$ 970,036.85	
			SALES TAX (MATERIALS) 5%	$ 383,166.67	***Labor Insurance 32%***	$ 163,840.99			
			SUBTOTALS	$ 8,046,500.00		$ 675,844.10		$ 970,036.85	
			TOTAL COST	$ 9,692,380.95					
			CONTIGENCY 20%	$ 1,938,476.19					
			OVERHEAD 10%	$ 969,238.09					
			PROFIT 8%	$ 1,008,007.62					
			TOTAL COST						$ 13,608,103
spat	EA	675000000	$ 0.010	$ 6,750,000.00		$ -		$ -	
Mob/Demob	HR	13			$ 172.98	$ 2,248.74	$ 118.83	$ 1,544.79	
barge delivery	HR	3		$ -	$ 172.98	$ 518.94	$ 151.41	$ 454.23	
spat planting	EA	675000000		$ -	$ 0.001	$ 632,475.00		$ -	
		22	***MATERIAL SUBTOTAL***	$ 6,750,000.00	***LABOR SUBTOTAL***	$ 635,242.68	***EQUIP SUBTOTAL***	$ 1,999.02	
			SALES TAX (MATERIALS) 5%	$ 337,500.00	***Labor Insurance 32%***	$ 203,277.66			
			SUBTOTALS	$ 7,087,500.00		$ 838,520.34		$ 1,999.02	
			TOTAL COST	$ 7,928,019.36					
			CONTIGENCY 20%	$ 1,585,603.87					
			OVERHEAD 10%	$ 792,801.94					
			PROFIT 8%	$ 824,514.01					
			TOTAL COST						$ 11,130,939

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 3.6M spat/ac)									
option 1 (25 acre site):									
granite	CY	40333.3333	$ 48.00	$ 1,936,000.00		$ -		$ -	
Mob/Demob	HR	22		$ -	$ 172.98	$ 3,805.56	$ 367.43	$ 8,083.46	
barge delivery	HR	314		$ -	$ 172.98	$ 54,315.72	$ 336.62	$ 105,698.68	
granite placement	CY	40333.3333		$ -	$ 1.16	$ 46,786.67	$ 2.09	$ 84,296.67	
			MATERIAL SUBTOTAL	$ 1,936,000.00	***LABOR SUBTOTAL***	$ 104,907.95	***EQUIP SUBTOTAL***	$ 198,078.81	
			SALES TAX (MATERIALS) 5%	$ 96,800.00	***Labor Insurance 32%***	$ 33,570.54			
			SUBTOTALS	$ 2,032,800.00		$ 138,478.49		$ 198,078.81	
			TOTAL COST	$ 2,369,357.30					
			CONTIGENCY 20%	$ 473,871.46					
			OVERHEAD 10%	$ 236,935.73					
			PROFIT 8%	$ 246,413.16					
			TOTAL COST						$ 3,326,578
spat	EA	90000000	$ 0.010	$ 900,000.00		$ -		$ -	
Mob/Demob	HR	13			$ 172.98	$ 2,248.74	$ 118.83	$ 1,544.79	
barge delivery	HR	3		$ -	$ 172.98	$ 518.94	$ 151.41	$ 454.23	
spat planting	EA	90000000		$ -	$ 0.001	$ 84,330.00		$ -	
			MATERIAL SUBTOTAL	$ 900,000.00	***LABOR SUBTOTAL***	$ 87,097.68	***EQUIP SUBTOTAL***	$ 1,999.02	
			SALES TAX (MATERIALS) 5%	$ 45,000.00	***Labor Insurance 32%***	$ 27,871.26			
			SUBTOTALS	$ 945,000.00		$ 114,968.94		$ 1,999.02	
			TOTAL COST	$ 1,061,967.96					
			CONTIGENCY 20%	$ 212,393.59					
			OVERHEAD 10%	$ 106,196.80					
			PROFIT 8%	$ 110,444.67					
			TOTAL COST						$ 1,491,003

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
granite	CY	80666.6667	$ 48.00	$ 3,872,000.00		$ -		$ -	
Mob/Demob	HR	22		$ -	$ 172.98	$ 3,805.56	$ 367.43	$ 8,083.46	
barge delivery	HR	627		$ -	$ 172.98	$ 108,458.46	$ 336.62	$ 211,060.74	
granite placement	CY	80666.6667		$ -	$ 1.16	$ 93,573.33	$ 2.09	$ 168,593.33	
			MATERIAL SUBTOTAL	$ 3,872,000.00	***LABOR SUBTOTAL***	$ 205,837.35	***EQUIP SUBTOTAL***	$ 387,737.53	
			SALES TAX (MATERIALS) 5%	$ 193,600.00	***Labor Insurance 32%***	$ 65,867.95			
			SUBTOTALS	$ 4,065,600.00		$ 271,705.31		$ 387,737.53	
			TOTAL COST	$ 4,725,042.84					
			CONTIGENCY 20%	$ 945,008.57					
			OVERHEAD 10%	$ 472,504.28					
			PROFIT 8%	$ 491,404.46					
			TOTAL COST						$ 6,633,960
spat	EA	180000000	$ 0.010	$ 1,800,000.00		$ -		$ -	
Mob/Demob	HR	13			$ 172.98	$ 2,248.74	$ 118.83	$ 1,544.79	
barge delivery	HR	3		$ -	$ 172.98	$ 518.94	$ 151.41	$ 454.23	
spat planting	EA	180000000		$ -	$ 0.001	$ 168,660.00		$ -	
			MATERIAL SUBTOTAL	$ 1,800,000.00	***LABOR SUBTOTAL***	$ 171,427.68	***EQUIP SUBTOTAL***	$ 1,999.02	
			SALES TAX (MATERIALS) 5%	$ 90,000.00	***Labor Insurance 32%***	$ 54,856.86			
			SUBTOTALS	$ 1,890,000.00		$ 226,284.54		$ 1,999.02	
			TOTAL COST	$ 2,118,283.56					
			CONTIGENCY 20%	$ 423,656.71					
			OVERHEAD 10%	$ 211,828.36					
			PROFIT 8%	$ 220,301.49					
			TOTAL COST						$ 2,974,070

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
granite	CY	161333.333	$ 48.00	$ 7,744,000.00		$ -		$ -	
Mob/Demob	HR	22		$ -	$ 172.98	$ 3,805.56	$ 367.43	$ 8,083.46	
barge delivery	HR	1254		$ -	$ 172.98	$ 216,916.92	$ 336.62	$ 422,121.48	
granite placement	CY	161333.333		$ -	$ 1.16	$ 187,146.67	$ 2.09	$ 337,186.67	
			MATERIAL SUBTOTAL	$ 7,744,000.00	***LABOR SUBTOTAL***	$ 407,869.15	***EQUIP SUBTOTAL***	$ 767,391.61	
			SALES TAX (MATERIALS) 5%	$ 387,200.00	***Labor Insurance 32%***	$ 130,518.13			
			SUBTOTALS	$ 8,131,200.00		$ 538,387.27		$ 767,391.61	
			TOTAL COST	$ 9,436,978.88					
			CONTIGENCY 20%	$ 1,887,395.78					
			OVERHEAD 10%	$ 943,697.89					
			PROFIT 8%	$ 981,445.80					
			TOTAL COST						$ 13,249,518
spat	EA	360000000	$ 0.010	$ 3,600,000.00		$ -		$ -	
Mob/Demob	HR	13			$ 172.98	$ 2,248.74	$ 118.83	$ 1,544.79	
barge delivery	HR	3		$ -	$ 172.98	$ 518.94	$ 151.41	$ 454.23	
spat planting	EA	360000000		$ -	$ 0.001	$ 337,320.00		$ -	
			MATERIAL SUBTOTAL	$ 3,600,000.00	***LABOR SUBTOTAL***	$ 340,087.68	***EQUIP SUBTOTAL***	$ 1,999.02	
			SALES TAX (MATERIALS) 5%	$ 180,000.00	***Labor Insurance 32%***	$ 108,828.06			
			SUBTOTALS	$ 3,780,000.00		$ 448,915.74		$ 1,999.02	
			TOTAL COST	$ 4,230,914.76					
			CONTIGENCY 20%	$ 846,182.95					
			OVERHEAD 10%	$ 423,091.48					
			PROFIT 8%	$ 440,015.13					
			TOTAL COST						$ 5,940,204

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 4.5M spat/ac)									
option 1 (25 acre site):									
granite	CY	40333.3333	$ 48.00	$ 1,936,000.00		$ -		$ -	
Mob/Demob	HR	22		$ -	$ 172.98	$ 3,805.56	$ 367.43	$ 8,083.46	
barge delivery	HR	314		$ -	$ 172.98	$ 54,315.72	$ 336.62	$ 105,698.68	
granite placement	CY	40333.3333		$ -	$ 1.16	$ 46,786.67	$ 2.09	$ 84,296.67	
			MATERIAL SUBTOTAL	$ 1,936,000.00	***LABOR SUBTOTAL***	$ 104,907.95	***EQUIP SUBTOTAL***	$ 198,078.81	
			SALES TAX (MATERIALS) 5%	$ 96,800.00	***Labor Insurance 32%***	$ 33,570.54			
			SUBTOTALS	$ 2,032,800.00		$ 138,478.49		$ 198,078.81	
			TOTAL COST	$ 2,369,357.30					
			CONTIGENCY 20%	$ 473,871.46					
			OVERHEAD 10%	$ 236,935.73					
			PROFIT 8%	$ 246,413.16					
			TOTAL COST						$ 3,326,578
spat	EA	112500000	$ 0.010	$ 1,125,000.00		$ -		$ -	
Mob/Demob	HR	13			$ 172.98	$ 2,248.74	$ 118.83	$ 1,544.79	
barge delivery	HR	3		$ -	$ 172.98	$ 518.94	$ 151.41	$ 454.23	
spat planting	EA	112500000		$ -	$ 0.001	$ 105,412.50		$ -	
			MATERIAL SUBTOTAL	$ 1,125,000.00	***LABOR SUBTOTAL***	$ 108,180.18	***EQUIP SUBTOTAL***	$ 1,999.02	
			SALES TAX (MATERIALS) 5%	$ 56,250.00	***Labor Insurance 32%***	$ 34,617.66			
			SUBTOTALS	$ 1,181,250.00		$ 142,797.84		$ 1,999.02	
			TOTAL COST	$ 1,326,046.86					
			CONTIGENCY 20%	$ 265,209.37					
			OVERHEAD 10%	$ 132,604.69					
			PROFIT 8%	$ 137,908.87					
			TOTAL COST						$ 1,861,770

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
granite	CY	80666.6667	$ 48.00	$ 3,872,000.00		$ -		$ -	
Mob/Demob	HR	22		$ -	$ 172.98	$ 3,805.56	$ 367.43	$ 8,083.46	
barge delivery	HR	627		$ -	$ 172.98	$ 108,458.46	$ 336.62	$ 211,060.74	
granite placement	CY	80666.6667		$ -	$ 1.16	$ 93,573.33	$ 2.09	$ 168,593.33	
			MATERIAL SUBTOTAL	$ 3,872,000.00	***LABOR SUBTOTAL***	$ 205,837.35	***EQUIP SUBTOTAL***	$ 387,737.53	
			SALES TAX (MATERIALS) 5%	$ 193,600.00	***Labor Insurance 32%***	$ 65,867.95			
			SUBTOTALS	$ 4,065,600.00		$ 271,705.31		$ 387,737.53	
			TOTAL COST	$ 4,725,042.84					
			CONTIGENCY 20%	$ 945,008.57					
			OVERHEAD 10%	$ 472,504.28					
			PROFIT 8%	$ 491,404.46					
			TOTAL COST						$ 6,633,960
spat	EA	225000000	$ 0.010	$ 2,250,000.00		$ -		$ -	
Mob/Demob	HR	13			$ 172.98	$ 2,248.74	$ 118.83	$ 1,544.79	
barge delivery	HR	3		$ -	$ 172.98	$ 518.94	$ 151.41	$ 454.23	
spat planting	EA	225000000		$ -	$ 0.001	$ 210,825.00		$ -	
			MATERIAL SUBTOTAL	$ 2,250,000.00	***LABOR SUBTOTAL***	$ 213,592.68	***EQUIP SUBTOTAL***	$ 1,999.02	
			SALES TAX (MATERIALS) 5%	$ 112,500.00	***Labor Insurance 32%***	$ 68,349.66			
			SUBTOTALS	$ 2,362,500.00		$ 281,942.34		$ 1,999.02	
			TOTAL COST	$ 2,646,441.36					
			CONTIGENCY 20%	$ 529,288.27					
			OVERHEAD 10%	$ 264,644.14					
			PROFIT 8%	$ 275,229.90					
			TOTAL COST						$ 3,715,604

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
granite	CY	161333.333	$ 48.00	$ 7,744,000.00		$ -		$ -	
Mob/Demob	HR	22		$ -	$ 172.98	$ 3,805.56	$ 367.43	$ 8,083.46	
barge delivery	HR	1254		$ -	$ 172.98	$ 216,916.92	$ 336.62	$ 422,121.48	
granite placement	CY	161333.333		$ -	$ 1.16	$ 187,146.67	$ 2.09	$ 337,186.67	
			MATERIAL SUBTOTAL	$ 7,744,000.00	***LABOR SUBTOTAL***	$ 407,869.15	***EQUIP SUBTOTAL***	$ 767,391.61	
			SALES TAX (MATERIALS) 5%	$ 387,200.00	***Labor Insurance 32%***	$ 130,518.13			
			SUBTOTALS	$ 8,131,200.00		$ 538,387.27		$ 767,391.61	
			TOTAL COST	$ 9,436,978.88					
			CONTIGENCY 20%	$ 1,887,395.78					
			OVERHEAD 10%	$ 943,697.89					
			PROFIT 8%	$ 981,445.80					
			TOTAL COST						$ 13,249,518
spat	EA	450000000	$ 0.010	$ 4,500,000.00		$ -		$ -	
Mob/Demob	HR	13			$ 172.98	$ 2,248.74	$ 118.83	$ 1,544.79	
barge delivery	HR	3		$ -	$ 172.98	$ 518.94	$ 151.41	$ 454.23	
spat planting	EA	450000000		$ -	$ 0.001	$ 421,650.00		$ -	
			MATERIAL SUBTOTAL	$ 4,500,000.00	***LABOR SUBTOTAL***	$ 424,417.68	***EQUIP SUBTOTAL***	$ 1,999.02	
			SALES TAX (MATERIALS) 5%	$ 225,000.00	***Labor Insurance 32%***	$ 135,813.66			
			SUBTOTALS	$ 4,725,000.00		$ 560,231.34		$ 1,999.02	
			TOTAL COST	$ 5,287,230.36					
			CONTIGENCY 20%	$ 1,057,446.07					
			OVERHEAD 10%	$ 528,723.04					
			PROFIT 8%	$ 549,871.96					
			TOTAL COST						$ 7,423,271

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 6.75M spat/ac)									
option 1 (25 acre site):									
granite	CY	40333.3333	$ 48.00	$ 1,936,000.00		$ -		$ -	
Mob/Demob	HR	22		$ -	$ 172.98	$ 3,805.56	$ 367.43	$ 8,083.46	
barge delivery	HR	314		$ -	$ 172.98	$ 54,315.72	$ 336.62	$ 105,698.68	
granite placement	CY	40333.3333		$ -	$ 1.16	$ 46,786.67	$ 2.09	$ 84,296.67	
			MATERIAL SUBTOTAL	$ 1,936,000.00	***LABOR SUBTOTAL***	$ 104,907.95	***EQUIP SUBTOTAL***	$ 198,078.81	
			SALES TAX (MATERIALS) 5%	$ 96,800.00	***Labor Insurance 32%***	$ 33,570.54			
			SUBTOTALS	$ 2,032,800.00		$ 138,478.49		$ 198,078.81	
			TOTAL COST	$ 2,369,357.30					
			CONTIGENCY 20%	$ 473,871.46					
			OVERHEAD 10%	$ 236,935.73					
			PROFIT 8%	$ 246,413.16					
			TOTAL COST						$ 3,326,578
spat	EA	168750000	$ 0.010	$ 1,687,500.00		$ -		$ -	
Mob/Demob	HR	13			$ 172.98	$ 2,248.74	$ 118.83	$ 1,544.79	
barge delivery	HR	3		$ -	$ 172.98	$ 518.94	$ 151.41	$ 454.23	
spat planting	EA	168750000		$ -	$ 0.001	$ 158,118.75		$ -	
			MATERIAL SUBTOTAL	$ 1,687,500.00	***LABOR SUBTOTAL***	$ 160,886.43	***EQUIP SUBTOTAL***	$ 1,999.02	
			SALES TAX (MATERIALS) 5%	$ 84,375.00	***Labor Insurance 32%***	$ 51,483.66			
			SUBTOTALS	$ 1,771,875.00		$ 212,370.09		$ 1,999.02	
			TOTAL COST	$ 1,986,244.11					
			CONTIGENCY 20%	$ 397,248.82					
			OVERHEAD 10%	$ 198,624.41					
			PROFIT 8%	$ 206,569.39					
			TOTAL COST						$ 2,788,687

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
granite	CY	80666.6667	$ 48.00	$ 3,872,000.00		$ -		$ -	
Mob/Demob	HR	22		$ -	$ 172.98	$ 3,805.56	$ 367.43	$ 8,083.46	
barge delivery	HR	627		$ -	$ 172.98	$ 108,458.46	$ 336.62	$ 211,060.74	
granite placement	CY	80666.6667		$ -	$ 1.16	$ 93,573.33	$ 2.09	$ 168,593.33	
			MATERIAL SUBTOTAL	$ 3,872,000.00	***LABOR SUBTOTAL***	$ 205,837.35	***EQUIP SUBTOTAL***	$ 387,737.53	
			SALES TAX (MATERIALS) 5%	$ 193,600.00	***Labor Insurance 32%***	$ 65,867.95			
			SUBTOTALS	$ 4,065,600.00		$ 271,705.31		$ 387,737.53	
			TOTAL COST	$ 4,725,042.84					
			CONTIGENCY 20%	$ 945,008.57					
			OVERHEAD 10%	$ 472,504.28					
			PROFIT 8%	$ 491,404.46					
			TOTAL COST						$ 6,633,960
spat	EA	337500000	$ 0.010	$ 3,375,000.00		$ -		$ -	
Mob/Demob	HR	13			$ 172.98	$ 2,248.74	$ 118.83	$ 1,544.79	
barge delivery	HR	3		$ -	$ 172.98	$ 518.94	$ 151.41	$ 454.23	
spat planting	EA	337500000		$ -	$ 0.001	$ 316,237.50		$ -	
			MATERIAL SUBTOTAL	$ 3,375,000.00	***LABOR SUBTOTAL***	$ 319,005.18	***EQUIP SUBTOTAL***	$ 1,999.02	
			SALES TAX (MATERIALS) 5%	$ 168,750.00	***Labor Insurance 32%***	$ 102,081.66			
			SUBTOTALS	$ 3,543,750.00		$ 421,086.84		$ 1,999.02	
			TOTAL COST	$ 3,966,835.86					
			CONTIGENCY 20%	$ 793,367.17					
			OVERHEAD 10%	$ 396,683.59					
			PROFIT 8%	$ 412,550.93					
			TOTAL COST						$ 5,569,438

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
granite	CY	161333.333	$ 48.00	$ 7,744,000.00		$ -		$ -	
Mob/Demob	HR	22		$ -	$ 172.98	$ 3,805.56	$ 367.43	$ 8,083.46	
barge delivery	HR	1254		$ -	$ 172.98	$ 216,916.92	$ 336.62	$ 422,121.48	
granite placement	CY	161333.333		$ -	$ 1.16	$ 187,146.67	$ 2.09	$ 337,186.67	
			MATERIAL SUBTOTAL	$ 7,744,000.00	***LABOR SUBTOTAL***	$ 407,869.15	***EQUIP SUBTOTAL***	$ 767,391.61	
			SALES TAX (MATERIALS) 5%	$ 387,200.00	***Labor Insurance 32%***	$ 130,518.13			
			SUBTOTALS	$ 8,131,200.00		$ 538,387.27		$ 767,391.61	
			TOTAL COST	$ 9,436,978.88					
			CONTIGENCY 20%	$ 1,887,395.78					
			OVERHEAD 10%	$ 943,697.89					
			PROFIT 8%	$ 981,445.80					
			TOTAL COST						$ 13,249,518
spat	EA	675000000	$ 0.010	$ 6,750,000.00		$ -		$ -	
Mob/Demob	HR	13			$ 172.98	$ 2,248.74	$ 118.83	$ 1,544.79	
barge delivery	HR	3		$ -	$ 172.98	$ 518.94	$ 151.41	$ 454.23	
spat planting	EA	675000000		$ -	$ 0.001	$ 632,475.00		$ -	
			MATERIAL SUBTOTAL	$ 6,750,000.00	***LABOR SUBTOTAL***	$ 635,242.68	***EQUIP SUBTOTAL***	$ 1,999.02	
			SALES TAX (MATERIALS) 5%	$ 337,500.00	***Labor Insurance 32%***	$ 203,277.66			
			SUBTOTALS	$ 7,087,500.00		$ 838,520.34		$ 1,999.02	
			TOTAL COST	$ 7,928,019.36					
			CONTIGENCY 20%	$ 1,585,603.87					
			OVERHEAD 10%	$ 792,801.94					
			PROFIT 8%	$ 824,514.01					
			TOTAL COST						$ 11,130,939

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 3.6M spat/ac)									
option 1 (25 acre site):									
concrete	CY	40333.3333	$ 30.00	$ 1,210,000.00		$ -		$ -	
Mob/Demob	HR	22		$ -	$ 172.98	$ 3,805.56	$ 367.43	$ 8,083.46	
barge delivery	HR	251		$ -	$ 172.98	$ 43,417.98	$ 336.62	$ 84,491.62	
concrete placement	CY	40333.3333		$ -	$ 0.92	$ 37,106.67	$ 1.67	$ 67,356.67	
			MATERIAL SUBTOTAL	$ 1,210,000.00	***LABOR SUBTOTAL***	$ 84,330.21	***EQUIP SUBTOTAL***	$ 159,931.75	
			SALES TAX (MATERIALS) 5%	$ 60,500.00	***Labor Insurance 32%***	$ 26,985.67			
			SUBTOTALS	$ 1,270,500.00		$ 111,315.87		$ 159,931.75	
			TOTAL COST	$ 1,541,747.62					
			CONTIGENCY 20%	$ 308,349.52					
			OVERHEAD 10%	$ 154,174.76					
			PROFIT 8%	$ 160,341.75					
			TOTAL COST						$ 2,164,614
spat	EA	90000000	$ 0.010	$ 900,000.00		$ -		$ -	
Mob/Demob	HR	13			$ 172.98	$ 2,248.74	$ 118.83	$ 1,544.79	
barge delivery	HR	3		$ -	$ 172.98	$ 518.94	$ 151.41	$ 454.23	
spat planting	EA	90000000		$ -	$ 0.001	$ 84,330.00		$ -	
			MATERIAL SUBTOTAL	$ 900,000.00	***LABOR SUBTOTAL***	$ 87,097.68	***EQUIP SUBTOTAL***	$ 1,999.02	
			SALES TAX (MATERIALS) 5%	$ 45,000.00	***Labor Insurance 32%***	$ 27,871.26			
			SUBTOTALS	$ 945,000.00		$ 114,968.94		$ 1,999.02	
			TOTAL COST	$ 1,061,967.96					
			CONTIGENCY 20%	$ 212,393.59					
			OVERHEAD 10%	$ 106,196.80					
			PROFIT 8%	$ 110,444.67					
			TOTAL COST						$ 1,491,003

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
concrete	CY	80666.6667	$ 30.00	$ 2,420,000.00		$ -		$ -	
Mob/Demob	HR	22		$ -	$ 172.98	$ 3,805.56	$ 367.43	$ 8,083.46	
barge delivery	HR	502		$ -	$ 172.98	$ 86,835.96	$ 336.62	$ 168,983.24	
concrete placement	CY	80666.6667		$ -	$ 0.92	$ 74,213.33	$ 1.67	$ 134,713.33	
			MATERIAL SUBTOTAL	$ 2,420,000.00	***LABOR SUBTOTAL***	$ 164,854.85	***EQUIP SUBTOTAL***	$ 311,780.03	
			SALES TAX (MATERIALS) 5%	$ 121,000.00	***Labor Insurance 32%***	$ 52,753.55			
			SUBTOTALS	$ 2,541,000.00		$ 217,608.41		$ 311,780.03	
			TOTAL COST	$ 3,070,388.44					
			CONTIGENCY 20%	$ 614,077.69					
			OVERHEAD 10%	$ 307,038.84					
			PROFIT 8%	$ 319,320.40					
			TOTAL COST						$ 4,310,825
spat	EA	180000000	$ 0.010	$ 1,800,000.00		$ -		$ -	
Mob/Demob	HR	13			$ 172.98	$ 2,248.74	$ 118.83	$ 1,544.79	
barge delivery	HR	3		$ -	$ 172.98	$ 518.94	$ 151.41	$ 454.23	
spat planting	EA	180000000		$ -	$ 0.001	$ 168,660.00		$ -	
			MATERIAL SUBTOTAL	$ 1,800,000.00	***LABOR SUBTOTAL***	$ 171,427.68	***EQUIP SUBTOTAL***	$ 1,999.02	
			SALES TAX (MATERIALS) 5%	$ 90,000.00	***Labor Insurance 32%***	$ 54,856.86			
			SUBTOTALS	$ 1,890,000.00		$ 226,284.54		$ 1,999.02	
			TOTAL COST	$ 2,118,283.56					
			CONTIGENCY 20%	$ 423,656.71					
			OVERHEAD 10%	$ 211,828.36					
			PROFIT 8%	$ 220,301.49					
			TOTAL COST						$ 2,974,070

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
concrete	CY	161333.333	$ 30.00	$ 4,840,000.00		$ -		$ -	
Mob/Demob	HR	22		$ -	$ 172.98	$ 3,805.56	$ 367.43	$ 8,083.46	
barge delivery	HR	1003		$ -	$ 172.98	$ 173,498.94	$ 336.62	$ 337,629.86	
concrete placement	CY	161333.333		$ -	$ 0.92	$ 148,426.67	$ 1.67	$ 269,426.67	
			MATERIAL SUBTOTAL	$ 4,840,000.00	***LABOR SUBTOTAL***	$ 325,731.17	***EQUIP SUBTOTAL***	$ 615,139.99	
			SALES TAX (MATERIALS) 5%	$ 242,000.00	***Labor Insurance 32%***	$ 104,233.97			
			SUBTOTALS	$ 5,082,000.00		$ 429,965.14		$ 615,139.99	
			TOTAL COST	$ 6,127,105.13					
			CONTIGENCY 20%	$ 1,225,421.03					
			OVERHEAD 10%	$ 612,710.51					
			PROFIT 8%	$ 637,218.93					
			TOTAL COST						$ 8,602,456
spat	EA	360000000	$ 0.010	$ 3,600,000.00		$ -		$ -	
Mob/Demob	HR	13			$ 172.98	$ 2,248.74	$ 118.83	$ 1,544.79	
barge delivery	HR	3		$ -	$ 172.98	$ 518.94	$ 151.41	$ 454.23	
spat planting	EA	360000000		$ -	$ 0.001	$ 337,320.00		$ -	
			MATERIAL SUBTOTAL	$ 3,600,000.00	***LABOR SUBTOTAL***	$ 340,087.68	***EQUIP SUBTOTAL***	$ 1,999.02	
			SALES TAX (MATERIALS) 5%	$ 180,000.00	***Labor Insurance 32%***	$ 108,828.06			
			SUBTOTALS	$ 3,780,000.00		$ 448,915.74		$ 1,999.02	
			TOTAL COST	$ 4,230,914.76					
			CONTIGENCY 20%	$ 846,182.95					
			OVERHEAD 10%	$ 423,091.48					
			PROFIT 8%	$ 440,015.13					
			TOTAL COST						$ 5,940,204

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 4.5M spat/ac)									
option 1 (25 acre site):									
concrete	CY	40333.3333	$ 30.00	$ 1,210,000.00		$ -		$ -	
Mob/Demob	HR	22		$ -	$ 172.98	$ 3,805.56	$ 367.43	$ 8,083.46	
barge delivery	HR	251		$ -	$ 172.98	$ 43,417.98	$ 336.62	$ 84,491.62	
concrete placement	CY	40333.3333		$ -	$ 0.92	$ 37,106.67	$ 1.67	$ 67,356.67	
			MATERIAL SUBTOTAL	$ 1,210,000.00	***LABOR SUBTOTAL***	$ 84,330.21	***EQUIP SUBTOTAL***	$ 159,931.75	
			SALES TAX (MATERIALS) 5%	$ 60,500.00	***Labor Insurance 32%***	$ 26,985.67			
			SUBTOTALS	$ 1,270,500.00		$ 111,315.87		$ 159,931.75	
			TOTAL COST	$ 1,541,747.62					
			CONTIGENCY 20%	$ 308,349.52					
			OVERHEAD 10%	$ 154,174.76					
			PROFIT 8%	$ 160,341.75					
			TOTAL COST						$ 2,164,614
spat	EA	112500000	$ 0.010	$ 1,125,000.00		$ -		$ -	
Mob/Demob	HR	13			$ 172.98	$ 2,248.74	$ 118.83	$ 1,544.79	
barge delivery	HR	3		$ -	$ 172.98	$ 518.94	$ 151.41	$ 454.23	
spat planting	EA	112500000		$ -	$ 0.001	$ 105,412.50		$ -	
			MATERIAL SUBTOTAL	$ 1,125,000.00	***LABOR SUBTOTAL***	$ 108,180.18	***EQUIP SUBTOTAL***	$ 1,999.02	
			SALES TAX (MATERIALS) 5%	$ 56,250.00	***Labor Insurance 32%***	$ 34,617.66			
			SUBTOTALS	$ 1,181,250.00		$ 142,797.84		$ 1,999.02	
			TOTAL COST	$ 1,326,046.86					
			CONTIGENCY 20%	$ 265,209.37					
			OVERHEAD 10%	$ 132,604.69					
			PROFIT 8%	$ 137,908.87					
			TOTAL COST						$ 1,861,770

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
concrete	CY	80666.6667	$ 30.00	$ 2,420,000.00		$ -		$ -	
Mob/Demob	HR	22		$ -	$ 172.98	$ 3,805.56	$ 367.43	$ 8,083.46	
barge delivery	HR	502		$ -	$ 172.98	$ 86,835.96	$ 336.62	$ 168,983.24	
concrete placement	CY	80666.6667		$ -	$ 0.92	$ 74,213.33	$ 1.67	$ 134,713.33	
			MATERIAL SUBTOTAL	$ 2,420,000.00	***LABOR SUBTOTAL***	$ 164,854.85	***EQUIP SUBTOTAL***	$ 311,780.03	
			SALES TAX (MATERIALS) 5%	$ 121,000.00	***Labor Insurance 32%***	$ 52,753.55			
			SUBTOTALS	$ 2,541,000.00		$ 217,608.41		$ 311,780.03	
			TOTAL COST	$ 3,070,388.44					
			CONTIGENCY 20%	$ 614,077.69					
			OVERHEAD 10%	$ 307,038.84					
			PROFIT 8%	$ 319,320.40					
			TOTAL COST						$ 4,310,825
spat	EA	225000000	$ 0.010	$ 2,250,000.00		$ -		$ -	
Mob/Demob	HR	13			$ 172.98	$ 2,248.74	$ 118.83	$ 1,544.79	
barge delivery	HR	3		$ -	$ 172.98	$ 518.94	$ 151.41	$ 454.23	
spat planting	EA	225000000		$ -	$ 0.001	$ 210,825.00		$ -	
			MATERIAL SUBTOTAL	$ 2,250,000.00	***LABOR SUBTOTAL***	$ 213,592.68	***EQUIP SUBTOTAL***	$ 1,999.02	
			SALES TAX (MATERIALS) 5%	$ 112,500.00	***Labor Insurance 32%***	$ 68,349.66			
			SUBTOTALS	$ 2,362,500.00		$ 281,942.34		$ 1,999.02	
			TOTAL COST	$ 2,646,441.36					
			CONTIGENCY 20%	$ 529,288.27					
			OVERHEAD 10%	$ 264,644.14					
			PROFIT 8%	$ 275,229.90					
			TOTAL COST						$ 3,715,604

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
concrete	CY	161333.333	$ 30.00	$ 4,840,000.00		$ -		$ -	
Mob/Demob	HR	22		$ -	$ 172.98	$ 3,805.56	$ 367.43	$ 8,083.46	
barge delivery	HR	1003		$ -	$ 172.98	$ 173,498.94	$ 336.62	$ 337,629.86	
concrete placement	CY	161333.333		$ -	$ 0.92	$ 148,426.67	$ 1.67	$ 269,426.67	
			MATERIAL SUBTOTAL	$ 4,840,000.00	***LABOR SUBTOTAL***	$ 325,731.17	***EQUIP SUBTOTAL***	$ 615,139.99	
			SALES TAX (MATERIALS) 5%	$ 242,000.00	***Labor Insurance 32%***	$ 104,233.97			
			SUBTOTALS	$ 5,082,000.00		$ 429,965.14		$ 615,139.99	
			TOTAL COST	$ 6,127,105.13					
			CONTIGENCY 20%	$ 1,225,421.03					
			OVERHEAD 10%	$ 612,710.51					
			PROFIT 8%	$ 637,218.93					
			TOTAL COST						$ 8,602,456
spat	EA	450000000	$ 0.010	$ 4,500,000.00		$ -		$ -	
Mob/Demob	HR	13			$ 172.98	$ 2,248.74	$ 118.83	$ 1,544.79	
barge delivery	HR	3		$ -	$ 172.98	$ 518.94	$ 151.41	$ 454.23	
spat planting	EA	450000000		$ -	$ 0.001	$ 421,650.00		$ -	
			MATERIAL SUBTOTAL	$ 4,500,000.00	***LABOR SUBTOTAL***	$ 424,417.68	***EQUIP SUBTOTAL***	$ 1,999.02	
			SALES TAX (MATERIALS) 5%	$ 225,000.00	***Labor Insurance 32%***	$ 135,813.66			
			SUBTOTALS	$ 4,725,000.00		$ 560,231.34		$ 1,999.02	
			TOTAL COST	$ 5,287,230.36					
			CONTIGENCY 20%	$ 1,057,446.07					
			OVERHEAD 10%	$ 528,723.04					
			PROFIT 8%	$ 549,871.96					
			TOTAL COST						$ 7,423,271

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 6.75M spat/ac)									
option 1 (25 acre site):									
concrete	CY	40333.3333	$ 30.00	$ 1,210,000.00		$ -		$ -	
Mob/Demob	HR	22		$ -	$ 172.98	$ 3,805.56	$ 367.43	$ 8,083.46	
barge delivery	HR	251		$ -	$ 172.98	$ 43,417.98	$ 336.62	$ 84,491.62	
concrete placement	CY	40333.3333		$ -	$ 0.92	$ 37,106.67	$ 1.67	$ 67,356.67	
			MATERIAL SUBTOTAL	$ 1,210,000.00	***LABOR SUBTOTAL***	$ 84,330.21	***EQUIP SUBTOTAL***	$ 159,931.75	
			SALES TAX (MATERIALS) 5%	$ 60,500.00	***Labor Insurance 32%***	$ 26,985.67			
			SUBTOTALS	$ 1,270,500.00		$ 111,315.87		$ 159,931.75	
			TOTAL COST	$ 1,541,747.62					
			CONTIGENCY 20%	$ 308,349.52					
			OVERHEAD 10%	$ 154,174.76					
			PROFIT 8%	$ 160,341.75					
			TOTAL COST						$ 2,164,614
spat	EA	168750000	$ 0.010	$ 1,687,500.00		$ -		$ -	
Mob/Demob	HR	13			$ 172.98	$ 2,248.74	$ 118.83	$ 1,544.79	
barge delivery	HR	3		$ -	$ 172.98	$ 518.94	$ 151.41	$ 454.23	
spat planting	EA	168750000		$ -	$ 0.001	$ 158,118.75		$ -	
			MATERIAL SUBTOTAL	$ 1,687,500.00	***LABOR SUBTOTAL***	$ 160,886.43	***EQUIP SUBTOTAL***	$ 1,999.02	
			SALES TAX (MATERIALS) 5%	$ 84,375.00	***Labor Insurance 32%***	$ 51,483.66			
			SUBTOTALS	$ 1,771,875.00		$ 212,370.09		$ 1,999.02	
			TOTAL COST	$ 1,986,244.11					
			CONTIGENCY 20%	$ 397,248.82					
			OVERHEAD 10%	$ 198,624.41					
			PROFIT 8%	$ 206,569.39					
			TOTAL COST						$ 2,788,687

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
concrete	CY	80666.6667	$ 30.00	$ 2,420,000.00		$ -		$ -	
Mob/Demob	HR	22		$ -	$ 172.98	$ 3,805.56	$ 367.43	$ 8,083.46	
barge delivery	HR	502		$ -	$ 172.98	$ 86,835.96	$ 336.62	$ 168,983.24	
concrete placement	CY	80666.6667		$ -	$ 0.92	$ 74,213.33	$ 1.67	$ 134,713.33	
			MATERIAL SUBTOTAL	$ 2,420,000.00	***LABOR SUBTOTAL***	$ 164,854.85	***EQUIP SUBTOTAL***	$ 311,780.03	
			SALES TAX (MATERIALS) 5%	$ 121,000.00	***Labor Insurance 32%***	$ 52,753.55			
			SUBTOTALS	$ 2,541,000.00		$ 217,608.41		$ 311,780.03	
			TOTAL COST	$ 3,070,388.44					
			CONTIGENCY 20%	$ 614,077.69					
			OVERHEAD 10%	$ 307,038.84					
			PROFIT 8%	$ 319,320.40					
			TOTAL COST						$ 4,310,825
spat	EA	337500000	$ 0.010	$ 3,375,000.00		$ -		$ -	
Mob/Demob	HR	13			$ 172.98	$ 2,248.74	$ 118.83	$ 1,544.79	
barge delivery	HR	3		$ -	$ 172.98	$ 518.94	$ 151.41	$ 454.23	
spat planting	EA	337500000		$ -	$ 0.001	$ 316,237.50		$ -	
			MATERIAL SUBTOTAL	$ 3,375,000.00	***LABOR SUBTOTAL***	$ 319,005.18	***EQUIP SUBTOTAL***	$ 1,999.02	
			SALES TAX (MATERIALS) 5%	$ 168,750.00	***Labor Insurance 32%***	$ 102,081.66			
			SUBTOTALS	$ 3,543,750.00		$ 421,086.84		$ 1,999.02	
			TOTAL COST	$ 3,966,835.86					
			CONTIGENCY 20%	$ 793,367.17					
			OVERHEAD 10%	$ 396,683.59					
			PROFIT 8%	$ 412,550.93					
			TOTAL COST						$ 5,569,438

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
concrete	CY	161333.333	$ 30.00	$ 4,840,000.00		$ -		$ -	
Mob/Demob	HR	22		$ -	$ 172.98	$ 3,805.56	$ 367.43	$ 8,083.46	
barge delivery	HR	1003		$ -	$ 172.98	$ 173,498.94	$ 336.62	$ 337,629.86	
concrete placement	CY	161333.333		$ -	$ 0.92	$ 148,426.67	$ 1.67	$ 269,426.67	
			MATERIAL SUBTOTAL	$ 4,840,000.00	***LABOR SUBTOTAL***	$ 325,731.17	***EQUIP SUBTOTAL***	$ 615,139.99	
			SALES TAX (MATERIALS) 5%	$ 242,000.00	***Labor Insurance 32%***	$ 104,233.97			
			SUBTOTALS	$ 5,082,000.00		$ 429,965.14		$ 615,139.99	
			TOTAL COST	$ 6,127,105.13					
			CONTIGENCY 20%	$ 1,225,421.03					
			OVERHEAD 10%	$ 612,710.51					
			PROFIT 8%	$ 637,218.93					
			TOTAL COST						$ 8,602,456
spat	EA	675000000	$ 0.010	$ 6,750,000.00		$ -		$ -	
Mob/Demob	HR	13			$ 172.98	$ 2,248.74	$ 118.83	$ 1,544.79	
barge delivery	HR	3		$ -	$ 172.98	$ 518.94	$ 151.41	$ 454.23	
spat planting	EA	675000000		$ -	$ 0.001	$ 632,475.00		$ -	
			MATERIAL SUBTOTAL	$ 6,750,000.00	***LABOR SUBTOTAL***	$ 635,242.68	***EQUIP SUBTOTAL***	$ 1,999.02	
			SALES TAX (MATERIALS) 5%	$ 337,500.00	***Labor Insurance 32%***	$ 203,277.66			
			SUBTOTALS	$ 7,087,500.00		$ 838,520.34		$ 1,999.02	
			TOTAL COST	$ 7,928,019.36					
			CONTIGENCY 20%	$ 1,585,603.87					
			OVERHEAD 10%	$ 792,801.94					
			PROFIT 8%	$ 824,514.01					
			TOTAL COST						$ 11,130,939

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 3.6M spat/ac)									
option 1 (25 acre site):									
oyster shell dredging	CY	40333.3333	$ 15.85	$ 639,283.33		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	209		$ -	$ 172.98	$ 36,152.82	$ 336.62	$ 70,353.58	
oyster placement	CY	40333.3333		$ -	$ 6.27	$ 252,890.00		$ -	
			SUBTOTAL	$ 639,283.33	***SUBTOTAL***	$ 294,232.22	***SUBTOTAL***	$ 81,376.48	
			(MATERIALS) 5%	$ 31,964.17	***Insurance 32%***	$ 94,154.31			
			SUBTOTALS	$ 671,247.50		$ 388,386.53		$ 81,376.48	
			TOTAL COST	$ 1,141,010.51					
			CONTIGENCY 20%	$ 228,202.10					
			OVERHEAD 10%	$ 114,101.05					
			PROFIT 8%	$ 118,665.09					
			TOTAL COST						$ 1,601,979
spat	EA	90000000	$ 0.010	$ 900,000.00		$ -		$ -	
Mob/Demob	HR	13			$ 172.98	$ 2,248.74	$ 118.83	$ 1,544.79	
barge delivery	HR	3		$ -	$ 172.98	$ 518.94	$ 151.41	$ 454.23	
spat planting	EA	90000000		$ -	$ 0.001	$ 84,330.00		$ -	
Turbidity control	LF	4200	$ 0.69	$ 2,898.00	$ 0.15	$ 630.00	$ 0.39	$ 1,638.00	
			MATERIAL SUBTOTAL	$ 902,898.00	***LABOR SUBTOTAL***	$ 87,727.68	***EQUIP SUBTOTAL***	$ 3,637.02	
			SALES TAX (MATERIALS) 5%	$ 45,144.90	***Labor Insurance 32%***	$ 28,072.86			
			SUBTOTALS	$ 948,042.90		$ 115,800.54		$ 3,637.02	
			TOTAL COST	$ 1,067,480.46					
			CONTIGENCY 20%	$ 213,496.09					
			OVERHEAD 10%	$ 106,748.05					
			PROFIT 8%	$ 111,017.97					
			TOTAL COST						$ 1,498,743

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
oyster shell dredging	CY	80666.6667	$ 15.85	$ 1,278,566.67		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	418		$ -	$ 172.98	$ 72,305.64	$ 336.62	$ 140,707.16	
oyster placement	CY	80666.6667		$ -	$ 6.27	$ 505,780.00		$ -	
			MATERIAL SUBTOTAL	$ 1,278,566.67	***LABOR SUBTOTAL***	$ 583,275.04	***EQUIP SUBTOTAL***	$ 151,730.06	
			SALES TAX (MATERIALS) 5%	$ 63,928.33	***Labor Insurance 32%***	$ 186,648.01			
			SUBTOTALS	$ 1,342,495.00		$ 769,923.05		$ 151,730.06	
			TOTAL COST	$ 2,264,148.11					
			CONTIGENCY 20%	$ 452,829.62					
			OVERHEAD 10%	$ 226,414.81					
			PROFIT 8%	$ 235,471.40					
			TOTAL COST						$ 3,178,864
spat	EA	180000000	$ 0.010	$ 1,800,000.00		$ -		$ -	
Mob/Demob	HR	13			$ 172.98	$ 2,248.74	$ 118.83	$ 1,544.79	
barge delivery	HR	3		$ -	$ 172.98	$ 518.94	$ 151.41	$ 454.23	
spat planting	EA	180000000		$ -	$ 0.001	$ 168,660.00		$ -	
Turbidity control	LF	5900	$ 0.69	$ 4,071.00	$ 0.15	$ 885.00	$ 0.39	$ 2,301.00	
			MATERIAL SUBTOTAL	$ 1,804,071.00	***LABOR SUBTOTAL***	$ 172,312.68	***EQUIP SUBTOTAL***	$ 4,300.02	
			SALES TAX (MATERIALS) 5%	$ 90,203.55	***Labor Insurance 32%***	$ 55,140.06			
			SUBTOTALS	$ 1,894,274.55		$ 227,452.74		$ 4,300.02	
			TOTAL COST	$ 2,126,027.31					
			CONTIGENCY 20%	$ 425,205.46					
			OVERHEAD 10%	$ 212,602.73					
			PROFIT 8%	$ 221,106.84					
			TOTAL COST						$ 2,984,942

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
oyster shell dredging	CY	161333.333	$ 15.85	$ 2,557,133.33		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	836		$ -	$ 172.98	$ 144,611.28	$ 336.62	$ 281,414.32	
oyster placement	CY	161333.333		$ -	$ 6.27	$ 1,011,560.00		$ -	
			MATERIAL SUBTOTAL	$ 2,557,133.33	***LABOR SUBTOTAL***	$ 1,161,360.68	***EQUIP SUBTOTAL***	$ 292,437.22	
			SALES TAX (MATERIALS) 5%	$ 127,856.67	***Labor Insurance 32%***	$ 371,635.42			
			SUBTOTALS	$ 2,684,990.00		$ 1,532,996.10		$ 292,437.22	
			TOTAL COST	$ 4,510,423.32					
			CONTIGENCY 20%	$ 902,084.66					
			OVERHEAD 10%	$ 451,042.33					
			PROFIT 8%	$ 469,084.03					
			TOTAL COST						$ 6,332,634
spat	EA	360000000	$ 0.010	$ 3,600,000.00		$ -		$ -	
Mob/Demob	HR	13			$ 172.98	$ 2,248.74	$ 118.83	$ 1,544.79	
barge delivery	HR	3		$ -	$ 172.98	$ 518.94	$ 151.41	$ 454.23	
spat planting	EA	360000000		$ -	$ 0.001	$ 337,320.00		$ -	
Turbidity control	LF	8350	$ 0.69	$ 5,761.50	$ 0.15	$ 1,252.50	$ 0.39	$ 3,256.50	
			MATERIAL SUBTOTAL	$ 3,605,761.50	***LABOR SUBTOTAL***	$ 341,340.18	***EQUIP SUBTOTAL***	$ 5,255.52	
			SALES TAX (MATERIALS) 5%	$ 180,288.08	***Labor Insurance 32%***	$ 109,228.86			
			SUBTOTALS	$ 3,786,049.58		$ 450,569.04		$ 5,255.52	
			TOTAL COST	$ 4,241,874.13					
			CONTIGENCY 20%	$ 848,374.83					
			OVERHEAD 10%	$ 424,187.41					
			PROFIT 8%	$ 441,154.91					
			TOTAL COST						$ 5,955,591

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 4.5M spat/ac)									
option 1 (25 acre site):									
oyster shell dredging	CY	40333.3333	$ 15.85	$ 639,283.33		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	209		$ -	$ 172.98	$ 36,152.82	$ 336.62	$ 70,353.58	
oyster placement	CY	40333.3333		$ -	$ 6.27	$ 252,890.00		$ -	
			MATERIAL SUBTOTAL	$ 639,283.33	***LABOR SUBTOTAL***	$ 294,232.22	***EQUIP SUBTOTAL***	$ 81,376.48	
			SALES TAX (MATERIALS) 5%	$ 31,964.17	***Labor Insurance 32%***	$ 94,154.31			
			SUBTOTALS	$ 671,247.50		$ 388,386.53		$ 81,376.48	
			TOTAL COST	$ 1,141,010.51					
			CONTIGENCY 20%	$ 228,202.10					
			OVERHEAD 10%	$ 114,101.05					
			PROFIT 8%	$ 118,665.09					
			TOTAL COST						$ 1,601,979
spat	EA	112500000	$ 0.010	$ 1,125,000.00		$ -		$ -	
Mob/Demob	HR	13			$ 172.98	$ 2,248.74	$ 118.83	$ 1,544.79	
barge delivery	HR	3		$ -	$ 172.98	$ 518.94	$ 151.41	$ 454.23	
spat planting	EA	112500000		$ -	$ 0.001	$ 105,412.50		$ -	
Turbidity control	LF	4200	$ 0.69	$ 2,898.00	$ 0.15	$ 630.00	$ 0.39	$ 1,638.00	
			MATERIAL SUBTOTAL	$ 1,127,898.00	***LABOR SUBTOTAL***	$ 108,810.18	***EQUIP SUBTOTAL***	$ 3,637.02	
			SALES TAX (MATERIALS) 5%	$ 56,394.90	***Labor Insurance 32%***	$ 34,819.26			
			SUBTOTALS	$ 1,184,292.90		$ 143,629.44		$ 3,637.02	
			TOTAL COST	$ 1,331,559.36					
			CONTIGENCY 20%	$ 266,311.87					
			OVERHEAD 10%	$ 133,155.94					
			PROFIT 8%	$ 138,482.17					
			TOTAL COST						$ 1,869,509

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
oyster shell dredging	CY	80666.6667	$ 15.85	$ 1,278,566.67		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	418		$ -	$ 172.98	$ 72,305.64	$ 336.62	$ 140,707.16	
oyster placement	CY	80666.6667		$ -	$ 6.27	$ 505,780.00		$ -	
			MATERIAL SUBTOTAL	$ 1,278,566.67	***LABOR SUBTOTAL***	$ 583,275.04	***EQUIP SUBTOTAL***	$ 151,730.06	
			SALES TAX (MATERIALS) 5%	$ 63,928.33	***Labor Insurance 32%***	$ 186,648.01			
			SUBTOTALS	$ 1,342,495.00		$ 769,923.05		$ 151,730.06	
			TOTAL COST	$ 2,264,148.11					
			CONTIGENCY 20%	$ 452,829.62					
			OVERHEAD 10%	$ 226,414.81					
			PROFIT 8%	$ 235,471.40					
			TOTAL COST						$ 3,178,864
spat	EA	225000000	$ 0.010	$ 2,250,000.00		$ -		$ -	
Mob/Demob	HR	13			$ 172.98	$ 2,248.74	$ 118.83	$ 1,544.79	
barge delivery	HR	3		$ -	$ 172.98	$ 518.94	$ 151.41	$ 454.23	
spat planting	EA	225000000		$ -	$ 0.001	$ 210,825.00		$ -	
Turbidity control	LF	5900	$ 0.69	$ 4,071.00	$ 0.15	$ 885.00	$ 0.39	$ 2,301.00	
			MATERIAL SUBTOTAL	$ 2,254,071.00	***LABOR SUBTOTAL***	$ 214,477.68	***EQUIP SUBTOTAL***	$ 4,300.02	
			SALES TAX (MATERIALS) 5%	$ 112,703.55	***Labor Insurance 32%***	$ 68,632.86			
			SUBTOTALS	$ 2,366,774.55		$ 283,110.54		$ 4,300.02	
			TOTAL COST	$ 2,654,185.11					
			CONTIGENCY 20%	$ 530,837.02					
			OVERHEAD 10%	$ 265,418.51					
			PROFIT 8%	$ 276,035.25					
			TOTAL COST						$ 3,726,476

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
oyster shell dredging	CY	161333.333	$ 15.85	$ 2,557,133.33		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	836		$ -	$ 172.98	$ 144,611.28	$ 336.62	$ 281,414.32	
oyster placement	CY	161333.333		$ -	$ 6.27	$ 1,011,560.00		$ -	
			MATERIAL SUBTOTAL	$ 2,557,133.33	***LABOR SUBTOTAL***	$ 1,161,360.68	***EQUIP SUBTOTAL***	$ 292,437.22	
			SALES TAX (MATERIALS) 5%	$ 127,856.67	***Labor Insurance 32%***	$ 371,635.42			
			SUBTOTALS	$ 2,684,990.00		$ 1,532,996.10		$ 292,437.22	
			TOTAL COST	$ 4,510,423.32					
			CONTIGENCY 20%	$ 902,084.66					
			OVERHEAD 10%	$ 451,042.33					
			PROFIT 8%	$ 469,084.03					
			TOTAL COST						$ 6,332,634
spat	EA	450000000	$ 0.010	$ 4,500,000.00		$ -		$ -	
Mob/Demob	HR	13			$ 172.98	$ 2,248.74	$ 118.83	$ 1,544.79	
barge delivery	HR	3		$ -	$ 172.98	$ 518.94	$ 151.41	$ 454.23	
spat planting	EA	450000000		$ -	$ 0.001	$ 421,650.00		$ -	
Turbidity control	LF	8350	$ 0.69	$ 5,761.50	$ 0.15	$ 1,252.50	$ 0.39	$ 3,256.50	
			MATERIAL SUBTOTAL	$ 4,505,761.50	***LABOR SUBTOTAL***	$ 425,670.18	***EQUIP SUBTOTAL***	$ 5,255.52	
			SALES TAX (MATERIALS) 5%	$ 225,288.08	***Labor Insurance 32%***	$ 136,214.46			
			SUBTOTALS	$ 4,731,049.58		$ 561,884.64		$ 5,255.52	
			TOTAL COST	$ 5,298,189.73					
			CONTIGENCY 20%	$ 1,059,637.95					
			OVERHEAD 10%	$ 529,818.97					
			PROFIT 8%	$ 551,011.73					
			TOTAL COST						$ 7,438,658

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 6.75M spat/ac)									
option 1 (25 acre site):									
oyster shell dredging	CY	40333.3333	$ 15.85	$ 639,283.33		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	209		$ -	$ 172.98	$ 36,152.82	$ 336.62	$ 70,353.58	
oyster placement	CY	40333.3333		$ -	$ 6.27	$ 252,890.00		$ -	
			MATERIAL SUBTOTAL	$ 639,283.33	***LABOR SUBTOTAL***	$ 294,232.22	***EQUIP SUBTOTAL***	$ 81,376.48	
			SALES TAX (MATERIALS) 5%	$ 31,964.17	***Labor Insurance 32%***	$ 94,154.31			
			SUBTOTALS	$ 671,247.50		$ 388,386.53		$ 81,376.48	
			TOTAL COST	$ 1,141,010.51					
			CONTIGENCY 20%	$ 228,202.10					
			OVERHEAD 10%	$ 114,101.05					
			PROFIT 8%	$ 118,665.09					
			TOTAL COST						$ 1,601,979
spat	EA	168750000	$ 0.010	$ 1,687,500.00		$ -		$ -	
Mob/Demob	HR	13			$ 172.98	$ 2,248.74	$ 118.83	$ 1,544.79	
barge delivery	HR	3		$ -	$ 172.98	$ 518.94	$ 151.41	$ 454.23	
spat planting	EA	168750000		$ -	$ 0.001	$ 158,118.75		$ -	
Turbidity control	LF	4200	$ 0.69	$ 2,898.00	$ 0.15	$ 630.00	$ 0.39	$ 1,638.00	
			MATERIAL SUBTOTAL	$ 1,690,398.00	***LABOR SUBTOTAL***	$ 161,516.43	***EQUIP SUBTOTAL***	$ 3,637.02	
			SALES TAX (MATERIALS) 5%	$ 84,519.90	***Labor Insurance 32%***	$ 51,685.26			
			SUBTOTALS	$ 1,774,917.90		$ 213,201.69		$ 3,637.02	
			TOTAL COST	$ 1,991,756.61					
			CONTIGENCY 20%	$ 398,351.32					
			OVERHEAD 10%	$ 199,175.66					
			PROFIT 8%	$ 207,142.69					
			TOTAL COST						$ 2,796,426

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
oyster shell dredging	CY	80666.6667	$ 15.85	$ 1,278,566.67		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	418		$ -	$ 172.98	$ 72,305.64	$ 336.62	$ 140,707.16	
oyster placement	CY	80666.6667		$ -	$ 6.27	$ 505,780.00		$ -	
			MATERIAL SUBTOTAL	$ 1,278,566.67	***LABOR SUBTOTAL***	$ 583,275.04	***EQUIP SUBTOTAL***	$ 151,730.06	
			SALES TAX (MATERIALS) 5%	$ 63,928.33	***Labor Insurance 32%***	$ 186,648.01			
			SUBTOTALS	$ 1,342,495.00		$ 769,923.05		$ 151,730.06	
			TOTAL COST	$ 2,264,148.11					
			CONTIGENCY 20%	$ 452,829.62					
			OVERHEAD 10%	$ 226,414.81					
			PROFIT 8%	$ 235,471.40					
			TOTAL COST						$ 3,178,864
spat	EA	337500000	$ 0.010	$ 3,375,000.00		$ -		$ -	
Mob/Demob	HR	13			$ 172.98	$ 2,248.74	$ 118.83	$ 1,544.79	
barge delivery	HR	3		$ -	$ 172.98	$ 518.94	$ 151.41	$ 454.23	
spat planting	EA	337500000		$ -	$ 0.001	$ 316,237.50		$ -	
Turbidity control	LF	5900	$ 0.69	$ 4,071.00	$ 0.15	$ 885.00	$ 0.39	$ 2,301.00	
			MATERIAL SUBTOTAL	$ 3,379,071.00	***LABOR SUBTOTAL***	$ 319,890.18	***EQUIP SUBTOTAL***	$ 4,300.02	
			SALES TAX (MATERIALS) 5%	$ 168,953.55	***Labor Insurance 32%***	$ 102,364.86			
			SUBTOTALS	$ 3,548,024.55		$ 422,255.04		$ 4,300.02	
			TOTAL COST	$ 3,974,579.61					
			CONTIGENCY 20%	$ 794,915.92					
			OVERHEAD 10%	$ 397,457.96					
			PROFIT 8%	$ 413,356.28					
			TOTAL COST						$ 5,580,310

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
oyster shell dredging	CY	161333.333	$ 15.85	$ 2,557,133.33		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	836		$ -	$ 172.98	$ 144,611.28	$ 336.62	$ 281,414.32	
oyster placement	CY	161333.333		$ -	$ 6.27	$ 1,011,560.00		$ -	
			MATERIAL SUBTOTAL	$ 2,557,133.33	***LABOR SUBTOTAL***	$ 1,161,360.68	***EQUIP SUBTOTAL***	$ 292,437.22	
			SALES TAX (MATERIALS) 5%	$ 127,856.67	***Labor Insurance 32%***	$ 371,635.42			
			SUBTOTALS	$ 2,684,990.00		$ 1,532,996.10		$ 292,437.22	
			TOTAL COST	$ 4,510,423.32					
			CONTIGENCY 20%	$ 902,084.66					
			OVERHEAD 10%	$ 451,042.33					
			PROFIT 8%	$ 469,084.03					
			TOTAL COST						$ 6,332,634
spat	EA	675000000	$ 0.010	$ 6,750,000.00		$ -		$ -	
Mob/Demob	HR	13			$ 172.98	$ 2,248.74	$ 118.83	$ 1,544.79	
barge delivery	HR	3		$ -	$ 172.98	$ 518.94	$ 151.41	$ 454.23	
spat planting	EA	675000000		$ -	$ 0.001	$ 632,475.00		$ -	
Turbidity control	LF	8350	$ 0.69	$ 5,761.50	$ 0.15	$ 1,252.50	$ 0.39	$ 3,256.50	
			MATERIAL SUBTOTAL	$ 6,755,761.50	***LABOR SUBTOTAL***	$ 636,495.18	***EQUIP SUBTOTAL***	$ 5,255.52	
			SALES TAX (MATERIALS) 5%	$ 337,788.08	***Labor Insurance 32%***	$ 203,678.46			
			SUBTOTALS	$ 7,093,549.58		$ 840,173.64		$ 5,255.52	
			TOTAL COST	$ 7,938,978.73					
			CONTIGENCY 20%	$ 1,587,795.75					
			OVERHEAD 10%	$ 793,897.87					
			PROFIT 8%	$ 825,653.79					
			TOTAL COST						$ 11,146,326

Monie Bay

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 3.6M spat/ac)									
option 1 (25 acre site):									
limestone	CY	40333.333	$ 47.50	$ 1,915,833.33		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	711		$ -	$ 172.98	$ 122,988.78	$ 336.62	$ 239,336.82	
limestone placement	CY	40333.333		$ -	$ 1.16	$ 46,786.67	$ 2.09	$ 84,296.67	
			MATERIAL SUBTOTAL	$ 1,915,833.33	***LABOR SUBTOTAL***	$ 174,964.85	***EQUIP SUBTOTAL***	$ 334,656.39	
			SALES TAX (MATERIALS) 5%	$ 95,791.67	***Labor Insurance 32%***	$ 55,988.75			
			SUBTOTALS	$ 2,011,625.00		$ 230,953.60		$ 334,656.39	
			TOTAL COST	$ 2,577,234.98					
			CONTIGENCY 20%	$ 515,447.00					
			OVERHEAD 10%	$ 257,723.50					
			PROFIT 8%	$ 268,032.44					
			TOTAL COST						$ 3,618,438
spat	EA	90000000	$ 0.010	$ 900,000.00		$ -		$ -	
Mob/Demob	HR	17			$ 172.98	$ 2,940.66	$ 118.83	$ 2,020.11	
barge delivery	HR	14		$ -	$ 172.98	$ 2,421.72	$ 151.41	$ 2,119.74	
spat planting	EA	90000000		$ -	$ 0.001	$ 84,330.00		$ -	
			MATERIAL SUBTOTAL	$ 900,000.00	***LABOR SUBTOTAL***	$ 89,692.38	***EQUIP SUBTOTAL***	$ 4,139.85	
			SALES TAX (MATERIALS) 5%	$ 45,000.00	***Labor Insurance 32%***	$ 28,701.56			
			SUBTOTALS	$ 945,000.00		$ 118,393.94		$ 4,139.85	
			TOTAL COST	$ 1,067,533.79					
			CONTIGENCY 20%	$ 213,506.76					
			OVERHEAD 10%	$ 106,753.38					
			PROFIT 8%	$ 111,023.51					
			TOTAL COST						$ 1,498,817

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
limestone	CY	80666.667	$ 47.50	$ 3,831,666.67		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	1421		$ -	$ 172.98	$ 245,804.58	$ 336.62	$ 478,337.02	
limestone placement	CY	80666.667		$ -	$ 1.16	$ 93,573.33	$ 2.09	$ 168,593.33	
			MATERIAL SUBTOTAL	$ 3,831,666.67	***LABOR SUBTOTAL***	$ 344,567.31	***EQUIP SUBTOTAL***	$ 657,953.25	
			SALES TAX (MATERIALS) 5%	$ 191,583.33	***Labor Insurance 32%***	$ 110,261.54			
			SUBTOTALS	$ 4,023,250.00		$ 454,828.85		$ 657,953.25	
			TOTAL COST	$ 5,136,032.11					
			CONTIGENCY 20%	$ 1,027,206.42					
			OVERHEAD 10%	$ 513,603.21					
			PROFIT 8%	$ 534,147.34					
			TOTAL COST						$ 7,210,989
spat	EA	180000000	$ 0.010	$ 1,800,000.00		$ -		$ -	
Mob/Demob	HR	17			$ 172.98	$ 2,940.66	$ 118.83	$ 2,020.11	
barge delivery	HR	14		$ -	$ 172.98	$ 2,421.72	$ 151.41	$ 2,119.74	
spat planting	EA	180000000		$ -	$ 0.001	$ 168,660.00		$ -	
			MATERIAL SUBTOTAL	$ 1,800,000.00	***LABOR SUBTOTAL***	$ 174,022.38	***EQUIP SUBTOTAL***	$ 4,139.85	
			SALES TAX (MATERIALS) 5%	$ 90,000.00	***Labor Insurance 32%***	$ 55,687.16			
			SUBTOTALS	$ 1,890,000.00		$ 229,709.54		$ 4,139.85	
			TOTAL COST	$ 2,123,849.39					
			CONTIGENCY 20%	$ 424,769.88					
			OVERHEAD 10%	$ 212,384.94					
			PROFIT 8%	$ 220,880.34					
			TOTAL COST						$ 2,981,885

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
limestone	CY	161333.33	$ 47.50	$ 7,663,333.33		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	2842		$ -	$ 172.98	$ 491,609.16	$ 336.62	$ 956,674.04	
limestone placement	CY	161333.33		$ -	$ 1.16	$ 187,146.67	$ 2.09	$ 337,186.67	
			MATERIAL SUBTOTAL	$ 7,663,333.33	***LABOR SUBTOTAL***	$ 683,945.23	***EQUIP SUBTOTAL***	$ 1,304,883.61	
			SALES TAX (MATERIALS) 5%	$ 383,166.67	***Labor Insurance 32%***	$ 218,862.47			
			SUBTOTALS	$ 8,046,500.00		$ 902,807.70		$ 1,304,883.61	
			TOTAL COST	$ 10,254,191.31					
			CONTIGENCY 20%	$ 2,050,838.26					
			OVERHEAD 10%	$ 1,025,419.13					
			PROFIT 8%	$ 1,066,435.90					
			TOTAL COST						$ 14,396,885
spat	EA	360000000	$ 0.010	$ 3,600,000.00		$ -		$ -	
Mob/Demob	HR	17			$ 172.98	$ 2,940.66	$ 118.83	$ 2,020.11	
barge delivery	HR	14		$ -	$ 172.98	$ 2,421.72	$ 151.41	$ 2,119.74	
spat planting	EA	360000000		$ -	$ 0.001	$ 337,320.00		$ -	
			MATERIAL SUBTOTAL	$ 3,600,000.00	***LABOR SUBTOTAL***	$ 342,682.38	***EQUIP SUBTOTAL***	$ 4,139.85	
			SALES TAX (MATERIALS) 5%	$ 180,000.00	***Labor Insurance 32%***	$ 109,658.36			
			SUBTOTALS	$ 3,780,000.00		$ 452,340.74		$ 4,139.85	
			TOTAL COST	$ 4,236,480.59					
			CONTIGENCY 20%	$ 847,296.12					
			OVERHEAD 10%	$ 423,648.06					
			PROFIT 8%	$ 440,593.98					
			TOTAL COST						$ 5,948,019

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 4.5M spat/ac)									
option 1 (25 acre site):									
limestone	CY	40333.333	$ 47.50	$ 1,915,833.33		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	711		$ -	$ 172.98	$ 122,988.78	$ 336.62	$ 239,336.82	
limestone placement	CY	40333.333		$ -	$ 1.16	$ 46,786.67	$ 2.09	$ 84,296.67	
			MATERIAL SUBTOTAL	$ 1,915,833.33	***LABOR SUBTOTAL***	$ 174,964.85	***EQUIP SUBTOTAL***	$ 334,656.39	
			SALES TAX (MATERIALS) 5%	$ 95,791.67	***Labor Insurance 32%***	$ 55,988.75			
			SUBTOTALS	$ 2,011,625.00		$ 230,953.60		$ 334,656.39	
			TOTAL COST	$ 2,577,234.98					
			CONTIGENCY 20%	$ 515,447.00					
			OVERHEAD 10%	$ 257,723.50					
			PROFIT 8%	$ 268,032.44					
			TOTAL COST						$ 3,618,438
spat	EA	112500000	$ 0.010	$ 1,125,000.00		$ -		$ -	
Mob/Demob	HR	17			$ 172.98	$ 2,940.66	$ 118.83	$ 2,020.11	
barge delivery	HR	14		$ -	$ 172.98	$ 2,421.72	$ 151.41	$ 2,119.74	
spat planting	EA	112500000		$ -	$ 0.001	$ 105,412.50		$ -	
			MATERIAL SUBTOTAL	$ 1,125,000.00	***LABOR SUBTOTAL***	$ 110,774.88	***EQUIP SUBTOTAL***	$ 4,139.85	
			SALES TAX (MATERIALS) 5%	$ 56,250.00	***Labor Insurance 32%***	$ 35,447.96			
			SUBTOTALS	$ 1,181,250.00		$ 146,222.84		$ 4,139.85	
			TOTAL COST	$ 1,331,612.69					
			CONTIGENCY 20%	$ 266,322.54					
			OVERHEAD 10%	$ 133,161.27					
			PROFIT 8%	$ 138,487.72					
			TOTAL COST						$ 1,869,584

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
limestone	CY	80666.667	$ 47.50	$ 3,831,666.67		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	30	1421		$ -	$ 172.98	$ 245,804.58	$ 336.62	$ 478,337.02	
limestone placement	CY	80666.667		$ -	$ 1.16	$ 93,573.33	$ 2.09	$ 168,593.33	
			MATERIAL SUBTOTAL	$ 3,831,666.67	***LABOR SUBTOTAL***	$ 344,567.31	***EQUIP SUBTOTAL***	$ 657,953.25	
			SALES TAX (MATERIALS) 5%	$ 191,583.33	***Labor Insurance 32%***	$ 110,261.54			
			SUBTOTALS	$ 4,023,250.00		$ 454,828.85		$ 657,953.25	
			TOTAL COST	$ 5,136,032.11					
			CONTIGENCY 20%	$ 1,027,206.42					
			OVERHEAD 10%	$ 513,603.21					
			PROFIT 8%	$ 534,147.34					
			TOTAL COST						$ 7,210,989
spat	EA	225000000	$ 0.010	$ 2,250,000.00		$ -		$ -	
Mob/Demob	HR	17			$ 172.98	$ 2,940.66	$ 118.83	$ 2,020.11	
barge delivery	HR	14		$ -	$ 172.98	$ 2,421.72	$ 151.41	$ 2,119.74	
spat planting	EA	225000000		$ -	$ 0.001	$ 210,825.00		$ -	
			MATERIAL SUBTOTAL	$ 2,250,000.00	***LABOR SUBTOTAL***	$ 216,187.38	***EQUIP SUBTOTAL***	$ 4,139.85	
			SALES TAX (MATERIALS) 5%	$ 112,500.00	***Labor Insurance 32%***	$ 69,179.96			
			SUBTOTALS	$ 2,362,500.00		$ 285,367.34		$ 4,139.85	
			TOTAL COST	$ 2,652,007.19					
			CONTIGENCY 20%	$ 530,401.44					
			OVERHEAD 10%	$ 265,200.72					
			PROFIT 8%	$ 275,808.75					
			TOTAL COST						$ 3,723,418

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
limestone	CY	161333.33	$ 47.50	$ 7,663,333.33		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	2842		$ -	$ 172.98	$ 491,609.16	$ 336.62	$ 956,674.04	
limestone placement	CY	161333.33		$ -	$ 1.16	$ 187,146.67	$ 2.09	$ 337,186.67	
			MATERIAL SUBTOTAL	$ 7,663,333.33	***LABOR SUBTOTAL***	$ 683,945.23	***EQUIP SUBTOTAL***	$ 1,304,883.61	
			SALES TAX (MATERIALS) 5%	$ 383,166.67	***Labor Insurance 32%***	$ 218,862.47			
			SUBTOTALS	$ 8,046,500.00		$ 902,807.70		$ 1,304,883.61	
			TOTAL COST	$ 10,254,191.31					
			CONTIGENCY 20%	$ 2,050,838.26					
			OVERHEAD 10%	$ 1,025,419.13					
			PROFIT 8%	$ 1,066,435.90					
			TOTAL COST						$ 14,396,885
spat	EA	450000000	$ 0.010	$ 4,500,000.00		$ -		$ -	
Mob/Demob	HR	17			$ 172.98	$ 2,940.66	$ 118.83	$ 2,020.11	
barge delivery	HR	14		$ -	$ 172.98	$ 2,421.72	$ 151.41	$ 2,119.74	
spat planting	EA	450000000		$ -	$ 0.001	$ 421,650.00		$ -	
			MATERIAL SUBTOTAL	$ 4,500,000.00	***LABOR SUBTOTAL***	$ 427,012.38	***EQUIP SUBTOTAL***	$ 4,139.85	
			SALES TAX (MATERIALS) 5%	$ 225,000.00	***Labor Insurance 32%***	$ 136,643.96			
			SUBTOTALS	$ 4,725,000.00		$ 563,656.34		$ 4,139.85	
			TOTAL COST	$ 5,292,796.19					
			CONTIGENCY 20%	$ 1,058,559.24					
			OVERHEAD 10%	$ 529,279.62					
			PROFIT 8%	$ 550,450.80					
			TOTAL COST						$ 7,431,086

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 6.75M spat/ac)									
option 1 (25 acre site):									
limestone	CY	40333.333	$ 47.50	$ 1,915,833.33		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	711		$ -	$ 172.98	$ 122,988.78	$ 336.62	$ 239,336.82	
limestone placement	CY	40333.333		$ -	$ 1.16	$ 46,786.67	$ 2.09	$ 84,296.67	
			MATERIAL SUBTOTAL	$ 1,915,833.33	***LABOR SUBTOTAL***	$ 174,964.85	***EQUIP SUBTOTAL***	$ 334,656.39	
			SALES TAX (MATERIALS) 5%	$ 95,791.67	***Labor Insurance 32%***	$ 55,988.75			
			SUBTOTALS	$ 2,011,625.00		$ 230,953.60		$ 334,656.39	
			TOTAL COST	$ 2,577,234.98					
			CONTIGENCY 20%	$ 515,447.00					
			OVERHEAD 10%	$ 257,723.50					
			PROFIT 8%	$ 268,032.44					
			TOTAL COST						$ 3,618,438
spat	EA	168750000	$ 0.010	$ 1,687,500.00		$ -		$ -	
Mob/Demob	HR	17			$ 172.98	$ 2,940.66	$ 118.83	$ 2,020.11	
barge delivery	HR	14		$ -	$ 172.98	$ 2,421.72	$ 151.41	$ 2,119.74	
spat planting	EA	168750000		$ -	$ 0.001	$ 158,118.75		$ -	
			MATERIAL SUBTOTAL	$ 1,687,500.00	***LABOR SUBTOTAL***	$ 163,481.13	***EQUIP SUBTOTAL***	$ 4,139.85	
			SALES TAX (MATERIALS) 5%	$ 84,375.00	***Labor Insurance 32%***	$ 52,313.96			
			SUBTOTALS	$ 1,771,875.00		$ 215,795.09		$ 4,139.85	
			TOTAL COST	$ 1,991,809.94					
			CONTIGENCY 20%	$ 398,361.99					
			OVERHEAD 10%	$ 199,180.99					
			PROFIT 8%	$ 207,148.23					
			TOTAL COST						$ 2,796,501

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
limestone	CY	80666.667	$ 47.50	$ 3,831,666.67		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	1421		$ -	$ 172.98	$ 245,804.58	$ 336.62	$ 478,337.02	
limestone placement	CY	80666.667		$ -	$ 1.16	$ 93,573.33	$ 2.09	$ 168,593.33	
			MATERIAL SUBTOTAL	$ 3,831,666.67	***LABOR SUBTOTAL***	$ 344,567.31	***EQUIP SUBTOTAL***	$ 657,953.25	
			SALES TAX (MATERIALS) 5%	$ 191,583.33	***Labor Insurance 32%***	$ 110,261.54			
			SUBTOTALS	$ 4,023,250.00		$ 454,828.85		$ 657,953.25	
			TOTAL COST	$ 5,136,032.11					
			CONTIGENCY 20%	$ 1,027,206.42					
			OVERHEAD 10%	$ 513,603.21					
			PROFIT 8%	$ 534,147.34					
			TOTAL COST						$ 7,210,989
spat	EA	337500000	$ 0.010	$ 3,375,000.00		$ -		$ -	
Mob/Demob	HR	17			$ 172.98	$ 2,940.66	$ 118.83	$ 2,020.11	
barge delivery	HR	14		$ -	$ 172.98	$ 2,421.72	$ 151.41	$ 2,119.74	
spat planting	EA	337500000		$ -	$ 0.001	$ 316,237.50		$ -	
			MATERIAL SUBTOTAL	$ 3,375,000.00	***LABOR SUBTOTAL***	$ 321,599.88	***EQUIP SUBTOTAL***	$ 4,139.85	
			SALES TAX (MATERIALS) 5%	$ 168,750.00	***Labor Insurance 32%***	$ 102,911.96			
			SUBTOTALS	$ 3,543,750.00		$ 424,511.84		$ 4,139.85	
			TOTAL COST	$ 3,972,401.69					
			CONTIGENCY 20%	$ 794,480.34					
			OVERHEAD 10%	$ 397,240.17					
			PROFIT 8%	$ 413,129.78					
			TOTAL COST						$ 5,577,252

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
limestone	CY	161333.33	$ 47.50	$ 7,663,333.33		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	2842		$ -	$ 172.98	$ 491,609.16	$ 336.62	$ 956,674.04	
limestone placement	CY	161333.33		$ -	$ 1.16	$ 187,146.67	$ 2.09	$ 337,186.67	
			MATERIAL SUBTOTAL	$ 7,663,333.33	***LABOR SUBTOTAL***	$ 683,945.23	***EQUIP SUBTOTAL***	$ 1,304,883.61	
			SALES TAX (MATERIALS) 5%	$ 383,166.67	***Labor Insurance 32%***	$ 218,862.47			
			SUBTOTALS	$ 8,046,500.00		$ 902,807.70		$ 1,304,883.61	
			TOTAL COST	$ 10,254,191.31					
			CONTIGENCY 20%	$ 2,050,838.26					
			OVERHEAD 10%	$ 1,025,419.13					
			PROFIT 8%	$ 1,066,435.90					
			TOTAL COST						$ 14,396,885
spat	EA	675000000	$ 0.010	$ 6,750,000.00		$ -		$ -	
Mob/Demob	HR	17			$ 172.98	$ 2,940.66	$ 118.83	$ 2,020.11	
barge delivery	HR	14		$ -	$ 172.98	$ 2,421.72	$ 151.41	$ 2,119.74	
spat planting	EA	675000000		$ -	$ 0.001	$ 632,475.00		$ -	
			MATERIAL SUBTOTAL	$ 6,750,000.00	***LABOR SUBTOTAL***	$ 637,837.38	***EQUIP SUBTOTAL***	$ 4,139.85	
			SALES TAX (MATERIALS) 5%	$ 337,500.00	***Labor Insurance 32%***	$ 204,107.96			
			SUBTOTALS	$ 7,087,500.00		$ 841,945.34		$ 4,139.85	
			TOTAL COST	$ 7,933,585.19					
			CONTIGENCY 20%	$ 1,586,717.04					
			OVERHEAD 10%	$ 793,358.52					
			PROFIT 8%	$ 825,092.86					
			TOTAL COST						$ 11,138,754

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 3.6M spat/ac)									
option 1 (25 acre site):									
granite	CY	40333.3333	$ 48.00	$ 1,936,000.00		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	480		$ -	$ 172.98	$ 83,030.40	$ 336.62	$ 161,577.60	
granite placement	CY	40333.3333		$ -	$ 1.16	$ 46,786.67	$ 2.09	$ 84,296.67	
			MATERIAL SUBTOTAL	$ 1,936,000.00	***LABOR SUBTOTAL***	$ 135,006.47	***EQUIP SUBTOTAL***	$ 256,897.17	
			SALES TAX (MATERIALS) 5%	$ 96,800.00	***Labor Insurance 32%***	$ 43,202.07			
			SUBTOTALS	$ 2,032,800.00		$ 178,208.54		$ 256,897.17	
			TOTAL COST	$ 2,467,905.70					
			CONTIGENCY 20%	$ 493,581.14					
			OVERHEAD 10%	$ 246,790.57					
			PROFIT 8%	$ 256,662.19					
			TOTAL COST						$ 3,464,940
spat	EA	90000000	$ 0.010	$ 900,000.00		$ -		$ -	
Mob/Demob	HR	17			$ 172.98	$ 2,940.66	$ 118.83	$ 2,020.11	
barge delivery	HR	14		$ -	$ 172.98	$ 2,421.72	$ 151.41	$ 2,119.74	
spat planting	EA	90000000		$ -	$ 0.001	$ 84,330.00		$ -	
			MATERIAL SUBTOTAL	$ 900,000.00	***LABOR SUBTOTAL***	$ 89,692.38	***EQUIP SUBTOTAL***	$ 4,139.85	
			SALES TAX (MATERIALS) 5%	$ 45,000.00	***Labor Insurance 32%***	$ 28,701.56			
			SUBTOTALS	$ 945,000.00		$ 118,393.94		$ 4,139.85	
			TOTAL COST	$ 1,067,533.79					
			CONTIGENCY 20%	$ 213,506.76					
			OVERHEAD 10%	$ 106,753.38					
			PROFIT 8%	$ 111,023.51					
			TOTAL COST						$ 1,498,817

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
granite	CY	80666.6667	$ 48.00	$ 3,872,000.00		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	960		$ -	$ 172.98	$ 166,060.80	$ 336.62	$ 323,155.20	
granite placement	CY	80666.6667		$ -	$ 1.16	$ 93,573.33	$ 2.09	$ 168,593.33	
			MATERIAL SUBTOTAL	$ 3,872,000.00	***LABOR SUBTOTAL***	$ 264,823.53	***EQUIP SUBTOTAL***	$ 502,771.43	
			SALES TAX (MATERIALS) 5%	$ 193,600.00	***Labor Insurance 32%***	$ 84,743.53			
			SUBTOTALS	$ 4,065,600.00		$ 349,567.06		$ 502,771.43	
			TOTAL COST	$ 4,917,938.50					
			CONTIGENCY 20%	$ 983,587.70					
			OVERHEAD 10%	$ 491,793.85					
			PROFIT 8%	$ 511,465.60					
			TOTAL COST						$ 6,904,786
spat	EA	180000000	$ 0.010	$ 1,800,000.00		$ -		$ -	
Mob/Demob	HR	17			$ 172.98	$ 2,940.66	$ 118.83	$ 2,020.11	
barge delivery	HR	14		$ -	$ 172.98	$ 2,421.72	$ 151.41	$ 2,119.74	
spat planting	EA	180000000		$ -	$ 0.001	$ 168,660.00		$ -	
			MATERIAL SUBTOTAL	$ 1,800,000.00	***LABOR SUBTOTAL***	$ 174,022.38	***EQUIP SUBTOTAL***	$ 4,139.85	
			SALES TAX (MATERIALS) 5%	$ 90,000.00	***Labor Insurance 32%***	$ 55,687.16			
			SUBTOTALS	$ 1,890,000.00		$ 229,709.54		$ 4,139.85	
			TOTAL COST	$ 2,123,849.39					
			CONTIGENCY 20%	$ 424,769.88					
			OVERHEAD 10%	$ 212,384.94					
			PROFIT 8%	$ 220,880.34					
			TOTAL COST						$ 2,981,885

DESCRIPTION	***UOM***	***QTY***	***MATERIAL UNIT COST***	***TOTAL MATERIAL***	***LABOR UNIT COST LABOR***	***TOTAL LABOR***	***EQUIP UNIT COST***	***TOTAL EQUIP***	
option 3 (100 acre site):									
granite	CY	161333.333	$ 48.00	$ 7,744,000.00		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	1921		$ -	$ 172.98	$ 332,294.58	$ 336.62	$ 646,647.02	
granite placement	CY	161333.333		$ -	$ 1.16	$ 187,146.67	$ 2.09	$ 337,186.67	
			MATERIAL SUBTOTAL	$ 7,744,000.00	***LABOR SUBTOTAL***	$ 524,630.65	***EQUIP SUBTOTAL***	$ 994,856.59	
			SALES TAX (MATERIALS) 5%	$ 387,200.00	***Labor Insurance 32%***	$ 167,881.81			
			SUBTOTALS	$ 8,131,200.00		$ 692,512.45		$ 994,856.59	
			TOTAL COST	$ 9,818,569.04					
			CONTIGENCY 20%	$ 1,963,713.81					
			OVERHEAD 10%	$ 981,856.90					
			PROFIT 8%	$ 1,021,131.18					
			TOTAL COST						$ 13,785,271
spat	EA	360000000	$ 0.010	$ 3,600,000.00		$ -		$ -	
Mob/Demob	HR	17			$ 172.98	$ 2,940.66	$ 118.83	$ 2,020.11	
barge delivery	HR	14		$ -	$ 172.98	$ 2,421.72	$ 151.41	$ 2,119.74	
spat planting	EA	360000000		$ -	$ 0.001	$ 337,320.00		$ -	
			MATERIAL SUBTOTAL	$ 3,600,000.00	***LABOR SUBTOTAL***	$ 342,682.38	***EQUIP SUBTOTAL***	$ 4,139.85	
			SALES TAX (MATERIALS) 5%	$ 180,000.00	***Labor Insurance 32%***	$ 109,658.36			
			SUBTOTALS	$ 3,780,000.00		$ 452,340.74		$ 4,139.85	
			TOTAL COST	$ 4,236,480.59					
			CONTIGENCY 20%	$ 847,296.12					
			OVERHEAD 10%	$ 423,648.06					
			PROFIT 8%	$ 440,593.98					
			TOTAL COST						$ 5,948,019

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 4.5M spat/ac)									
option 1 (25 acre site):									
granite	CY	40333.3333	$ 48.00	$ 1,936,000.00		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	480		$ -	$ 172.98	$ 83,030.40	$ 336.62	$ 161,577.60	
granite placement	CY	40333.3333		$ -	$ 1.16	$ 46,786.67	$ 2.09	$ 84,296.67	
			MATERIAL SUBTOTAL	$ 1,936,000.00	***LABOR SUBTOTAL***	$ 135,006.47	***EQUIP SUBTOTAL***	$ 256,897.17	
			SALES TAX (MATERIALS) 5%	$ 96,800.00	***Labor Insurance 32%***	$ 43,202.07			
			SUBTOTALS	$ 2,032,800.00		$ 178,208.54		$ 256,897.17	
			TOTAL COST	$ 2,467,905.70					
			CONTIGENCY 20%	$ 493,581.14					
			OVERHEAD 10%	$ 246,790.57					
			PROFIT 8%	$ 256,662.19					
			TOTAL COST						$ 3,464,940
spat	EA	112500000	$ 0.010	$ 1,125,000.00		$ -		$ -	
Mob/Demob	HR	17			$ 172.98	$ 2,940.66	$ 118.83	$ 2,020.11	
barge delivery	HR	14		$ -	$ 172.98	$ 2,421.72	$ 151.41	$ 2,119.74	
spat planting	EA	112500000		$ -	$ 0.001	$ 105,412.50		$ -	
			MATERIAL SUBTOTAL	$ 1,125,000.00	***LABOR SUBTOTAL***	$ 110,774.88	***EQUIP SUBTOTAL***	$ 4,139.85	
			SALES TAX (MATERIALS) 5%	$ 56,250.00	***Labor Insurance 32%***	$ 35,447.96			
			SUBTOTALS	$ 1,181,250.00		$ 146,222.84		$ 4,139.85	
			TOTAL COST	$ 1,331,612.69					
			CONTIGENCY 20%	$ 266,322.54					
			OVERHEAD 10%	$ 133,161.27					
			PROFIT 8%	$ 138,487.72					
			TOTAL COST						$ 1,869,584

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
granite	CY	80666.6667	$ 48.00	$ 3,872,000.00		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	960		$ -	$ 172.98	$ 166,060.80	$ 336.62	$ 323,155.20	
granite placement	CY	80666.6667		$ -	$ 1.16	$ 93,573.33	$ 2.09	$ 168,593.33	
			MATERIAL SUBTOTAL	$ 3,872,000.00	***LABOR SUBTOTAL***	$ 264,823.53	***EQUIP SUBTOTAL***	$ 502,771.43	
			SALES TAX (MATERIALS) 5%	$ 193,600.00	***Labor Insurance 32%***	$ 84,743.53			
			SUBTOTALS	$ 4,065,600.00		$ 349,567.06		$ 502,771.43	
			TOTAL COST	$ 4,917,938.50					
			CONTIGENCY 20%	$ 983,587.70					
			OVERHEAD 10%	$ 491,793.85					
			PROFIT 8%	$ 511,465.60					
			TOTAL COST						$ 6,904,786
spat	EA	225000000	$ 0.010	$ 2,250,000.00		$ -		$ -	
Mob/Demob	HR	17			$ 172.98	$ 2,940.66	$ 118.83	$ 2,020.11	
barge delivery	HR	14		$ -	$ 172.98	$ 2,421.72	$ 151.41	$ 2,119.74	
spat planting	EA	225000000		$ -	$ 0.001	$ 210,825.00		$ -	
			MATERIAL SUBTOTAL	$ 2,250,000.00	***LABOR SUBTOTAL***	$ 216,187.38	***EQUIP SUBTOTAL***	$ 4,139.85	
			SALES TAX (MATERIALS) 5%	$ 112,500.00	***Labor Insurance 32%***	$ 69,179.96			
			SUBTOTALS	$ 2,362,500.00		$ 285,367.34		$ 4,139.85	
			TOTAL COST	$ 2,652,007.19					
			CONTIGENCY 20%	$ 530,401.44					
			OVERHEAD 10%	$ 265,200.72					
			PROFIT 8%	$ 275,808.75					
			TOTAL COST						$ 3,723,418

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
granite	CY	161333.333	$ 48.00	$ 7,744,000.00		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	1921		$ -	$ 172.98	$ 332,294.58	$ 336.62	$ 646,647.02	
granite placement	CY	161333.333		$ -	$ 1.16	$ 187,146.67	$ 2.09	$ 337,186.67	
			MATERIAL SUBTOTAL	$ 7,744,000.00	***LABOR SUBTOTAL***	$ 524,630.65	***EQUIP SUBTOTAL***	$ 994,856.59	
			SALES TAX (MATERIALS) 5%	$ 387,200.00	***Labor Insurance 32%***	$ 167,881.81			
			SUBTOTALS	$ 8,131,200.00		$ 692,512.45		$ 994,856.59	
			TOTAL COST	$ 9,818,569.04					
			CONTIGENCY 20%	$ 1,963,713.81					
			OVERHEAD 10%	$ 981,856.90					
			PROFIT 8%	$ 1,021,131.18					
			TOTAL COST						$ 13,785,271
spat	EA	450000000	$ 0.010	$ 4,500,000.00		$ -		$ -	
Mob/Demob	HR	17			$ 172.98	$ 2,940.66	$ 118.83	$ 2,020.11	
barge delivery	HR	14		$ -	$ 172.98	$ 2,421.72	$ 151.41	$ 2,119.74	
spat planting	EA	450000000		$ -	$ 0.001	$ 421,650.00		$ -	
			MATERIAL SUBTOTAL	$ 4,500,000.00	***LABOR SUBTOTAL***	$ 427,012.38	***EQUIP SUBTOTAL***	$ 4,139.85	
			SALES TAX (MATERIALS) 5%	$ 225,000.00	***Labor Insurance 32%***	$ 136,643.96			
			SUBTOTALS	$ 4,725,000.00		$ 563,656.34		$ 4,139.85	
			TOTAL COST	$ 5,292,796.19					
			CONTIGENCY 20%	$ 1,058,559.24					
			OVERHEAD 10%	$ 529,279.62					
			PROFIT 8%	$ 550,450.80					
			TOTAL COST						$ 7,431,086

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 6.75M spat/ac)									
option 1 (25 acre site):									
granite	CY	40333.3333	$ 48.00	$ 1,936,000.00		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	480		$ -	$ 172.98	$ 83,030.40	$ 336.62	$ 161,577.60	
granite placement	CY	40333.3333		$ -	$ 1.16	$ 46,786.67	$ 2.09	$ 84,296.67	
			MATERIAL SUBTOTAL	$ 1,936,000.00	***LABOR SUBTOTAL***	$ 135,006.47	***EQUIP SUBTOTAL***	$ 256,897.17	
			SALES TAX (MATERIALS) 5%	$ 96,800.00	***Labor Insurance 32%***	$ 43,202.07			
			SUBTOTALS	$ 2,032,800.00		$ 178,208.54		$ 256,897.17	
			TOTAL COST	$ 2,467,905.70					
			CONTIGENCY 20%	$ 493,581.14					
			OVERHEAD 10%	$ 246,790.57					
			PROFIT 8%	$ 256,662.19					
			TOTAL COST						$ 3,464,940
spat	EA	168750000	$ 0.010	$ 1,687,500.00		$ -		$ -	
Mob/Demob	HR	17			$ 172.98	$ 2,940.66	$ 118.83	$ 2,020.11	
barge delivery	HR	14		$ -	$ 172.98	$ 2,421.72	$ 151.41	$ 2,119.74	
spat planting	EA	168750000		$ -	$ 0.001	$ 158,118.75		$ -	
			MATERIAL SUBTOTAL	$ 1,687,500.00	***LABOR SUBTOTAL***	$ 163,481.13	***EQUIP SUBTOTAL***	$ 4,139.85	
			SALES TAX (MATERIALS) 5%	$ 84,375.00	***Labor Insurance 32%***	$ 52,313.96			
			SUBTOTALS	$ 1,771,875.00		$ 215,795.09		$ 4,139.85	
			TOTAL COST	$ 1,991,809.94					
			CONTIGENCY 20%	$ 398,361.99					
			OVERHEAD 10%	$ 199,180.99					
			PROFIT 8%	$ 207,148.23					
			TOTAL COST						$ 2,796,501

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
granite	CY	80666.6667	$ 48.00	$ 3,872,000.00		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	960		$ -	$ 172.98	$ 166,060.80	$ 336.62	$ 323,155.20	
granite placement	CY	80666.6667		$ -	$ 1.16	$ 93,573.33	$ 2.09	$ 168,593.33	
			MATERIAL SUBTOTAL	$ 3,872,000.00	***LABOR SUBTOTAL***	$ 264,823.53	***EQUIP SUBTOTAL***	$ 502,771.43	
			SALES TAX (MATERIALS) 5%	$ 193,600.00	***Labor Insurance 32%***	$ 84,743.53			
			SUBTOTALS	$ 4,065,600.00		$ 349,567.06		$ 502,771.43	
			TOTAL COST	$ 4,917,938.50					
			CONTIGENCY 20%	$ 983,587.70					
			OVERHEAD 10%	$ 491,793.85					
			PROFIT 8%	$ 511,465.60					
			TOTAL COST						$ 6,904,786
spat	EA	337500000	$ 0.010	$ 3,375,000.00		$ -		$ -	
Mob/Demob	HR	17			$ 172.98	$ 2,940.66	$ 118.83	$ 2,020.11	
barge delivery	HR	14		$ -	$ 172.98	$ 2,421.72	$ 151.41	$ 2,119.74	
spat planting	EA	337500000		$ -	$ 0.001	$ 316,237.50		$ -	
			MATERIAL SUBTOTAL	$ 3,375,000.00	***LABOR SUBTOTAL***	$ 321,599.88	***EQUIP SUBTOTAL***	$ 4,139.85	
			SALES TAX (MATERIALS) 5%	$ 168,750.00	***Labor Insurance 32%***	$ 102,911.96			
			SUBTOTALS	$ 3,543,750.00		$ 424,511.84		$ 4,139.85	
			TOTAL COST	$ 3,972,401.69					
			CONTIGENCY 20%	$ 794,480.34					
			OVERHEAD 10%	$ 397,240.17					
			PROFIT 8%	$ 413,129.78					
			TOTAL COST						$ 5,577,252

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
granite	CY	161333.333	$ 48.00	$ 7,744,000.00		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	1921		$ -	$ 172.98	$ 332,294.58	$ 336.62	$ 646,647.02	
granite placement	CY	161333.333		$ -	$ 1.16	$ 187,146.67	$ 2.09	$ 337,186.67	
			MATERIAL SUBTOTAL	$ 7,744,000.00	***LABOR SUBTOTAL***	$ 524,630.65	***EQUIP SUBTOTAL***	$ 994,856.59	
			SALES TAX (MATERIALS) 5%	$ 387,200.00	***Labor Insurance 32%***	$ 167,881.81			
			SUBTOTALS	$ 8,131,200.00		$ 692,512.45		$ 994,856.59	
			TOTAL COST	$ 9,818,569.04					
			CONTIGENCY 20%	$ 1,963,713.81					
			OVERHEAD 10%	$ 981,856.90					
			PROFIT 8%	$ 1,021,131.18					
			TOTAL COST						$ 13,785,271
spat	EA	675000000	$ 0.010	$ 6,750,000.00		$ -		$ -	
Mob/Demob	HR	17			$ 172.98	$ 2,940.66	$ 118.83	$ 2,020.11	
barge delivery	HR	14		$ -	$ 172.98	$ 2,421.72	$ 151.41	$ 2,119.74	
spat planting	EA	675000000		$ -	$ 0.001	$ 632,475.00		$ -	
			MATERIAL SUBTOTAL	$ 6,750,000.00	***LABOR SUBTOTAL***	$ 637,837.38	***EQUIP SUBTOTAL***	$ 4,139.85	
			SALES TAX (MATERIALS) 5%	$ 337,500.00	***Labor Insurance 32%***	$ 204,107.96			
			SUBTOTALS	$ 7,087,500.00		$ 841,945.34		$ 4,139.85	
			TOTAL COST	$ 7,933,585.19					
			CONTIGENCY 20%	$ 1,586,717.04					
			OVERHEAD 10%	$ 793,358.52					
			PROFIT 8%	$ 825,092.86					
			TOTAL COST						$ 11,138,754

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 3.6M spat/ac)									
option 1 (25 acre site):									
concrete	CY	40333.3333	$ 30.00	$ 1,210,000.00		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	384		$ -	$ 172.98	$ 66,424.32	$ 336.62	$ 129,262.08	
concrete placement	CY	40333.3333		$ -	$ 0.92	$ 37,106.67	$ 1.67	$ 67,356.67	
			MATERIAL SUBTOTAL	$ 1,210,000.00	***LABOR SUBTOTAL***	$ 108,720.39	***EQUIP SUBTOTAL***	$ 207,641.65	
			SALES TAX (MATERIALS) 5%	$ 60,500.00	***Labor Insurance 32%***	$ 34,790.52			
			SUBTOTALS	$ 1,270,500.00		$ 143,510.91		$ 207,641.65	
			TOTAL COST	$ 1,621,652.56					
			CONTIGENCY 20%	$ 324,330.51					
			OVERHEAD 10%	$ 162,165.26					
			PROFIT 8%	$ 168,651.87					
			TOTAL COST						$ 2,276,800.19
spat	EA	90000000	$ 0.010	$ 900,000.00		$ -		$ -	
Mob/Demob	HR	17			$ 172.98	$ 2,940.66	$ 118.83	$ 2,020.11	
barge delivery	HR	14		$ -	$ 172.98	$ 2,421.72	$ 151.41	$ 2,119.74	
spat planting	EA	90000000		$ -	$ 0.001	$ 84,330.00		$ -	
			MATERIAL SUBTOTAL	$ 900,000.00	***LABOR SUBTOTAL***	$ 89,692.38	***EQUIP SUBTOTAL***	$ 4,139.85	
			SALES TAX (MATERIALS) 5%	$ 45,000.00	***Labor Insurance 32%***	$ 28,701.56			
			SUBTOTALS	$ 945,000.00		$ 118,393.94		$ 4,139.85	
			TOTAL COST	$ 1,067,533.79					
			CONTIGENCY 20%	$ 213,506.76					
			OVERHEAD 10%	$ 106,753.38					
			PROFIT 8%	$ 111,023.51					
			TOTAL COST						$ 1,498,817.44

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
concrete	CY	80666.6667	$ 30.00	$ 2,420,000.00		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	768		$ -	$ 172.98	$ 132,848.64	$ 336.62	$ 258,524.16	
concrete placement	CY	80666.6667		$ -	$ 0.92	$ 74,213.33	$ 1.67	$ 134,713.33	
			MATERIAL SUBTOTAL	$ 2,420,000.00	***LABOR SUBTOTAL***	$ 212,251.37	***EQUIP SUBTOTAL***	$ 404,260.39	
			SALES TAX (MATERIALS) 5%	$ 121,000.00	***Labor Insurance 32%***	$ 67,920.44			
			SUBTOTALS	$ 2,541,000.00		$ 280,171.81		$ 404,260.39	
			TOTAL COST	$ 3,225,432.21					
			CONTIGENCY 20%	$ 645,086.44					
			OVERHEAD 10%	$ 322,543.22					
			PROFIT 8%	$ 335,444.95					
			TOTAL COST						$ 4,528,506.82
spat	EA	180000000	$ 0.010	$ 1,800,000.00		$ -		$ -	
Mob/Demob	HR	17			$ 172.98	$ 2,940.66	$ 118.83	$ 2,020.11	
barge delivery	HR	14		$ -	$ 172.98	$ 2,421.72	$ 151.41	$ 2,119.74	
spat planting	EA	180000000		$ -	$ 0.001	$ 168,660.00		$ -	
			MATERIAL SUBTOTAL	$ 1,800,000.00	***LABOR SUBTOTAL***	$ 174,022.38	***EQUIP SUBTOTAL***	$ 4,139.85	
			SALES TAX (MATERIALS) 5%	$ 90,000.00	***Labor Insurance 32%***	$ 55,687.16			
			SUBTOTALS	$ 1,890,000.00		$ 229,709.54		$ 4,139.85	
			TOTAL COST	$ 2,123,849.39					
			CONTIGENCY 20%	$ 424,769.88					
			OVERHEAD 10%	$ 212,384.94					
			PROFIT 8%	$ 220,880.34					
			TOTAL COST						$ 2,981,884.55

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
concrete	CY	161333.333	$ 30.00	$ 4,840,000.00		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	1536		$ -	$ 172.98	$ 265,697.28	$ 336.62	$ 517,048.32	
concrete placement	CY	161333.333		$ -	$ 0.92	$ 148,426.67	$ 1.67	$ 269,426.67	
			MATERIAL SUBTOTAL	$ 4,840,000.00	***LABOR SUBTOTAL***	$ 419,313.35	***EQUIP SUBTOTAL***	$ 797,497.89	
			SALES TAX (MATERIALS) 5%	$ 242,000.00	***Labor Insurance 32%***	$ 134,180.27			
			SUBTOTALS	$ 5,082,000.00		$ 553,493.62		$ 797,497.89	
			TOTAL COST	$ 6,432,991.50					
			CONTIGENCY 20%	$ 1,286,598.30					
			OVERHEAD 10%	$ 643,299.15					
			PROFIT 8%	$ 669,031.12					
			TOTAL COST						$ 9,031,920.07
spat	EA	360000000	$ 0.010	$ 3,600,000.00		$ -		$ -	
Mob/Demob	HR	17			$ 172.98	$ 2,940.66	$ 118.83	$ 2,020.11	
barge delivery	HR	14		$ -	$ 172.98	$ 2,421.72	$ 151.41	$ 2,119.74	
spat planting	EA	360000000		$ -	$ 0.001	$ 337,320.00		$ -	
			MATERIAL SUBTOTAL	$ 3,600,000.00	***LABOR SUBTOTAL***	$ 342,682.38	***EQUIP SUBTOTAL***	$ 4,139.85	
			SALES TAX (MATERIALS) 5%	$ 180,000.00	***Labor Insurance 32%***	$ 109,658.36			
			SUBTOTALS	$ 3,780,000.00		$ 452,340.74		$ 4,139.85	
			TOTAL COST	$ 4,236,480.59					
			CONTIGENCY 20%	$ 847,296.12					
			OVERHEAD 10%	$ 423,648.06					
			PROFIT 8%	$ 440,593.98					
			TOTAL COST						$ 5,948,018.75

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 4.5M spat/ac)									
option 1 (25 acre site):									
concrete	CY	40333.3333	$ 30.00	$ 1,210,000.00		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	384		$ -	$ 172.98	$ 66,424.32	$ 336.62	$ 129,262.08	
concrete placement	CY	40333.3333		$ -	$ 0.92	$ 37,106.67	$ 1.67	$ 67,356.67	
			MATERIAL SUBTOTAL	$ 1,210,000.00	***LABOR SUBTOTAL***	$ 108,720.39	***EQUIP SUBTOTAL***	$ 207,641.65	
			SALES TAX (MATERIALS) 5%	$ 60,500.00	***Labor Insurance 32%***	$ 34,790.52			
			SUBTOTALS	$ 1,270,500.00		$ 143,510.91		$ 207,641.65	
			TOTAL COST	$ 1,621,652.56					
			CONTIGENCY 20%	$ 324,330.51					
			OVERHEAD 10%	$ 162,165.26					
			PROFIT 8%	$ 168,651.87					
			TOTAL COST						$ 2,276,800.19
spat	EA	112500000	$ 0.010	$ 1,125,000.00		$ -		$ -	
Mob/Demob	HR	17			$ 172.98	$ 2,940.66	$ 118.83	$ 2,020.11	
barge delivery	HR	14		$ -	$ 172.98	$ 2,421.72	$ 151.41	$ 2,119.74	
spat planting	EA	112500000		$ -	$ 0.001	$ 105,412.50		$ -	
			MATERIAL SUBTOTAL	$ 1,125,000.00	***LABOR SUBTOTAL***	$ 110,774.88	***EQUIP SUBTOTAL***	$ 4,139.85	
			SALES TAX (MATERIALS) 5%	$ 56,250.00	***Labor Insurance 32%***	$ 35,447.96			
			SUBTOTALS	$ 1,181,250.00		$ 146,222.84		$ 4,139.85	
			TOTAL COST	$ 1,331,612.69					
			CONTIGENCY 20%	$ 266,322.54					
			OVERHEAD 10%	$ 133,161.27					
			PROFIT 8%	$ 138,487.72					
			TOTAL COST						$ 1,869,584.22

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
concrete	CY	80666.6667	$ 30.00	$ 2,420,000.00		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	768		$ -	$ 172.98	$ 132,848.64	$ 336.62	$ 258,524.16	
concrete placement	CY	80666.6667		$ -	$ 0.92	$ 74,213.33	$ 1.67	$ 134,713.33	
			MATERIAL SUBTOTAL	$ 2,420,000.00	***LABOR SUBTOTAL***	$ 212,251.37	***EQUIP SUBTOTAL***	$ 404,260.39	
			SALES TAX (MATERIALS) 5%	$ 121,000.00	***Labor Insurance 32%***	$ 67,920.44			
			SUBTOTALS	$ 2,541,000.00		$ 280,171.81		$ 404,260.39	
			TOTAL COST	$ 3,225,432.21					
			CONTIGENCY 20%	$ 645,086.44					
			OVERHEAD 10%	$ 322,543.22					
			PROFIT 8%	$ 335,444.95					
			TOTAL COST						$ 4,528,506.82
spat	EA	225000000	$ 0.010	$ 2,250,000.00		$ -		$ -	
Mob/Demob	HR	17			$ 172.98	$ 2,940.66	$ 118.83	$ 2,020.11	
barge delivery	HR	14		$ -	$ 172.98	$ 2,421.72	$ 151.41	$ 2,119.74	
spat planting	EA	225000000		$ -	$ 0.001	$ 210,825.00		$ -	
			MATERIAL SUBTOTAL	$ 2,250,000.00	***LABOR SUBTOTAL***	$ 216,187.38	***EQUIP SUBTOTAL***	$ 4,139.85	
			SALES TAX (MATERIALS) 5%	$ 112,500.00	***Labor Insurance 32%***	$ 69,179.96			
			SUBTOTALS	$ 2,362,500.00		$ 285,367.34		$ 4,139.85	
			TOTAL COST	$ 2,652,007.19					
			CONTIGENCY 20%	$ 530,401.44					
			OVERHEAD 10%	$ 265,200.72					
			PROFIT 8%	$ 275,808.75					
			TOTAL COST						$ 3,723,418.10

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
concrete	CY	161333.333	$ 30.00	$ 4,840,000.00		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	1536		$ -	$ 172.98	$ 265,697.28	$ 336.62	$ 517,048.32	
concrete placement	CY	161333.333		$ -	$ 0.92	$ 148,426.67	$ 1.67	$ 269,426.67	
			MATERIAL SUBTOTAL	$ 4,840,000.00	***LABOR SUBTOTAL***	$ 419,313.35	***EQUIP SUBTOTAL***	$ 797,497.89	
			SALES TAX (MATERIALS) 5%	$ 242,000.00	***Labor Insurance 32%***	$ 134,180.27			
			SUBTOTALS	$ 5,082,000.00		$ 553,493.62		$ 797,497.89	
			TOTAL COST	$ 6,432,991.50					
			CONTIGENCY 20%	$ 1,286,598.30					
			OVERHEAD 10%	$ 643,299.15					
			PROFIT 8%	$ 669,031.12					
			TOTAL COST						$ 9,031,920.07
spat	EA	450000000	$ 0.010	$ 4,500,000.00		$ -		$ -	
Mob/Demob	HR	17			$ 172.98	$ 2,940.66	$ 118.83	$ 2,020.11	
barge delivery	HR	14		$ -	$ 172.98	$ 2,421.72	$ 151.41	$ 2,119.74	
spat planting	EA	450000000		$ -	$ 0.001	$ 421,650.00		$ -	
			MATERIAL SUBTOTAL	$ 4,500,000.00	***LABOR SUBTOTAL***	$ 427,012.38	***EQUIP SUBTOTAL***	$ 4,139.85	
			SALES TAX (MATERIALS) 5%	$ 225,000.00	***Labor Insurance 32%***	$ 136,643.96			
			SUBTOTALS	$ 4,725,000.00		$ 563,656.34		$ 4,139.85	
			TOTAL COST	$ 5,292,796.19					
			CONTIGENCY 20%	$ 1,058,559.24					
			OVERHEAD 10%	$ 529,279.62					
			PROFIT 8%	$ 550,450.80					
			TOTAL COST						$ 7,431,085.85

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 6.75M spat/ac)									
option 1 (25 acre site):									
concrete	CY	40333.3333	$ 30.00	$ 1,210,000.00		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	384		$ -	$ 172.98	$ 66,424.32	$ 336.62	$ 129,262.08	
concrete placement	CY	40333.3333		$ -	$ 0.92	$ 37,106.67	$ 1.67	$ 67,356.67	
			MATERIAL SUBTOTAL	$ 1,210,000.00	***LABOR SUBTOTAL***	$ 108,720.39	***EQUIP SUBTOTAL***	$ 207,641.65	
			SALES TAX (MATERIALS) 5%	$ 60,500.00	***Labor Insurance 32%***	$ 34,790.52			
			SUBTOTALS	$ 1,270,500.00		$ 143,510.91		$ 207,641.65	
			TOTAL COST	$ 1,621,652.56					
			CONTIGENCY 20%	$ 324,330.51					
			OVERHEAD 10%	$ 162,165.26					
			PROFIT 8%	$ 168,651.87					
			TOTAL COST						$ 2,276,800.19
spat	EA	168750000	$ 0.010	$ 1,687,500.00		$ -		$ -	
Mob/Demob	HR	17			$ 172.98	$ 2,940.66	$ 118.83	$ 2,020.11	
barge delivery	HR	14		$ -	$ 172.98	$ 2,421.72	$ 151.41	$ 2,119.74	
spat planting	EA	168750000		$ -	$ 0.001	$ 158,118.75		$ -	
			MATERIAL SUBTOTAL	$ 1,687,500.00	***LABOR SUBTOTAL***	$ 163,481.13	***EQUIP SUBTOTAL***	$ 4,139.85	
			SALES TAX (MATERIALS) 5%	$ 84,375.00	***Labor Insurance 32%***	$ 52,313.96			
			SUBTOTALS	$ 1,771,875.00		$ 215,795.09		$ 4,139.85	
			TOTAL COST	$ 1,991,809.94					
			CONTIGENCY 20%	$ 398,361.99					
			OVERHEAD 10%	$ 199,180.99					
			PROFIT 8%	$ 207,148.23					
			TOTAL COST						$ 2,796,501.16

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
concrete	CY	80666.6667	$ 30.00	$ 2,420,000.00		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	768		$ -	$ 172.98	$ 132,848.64	$ 336.62	$ 258,524.16	
concrete placement	CY	80666.6667		$ -	$ 0.92	$ 74,213.33	$ 1.67	$ 134,713.33	
			MATERIAL SUBTOTAL	$ 2,420,000.00	***LABOR SUBTOTAL***	$ 212,251.37	***EQUIP SUBTOTAL***	$ 404,260.39	
			SALES TAX (MATERIALS) 5%	$ 121,000.00	***Labor Insurance 32%***	$ 67,920.44			
			SUBTOTALS	$ 2,541,000.00		$ 280,171.81		$ 404,260.39	
			TOTAL COST	$ 3,225,432.21					
			CONTIGENCY 20%	$ 645,086.44					
			OVERHEAD 10%	$ 322,543.22					
			PROFIT 8%	$ 335,444.95					
			TOTAL COST						$ 4,528,506.82
spat	EA	337500000	$ 0.010	$ 3,375,000.00		$ -		$ -	
Mob/Demob	HR	17			$ 172.98	$ 2,940.66	$ 118.83	$ 2,020.11	
barge delivery	HR	14		$ -	$ 172.98	$ 2,421.72	$ 151.41	$ 2,119.74	
spat planting	EA	337500000		$ -	$ 0.001	$ 316,237.50		$ -	
			MATERIAL SUBTOTAL	$ 3,375,000.00	***LABOR SUBTOTAL***	$ 321,599.88	***EQUIP SUBTOTAL***	$ 4,139.85	
			SALES TAX (MATERIALS) 5%	$ 168,750.00	***Labor Insurance 32%***	$ 102,911.96			
			SUBTOTALS	$ 3,543,750.00		$ 424,511.84		$ 4,139.85	
			TOTAL COST	$ 3,972,401.69					
			CONTIGENCY 20%	$ 794,480.34					
			OVERHEAD 10%	$ 397,240.17					
			PROFIT 8%	$ 413,129.78					
			TOTAL COST						$ 5,577,251.98

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
concrete	CY	161333.333	$ 30.00	$ 4,840,000.00		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	1536		$ -	$ 172.98	$ 265,697.28	$ 336.62	$ 517,048.32	
concrete placement	CY	161333.333		$ -	$ 0.92	$ 148,426.67	$ 1.67	$ 269,426.67	
			MATERIAL SUBTOTAL	$ 4,840,000.00	***LABOR SUBTOTAL***	$ 419,313.35	***EQUIP SUBTOTAL***	$ 797,497.89	
			SALES TAX (MATERIALS) 5%	$ 242,000.00	***Labor Insurance 32%***	$ 134,180.27			
			SUBTOTALS	$ 5,082,000.00		$ 553,493.62		$ 797,497.89	
			TOTAL COST	$ 6,432,991.50					
			CONTIGENCY 20%	$ 1,286,598.30					
			OVERHEAD 10%	$ 643,299.15					
			PROFIT 8%	$ 669,031.12					
			TOTAL COST						$ 9,031,920.07
spat	EA	675000000	$ 0.010	$ 6,750,000.00		$ -		$ -	
Mob/Demob	HR	17			$ 172.98	$ 2,940.66	$ 118.83	$ 2,020.11	
barge delivery	HR	14		$ -	$ 172.98	$ 2,421.72	$ 151.41	$ 2,119.74	
spat planting	EA	675000000		$ -	$ 0.001	$ 632,475.00		$ -	
			MATERIAL SUBTOTAL	$ 6,750,000.00	***LABOR SUBTOTAL***	$ 637,837.38	***EQUIP SUBTOTAL***	$ 4,139.85	
			SALES TAX (MATERIALS) 5%	$ 337,500.00	***Labor Insurance 32%***	$ 204,107.96			
			SUBTOTALS	$ 7,087,500.00		$ 841,945.34		$ 4,139.85	
			TOTAL COST	$ 7,933,585.19					
			CONTIGENCY 20%	$ 1,586,717.04					
			OVERHEAD 10%	$ 793,358.52					
			PROFIT 8%	$ 825,092.86					
			TOTAL COST						$ 11,138,753.61

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 3.6M spat/ac)									
option 1 (25 acre site):									
oyster shell dredging	CY	40333.3333	$ 15.85	$ 639,283.33		$ -		$ -	
Mob/Demob	HR	35		$ -	$ 172.98	$ 6,054.30	$ 367.43	$ 12,860.05	
barge delivery	HR	320		$ -	$ 172.98	$ 55,353.60	$ 336.62	$ 107,718.40	
oyster placement	CY	40333.3333		$ -	$ 6.27	$ 252,890.00		$ -	
			MATERIAL SUBTOTAL	$ 639,283.33	***LABOR SUBTOTAL***	$ 314,297.90	***EQUIP SUBTOTAL***	$ 120,578.45	
			SALES TAX (MATERIALS) 5%	$ 31,964.17	***Labor Insurance 32%***	$ 100,575.33			
			SUBTOTALS	$ 671,247.50		$ 414,873.23		$ 120,578.45	
			TOTAL COST	$ 1,206,699.18					
			CONTIGENCY 20%	$ 241,339.84					
			OVERHEAD 10%	$ 120,669.92					
			PROFIT 8%	$ 125,496.71					
			TOTAL COST						$ 1,694,206
spat	EA	90000000	$ 0.010	$ 900,000.00		$ -		$ -	
Mob/Demob	HR	17			$ 172.98	$ 2,940.66	$ 118.83	$ 2,020.11	
barge delivery	HR	14		$ -	$ 172.98	$ 2,421.72	$ 151.41	$ 2,119.74	
spat planting	EA	90000000		$ -	$ 0.001	$ 84,330.00		$ -	
Turbidity control	LF	4200	$ 0.69	$ 2,898.00	$ 0.15	$ 630.00	$ 0.39	$ 1,638.00	
			MATERIAL SUBTOTAL	$ 902,898.00	***LABOR SUBTOTAL***	$ 90,322.38	***EQUIP SUBTOTAL***	$ 5,777.85	
			SALES TAX (MATERIALS) 5%	$ 45,144.90	***Labor Insurance 32%***	$ 28,903.16			
			SUBTOTALS	$ 948,042.90		$ 119,225.54		$ 5,777.85	
			TOTAL COST	$ 1,073,046.29					
			CONTIGENCY 20%	$ 214,609.26					
			OVERHEAD 10%	$ 107,304.63					
			PROFIT 8%	$ 111,596.81					
			TOTAL COST						$ 1,506,557

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
oyster shell dredging	CY	80666.6667	$ 15.85	$ 1,278,566.67		$ -		$ -	
Mob/Demob	HR	35		$ -	$ 172.98	$ 6,054.30	$ 367.43	$ 12,860.05	
barge delivery	HR	640		$ -	$ 172.98	$ 110,707.20	$ 336.62	$ 215,436.80	
oyster placement	CY	80666.6667		$ -	$ 6.27	$ 505,780.00		$ -	
			MATERIAL SUBTOTAL	$ 1,278,566.67	***LABOR SUBTOTAL***	$ 622,541.50	***EQUIP SUBTOTAL***	$ 228,296.85	
			SALES TAX (MATERIALS) 5%	$ 63,928.33	***Labor Insurance 32%***	$ 199,213.28			
			SUBTOTALS	$ 1,342,495.00		$ 821,754.78		$ 228,296.85	
			TOTAL COST	$ 2,392,546.63					
			CONTIGENCY 20%	$ 478,509.33					
			OVERHEAD 10%	$ 239,254.66					
			PROFIT 8%	$ 248,824.85					
			TOTAL COST						$ 3,359,135
spat	EA	180000000	$ 0.010	$ 1,800,000.00		$ -		$ -	
Mob/Demob	HR	17			$ 172.98	$ 2,940.66	$ 118.83	$ 2,020.11	
barge delivery	HR	14		$ -	$ 172.98	$ 2,421.72	$ 151.41	$ 2,119.74	
spat planting	EA	180000000		$ -	$ 0.001	$ 168,660.00		$ -	
Turbidity control	LF	5900	$ 0.69	$ 4,071.00	$ 0.15	$ 885.00	$ 0.39	$ 2,301.00	
			MATERIAL SUBTOTAL	$ 1,804,071.00	***LABOR SUBTOTAL***	$ 174,907.38	***EQUIP SUBTOTAL***	$ 6,440.85	
			SALES TAX (MATERIALS) 5%	$ 90,203.55	***Labor Insurance 32%***	$ 55,970.36			
			SUBTOTALS	$ 1,894,274.55		$ 230,877.74		$ 6,440.85	
			TOTAL COST	$ 2,131,593.14					
			CONTIGENCY 20%	$ 426,318.63					
			OVERHEAD 10%	$ 213,159.31					
			PROFIT 8%	$ 221,685.69					
			TOTAL COST						$ 2,992,757

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
oyster shell dredging	CY	161333.333	$ 15.85	$ 2,557,133.33		$ -		$ -	
Mob/Demob	HR	35		$ -	$ 172.98	$ 6,054.30	$ 367.43	$ 12,860.05	
barge delivery	HR	1280		$ -	$ 172.98	$ 221,414.40	$ 336.62	$ 430,873.60	
oyster placement	CY	35		$ -	$ 6.27	$ 219.45		$ -	
			MATERIAL SUBTOTAL	$ 2,557,133.33	***LABOR SUBTOTAL***	$ 227,688.15	***EQUIP SUBTOTAL***	$ 443,733.65	
			SALES TAX (MATERIALS) 5%	$ 127,856.67	***Labor Insurance 32%***	$ 72,860.21			
			SUBTOTALS	$ 2,684,990.00		$ 300,548.36		$ 443,733.65	
			TOTAL COST	$ 3,429,272.01					
			CONTIGENCY 20%	$ 685,854.40					
			OVERHEAD 10%	$ 342,927.20					
			PROFIT 8%	$ 356,644.29					
			TOTAL COST						$ 4,814,698
spat	EA	360000000	$ 0.010	$ 3,600,000.00		$ -		$ -	
Mob/Demob	HR	17			$ 172.98	$ 2,940.66	$ 118.83	$ 2,020.11	
barge delivery	HR	14		$ -	$ 172.98	$ 2,421.72	$ 151.41	$ 2,119.74	
spat planting	EA	360000000		$ -	$ 0.001	$ 337,320.00		$ -	
Turbidity control	LF	8350	$ 0.69	$ 5,761.50	$ 0.15	$ 1,252.50	$ 0.39	$ 3,256.50	
			MATERIAL SUBTOTAL	$ 3,605,761.50	***LABOR SUBTOTAL***	$ 343,934.88	***EQUIP SUBTOTAL***	$ 7,396.35	
			SALES TAX (MATERIALS) 5%	$ 180,288.08	***Labor Insurance 32%***	$ 110,059.16			
			SUBTOTALS	$ 3,786,049.58		$ 453,994.04		$ 7,396.35	
			TOTAL COST	$ 4,247,439.97					
			CONTIGENCY 20%	$ 849,487.99					
			OVERHEAD 10%	$ 424,744.00					
			PROFIT 8%	$ 441,733.76					
			TOTAL COST						$ 5,963,406

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 4.5M spat/ac)									
option 1 (25 acre site):									
oyster shell dredging	CY	40333.3333	$ 15.85	$ 639,283.33		$ -		$ -	
Mob/Demob	HR	35		$ -	$ 172.98	$ 6,054.30	$ 367.43	$ 12,860.05	
barge delivery	HR	320		$ -	$ 172.98	$ 55,353.60	$ 336.62	$ 107,718.40	
oyster placement	CY	40333.3333		$ -	$ 6.27	$ 252,890.00		$ -	
			MATERIAL SUBTOTAL	$ 639,283.33	***LABOR SUBTOTAL***	$ 314,297.90	***EQUIP SUBTOTAL***	$ 120,578.45	
			SALES TAX (MATERIALS) 5%	$ 31,964.17	***Labor Insurance 32%***	$ 100,575.33			
			SUBTOTALS	$ 671,247.50		$ 414,873.23		$ 120,578.45	
			TOTAL COST	$ 1,206,699.18					
			CONTIGENCY 20%	$ 241,339.84					
			OVERHEAD 10%	$ 120,669.92					
			PROFIT 8%	$ 125,496.71					
			TOTAL COST						$ 1,694,206
spat	EA	112500000	$ 0.010	$ 1,125,000.00		$ -		$ -	
Mob/Demob	HR	17			$ 172.98	$ 2,940.66	$ 118.83	$ 2,020.11	
barge delivery	HR	14		$ -	$ 172.98	$ 2,421.72	$ 151.41	$ 2,119.74	
spat planting	EA	112500000		$ -	$ 0.001	$ 105,412.50		$ -	
Turbidity control	LF	4200	$ 0.69	$ 2,898.00	$ 0.15	$ 630.00	$ 0.39	$ 1,638.00	
			MATERIAL SUBTOTAL	$ 1,127,898.00	***LABOR SUBTOTAL***	$ 111,404.88	***EQUIP SUBTOTAL***	$ 5,777.85	
			SALES TAX (MATERIALS) 5%	$ 56,394.90	***Labor Insurance 32%***	$ 35,649.56			
			SUBTOTALS	$ 1,184,292.90		$ 147,054.44		$ 5,777.85	
			TOTAL COST	$ 1,337,125.19					
			CONTIGENCY 20%	$ 267,425.04					
			OVERHEAD 10%	$ 133,712.52					
			PROFIT 8%	$ 139,061.02					
			TOTAL COST						$ 1,877,324

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
oyster shell dredging	CY	80666.6667	$ 15.85	$ 1,278,566.67		$ -		$ -	
Mob/Demob	HR	35		$ -	$ 172.98	$ 6,054.30	$ 367.43	$ 12,860.05	
barge delivery	HR	640		$ -	$ 172.98	$ 110,707.20	$ 336.62	$ 215,436.80	
oyster placement	CY	80666.6667		$ -	$ 6.27	$ 505,780.00		$ -	
			MATERIAL SUBTOTAL	$ 1,278,566.67	***LABOR SUBTOTAL***	$ 622,541.50	***EQUIP SUBTOTAL***	$ 228,296.85	
			SALES TAX (MATERIALS) 5%	$ 63,928.33	***Labor Insurance 32%***	$ 199,213.28			
			SUBTOTALS	$ 1,342,495.00		$ 821,754.78		$ 228,296.85	
			TOTAL COST	$ 2,392,546.63					
			CONTIGENCY 20%	$ 478,509.33					
			OVERHEAD 10%	$ 239,254.66					
			PROFIT 8%	$ 248,824.85					
			TOTAL COST						$ 3,359,135
spat	EA	225000000	$ 0.010	$ 2,250,000.00		$ -		$ -	
Mob/Demob	HR	17			$ 172.98	$ 2,940.66	$ 118.83	$ 2,020.11	
barge delivery	HR	14		$ -	$ 172.98	$ 2,421.72	$ 151.41	$ 2,119.74	
spat planting	EA	225000000		$ -	$ 0.001	$ 210,825.00		$ -	
Turbidity control	LF	5900	$ 0.69	$ 4,071.00	$ 0.15	$ 885.00	$ 0.39	$ 2,301.00	
			MATERIAL SUBTOTAL	$ 2,254,071.00	***LABOR SUBTOTAL***	$ 217,072.38	***EQUIP SUBTOTAL***	$ 6,440.85	
			SALES TAX (MATERIALS) 5%	$ 112,703.55	***Labor Insurance 32%***	$ 69,463.16			
			SUBTOTALS	$ 2,366,774.55		$ 286,535.54		$ 6,440.85	
			TOTAL COST	$ 2,659,750.94					
			CONTIGENCY 20%	$ 531,950.19					
			OVERHEAD 10%	$ 265,975.09					
			PROFIT 8%	$ 276,614.10					
			TOTAL COST						$ 3,734,290

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
oyster shell dredging	CY	161333.333	$ 15.85	$ 2,557,133.33		$ -		$ -	
Mob/Demob	HR	35		$ -	$ 172.98	$ 6,054.30	$ 367.43	$ 12,860.05	
barge delivery	HR	1280		$ -	$ 172.98	$ 221,414.40	$ 336.62	$ 430,873.60	
oyster placement	CY	161333.333		$ -	$ 6.27	$ 1,011,560.00		$ -	
			MATERIAL SUBTOTAL	$ 2,557,133.33	***LABOR SUBTOTAL***	$ 1,239,028.70	***EQUIP SUBTOTAL***	$ 443,733.65	
			SALES TAX (MATERIALS) 5%	$ 127,856.67	***Labor Insurance 32%***	$ 396,489.18			
			SUBTOTALS	$ 2,684,990.00		$ 1,635,517.88		$ 443,733.65	
			TOTAL COST	$ 4,764,241.53					
			CONTIGENCY 20%	$ 952,848.31					
			OVERHEAD 10%	$ 476,424.15					
			PROFIT 8%	$ 495,481.12					
			TOTAL COST						$ 6,688,995
spat	EA	450000000	$ 0.010	$ 4,500,000.00		$ -		$ -	
Mob/Demob	HR	17			$ 172.98	$ 2,940.66	$ 118.83	$ 2,020.11	
barge delivery	HR	14		$ -	$ 172.98	$ 2,421.72	$ 151.41	$ 2,119.74	
spat planting	EA	450000000		$ -	$ 0.001	$ 421,650.00		$ -	
Turbidity control	LF	8350	$ 0.69	$ 5,761.50	$ 0.15	$ 1,252.50	$ 0.39	$ 3,256.50	
			MATERIAL SUBTOTAL	$ 4,505,761.50	***LABOR SUBTOTAL***	$ 428,264.88	***EQUIP SUBTOTAL***	$ 7,396.35	
			SALES TAX (MATERIALS) 5%	$ 225,288.08	***Labor Insurance 32%***	$ 137,044.76			
			SUBTOTALS	$ 4,731,049.58		$ 565,309.64		$ 7,396.35	
			TOTAL COST	$ 5,303,755.57					
			CONTIGENCY 20%	$ 1,060,751.11					
			OVERHEAD 10%	$ 530,375.56					
			PROFIT 8%	$ 551,590.58					
			TOTAL COST						$ 7,446,473

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 6.75M spat/ac)									
option 1 (25 acre site):									
oyster shell dredging	CY	40333.3333	$ 15.85	$ 639,283.33		$ -		$ -	
Mob/Demob	HR	35		$ -	$ 172.98	$ 6,054.30	$ 367.43	$ 12,860.05	
barge delivery	HR	320		$ -	$ 172.98	$ 55,353.60	$ 336.62	$ 107,718.40	
oyster placement	CY	40333.3333		$ -	$ 6.27	$ 252,890.00		$ -	
			MATERIAL SUBTOTAL	$ 639,283.33	***LABOR SUBTOTAL***	$ 314,297.90	***EQUIP SUBTOTAL***	$ 120,578.45	
			SALES TAX (MATERIALS) 5%	$ 31,964.17	***Labor Insurance 32%***	$ 100,575.33			
			SUBTOTALS	$ 671,247.50		$ 414,873.23		$ 120,578.45	
			TOTAL COST	$ 1,206,699.18					
			CONTIGENCY 20%	$ 241,339.84					
			OVERHEAD 10%	$ 120,669.92					
			PROFIT 8%	$ 125,496.71					
			TOTAL COST						$ 1,694,206
spat	EA	168750000	$ 0.010	$ 1,687,500.00		$ -		$ -	
Mob/Demob	HR	17			$ 172.98	$ 2,940.66	$ 118.83	$ 2,020.11	
barge delivery	HR	14		$ -	$ 172.98	$ 2,421.72	$ 151.41	$ 2,119.74	
spat planting	EA	168750000		$ -	$ 0.001	$ 158,118.75		$ -	
Turbidity control	LF	4200	$ 0.69	$ 2,898.00	$ 0.15	$ 630.00	$ 0.39	$ 1,638.00	
			MATERIAL SUBTOTAL	$ 1,690,398.00	***LABOR SUBTOTAL***	$ 164,111.13	***EQUIP SUBTOTAL***	$ 5,777.85	
			SALES TAX (MATERIALS) 5%	$ 84,519.90	***Labor Insurance 32%***	$ 52,515.56			
			SUBTOTALS	$ 1,774,917.90		$ 216,626.69		$ 5,777.85	
			TOTAL COST	$ 1,997,322.44					
			CONTIGENCY 20%	$ 399,464.49					
			OVERHEAD 10%	$ 199,732.24					
			PROFIT 8%	$ 207,721.53					
			TOTAL COST						$ 2,804,241

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
oyster shell dredging	CY	80666.6667	$ 15.85	$ 1,278,566.67		$ -		$ -	
Mob/Demob	HR	35		$ -	$ 172.98	$ 6,054.30	$ 367.43	$ 12,860.05	
barge delivery	HR	640		$ -	$ 172.98	$ 110,707.20	$ 336.62	$ 215,436.80	
oyster placement	CY	80666.6667		$ -	$ 6.27	$ 505,780.00		$ -	
			MATERIAL SUBTOTAL	$ 1,278,566.67	***LABOR SUBTOTAL***	$ 622,541.50	***EQUIP SUBTOTAL***	$ 228,296.85	
			SALES TAX (MATERIALS) 5%	$ 63,928.33	***Labor Insurance 32%***	$ 199,213.28			
			SUBTOTALS	$ 1,342,495.00		$ 821,754.78		$ 228,296.85	
			TOTAL COST	$ 2,392,546.63					
			CONTIGENCY 20%	$ 478,509.33					
			OVERHEAD 10%	$ 239,254.66					
			PROFIT 8%	$ 248,824.85					
			TOTAL COST						$ 3,359,135
spat	EA	337500000	$ 0.010	$ 3,375,000.00		$ -		$ -	
Mob/Demob	HR	17			$ 172.98	$ 2,940.66	$ 118.83	$ 2,020.11	
barge delivery	HR	14		$ -	$ 172.98	$ 2,421.72	$ 151.41	$ 2,119.74	
spat planting	EA	337500000		$ -	$ 0.001	$ 316,237.50		$ -	
Turbidity control	LF	5900	$ 0.69	$ 4,071.00	$ 0.15	$ 885.00	$ 0.39	$ 2,301.00	
			MATERIAL SUBTOTAL	$ 3,379,071.00	***LABOR SUBTOTAL***	$ 322,484.88	***EQUIP SUBTOTAL***	$ 6,440.85	
			SALES TAX (MATERIALS) 5%	$ 168,953.55	***Labor Insurance 32%***	$ 103,195.16			
			SUBTOTALS	$ 3,548,024.55		$ 425,680.04		$ 6,440.85	
			TOTAL COST	$ 3,980,145.44					
			CONTIGENCY 20%	$ 796,029.09					
			OVERHEAD 10%	$ 398,014.54					
			PROFIT 8%	$ 413,935.13					
			TOTAL COST						$ 5,588,124

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
oyster shell dredging	CY	161333.333	$ 15.85	$ 2,557,133.33		$ -		$ -	
Mob/Demob	HR	35		$ -	$ 172.98	$ 6,054.30	$ 367.43	$ 12,860.05	
barge delivery	HR	1280		$ -	$ 172.98	$ 221,414.40	$ 336.62	$ 430,873.60	
oyster placement	CY	161333.333		$ -	$ 6.27	$ 1,011,560.00		$ -	
			MATERIAL SUBTOTAL	$ 2,557,133.33	***LABOR SUBTOTAL***	$ 1,239,028.70	***EQUIP SUBTOTAL***	$ 443,733.65	
			SALES TAX (MATERIALS) 5%	$ 127,856.67	***Labor Insurance 32%***	$ 396,489.18			
			SUBTOTALS	$ 2,684,990.00		$ 1,635,517.88		$ 443,733.65	
			TOTAL COST	$ 4,764,241.53					
			CONTIGENCY 20%	$ 952,848.31					
			OVERHEAD 10%	$ 476,424.15					
			PROFIT 8%	$ 495,481.12					
			TOTAL COST						$ 6,688,995
spat	EA	675000000	$ 0.010	$ 6,750,000.00		$ -		$ -	
Mob/Demob	HR	17			$ 172.98	$ 2,940.66	$ 118.83	$ 2,020.11	
barge delivery	HR	14		$ -	$ 172.98	$ 2,421.72	$ 151.41	$ 2,119.74	
spat planting	EA	675000000		$ -	$ 0.001	$ 632,475.00		$ -	
Turbidity control	LF	8350	$ 0.69	$ 5,761.50	$ 0.15	$ 1,252.50	$ 0.39	$ 3,256.50	
			MATERIAL SUBTOTAL	$ 6,755,761.50	***LABOR SUBTOTAL***	$ 639,089.88	***EQUIP SUBTOTAL***	$ 7,396.35	
			SALES TAX (MATERIALS) 5%	$ 337,788.08	***Labor Insurance 32%***	$ 204,508.76			
			SUBTOTALS	$ 7,093,549.58		$ 843,598.64		$ 7,396.35	
			TOTAL COST	$ 7,944,544.57					
			CONTIGENCY 20%	$ 1,588,908.91					
			OVERHEAD 10%	$ 794,454.46					
			PROFIT 8%	$ 826,232.63					
			TOTAL COST						$ 11,154,141

Virginia Tributary Cost Estimate Worksheets

Nansemond River

Piankatank River

Little Wicomico River

Nansemond River

DESCRIPTION	***UOM***	***QTY***	***MATERIAL UNIT COST***	***TOTAL MATERIAL***	***LABOR UNIT COST LABOR***	***TOTAL LABOR***	***EQUIP UNIT COST***	***TOTAL EQUIP***	
high relief reef (12 inch depth, 3.6M spat/ac)									
option 1 (25 acre site):									
limestone	CY	40333	$ 47.50	$ 1,915,833.33		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	587		$ -	$ 172.98	$ 101,539.26	$ 336.62	$ 197,595.94	
limestone placement	CY	40333		$ -	$ 1.16	$ 46,786.67	$ 2.09	$ 84,296.67	
			MATERIAL SUBTOTAL	$ 1,915,833.33	***LABOR SUBTOTAL***	$ 153,515.33	***EQUIP SUBTOTAL***	$ 292,915.51	
			SALES TAX (MATERIALS) 5%	$ 95,791.67	***Labor Insurance 32%***	$ 49,124.90			
			SUBTOTALS	$ 2,011,625.00		$ 202,640.23		$ 292,915.51	
			TOTAL COST	$ 2,507,180.74					
			CONTIGENCY 20%	$ 501,436.15					
			OVERHEAD 10%	$ 250,718.07					
			PROFIT 8%	$ 260,746.80					
			TOTAL COST						$ 3,520,082
spat	EA	90000000	$ 0.010	$ 900,000.00		$ -		$ -	
Mob/Demob	HR	7			$ 172.98	$ 1,210.86	$ 118.83	$ 831.81	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	90000000		$ -	$ 0.001	$ 84,330.00		$ -	
			MATERIAL SUBTOTAL	$ 900,000.00	***LABOR SUBTOTAL***	$ 87,097.68	***EQUIP SUBTOTAL***	$ 2,194.50	
			SALES TAX (MATERIALS) 5%	$ 45,000.00	***Labor Insurance 32%***	$ 27,871.26			
			SUBTOTALS	$ 945,000.00		$ 114,968.94		$ 2,194.50	
			TOTAL COST	$ 1,062,163.44					
			CONTIGENCY 20%	$ 212,432.69					
			OVERHEAD 10%	$ 106,216.34					
			PROFIT 8%	$ 110,465.00					
			TOTAL COST						$ 1,491,277

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
limestone	CY	80667	$ 47.50	$ 3,831,666.67		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	1174		$ -	$ 172.98	$ 203,078.52	$ 336.62	$ 395,191.88	
limestone placement	CY	80667		$ -	$ 1.16	$ 93,573.33	$ 2.09	$ 168,593.33	
			MATERIAL SUBTOTAL	$ 3,831,666.67	*LABOR SUBTOTAL*	$ 301,841.25	*EQUIP SUBTOTAL*	$ 574,808.11	
			SALES TAX (MATERIALS) 5%	$ 191,583.33	*Labor Insurance 32%*	$ 96,589.20			
			SUBTOTALS	$ 4,023,250.00		$ 398,430.45		$ 574,808.11	
			TOTAL COST	$ 4,996,488.57					
			CONTIGENCY 20%	$ 999,297.71					
			OVERHEAD 10%	$ 499,648.86					
			PROFIT 8%	$ 519,634.81					
			TOTAL COST						$ 7,015,070
spat	EA	180000000	$ 0.010	$ 1,800,000.00		$ -		$ -	
Mob/Demob	HR	7			$ 172.98	$ 1,210.86	$ 118.83	$ 831.81	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	180000000		$ -	$ 0.001	$ 168,660.00		$ -	
			MATERIAL SUBTOTAL	$ 1,800,000.00	*LABOR SUBTOTAL*	$ 171,427.68	*EQUIP SUBTOTAL*	$ 2,194.50	
			SALES TAX (MATERIALS) 5%	$ 90,000.00	*Labor Insurance 32%*	$ 54,856.86			
			SUBTOTALS	$ 1,890,000.00		$ 226,284.54		$ 2,194.50	
			TOTAL COST	$ 2,118,479.04					
			CONTIGENCY 20%	$ 423,695.81					
			OVERHEAD 10%	$ 211,847.90					
			PROFIT 8%	$ 220,321.82					
			TOTAL COST						$ 2,974,345

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
limestone	CY	161333	$ 47.50	$ 7,663,333.33		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	2349		$ -	$ 172.98	$ 406,330.02	$ 336.62	$ 790,720.38	
limestone placement	CY	161333		$ -	$ 1.16	$ 187,146.67	$ 2.09	$ 337,186.67	
			MATERIAL SUBTOTAL	$ 7,663,333.33	***LABOR SUBTOTAL***	$ 598,666.09	***EQUIP SUBTOTAL***	$ 1,138,929.95	
			SALES TAX (MATERIALS) 5%	$ 383,166.67	***Labor Insurance 32%***	$ 191,573.15			
			SUBTOTALS	$ 8,046,500.00		$ 790,239.23		$ 1,138,929.95	
			TOTAL COST	$ 9,975,669.18					
			CONTIGENCY 20%	$ 1,995,133.84					
			OVERHEAD 10%	$ 997,566.92					
			PROFIT 8%	$ 1,037,469.59					
			TOTAL COST						$ 14,005,840
spat	EA	360000000	$ 0.010	$ 3,600,000.00		$ -		$ -	
Mob/Demob	HR	7			$ 172.98	$ 1,210.86	$ 118.83	$ 831.81	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	360000000		$ -	$ 0.001	$ 337,320.00		$ -	
			MATERIAL SUBTOTAL	$ 3,600,000.00	***LABOR SUBTOTAL***	$ 340,087.68	***EQUIP SUBTOTAL***	$ 2,194.50	
			SALES TAX (MATERIALS) 5%	$ 180,000.00	***Labor Insurance 32%***	$ 108,828.06			
			SUBTOTALS	$ 3,780,000.00		$ 448,915.74		$ 2,194.50	
			TOTAL COST	$ 4,231,110.24					
			CONTIGENCY 20%	$ 846,222.05					
			OVERHEAD 10%	$ 423,111.02					
			PROFIT 8%	$ 440,035.46					
			TOTAL COST						$ 5,940,479

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 4.5M spat/ac)									
option 1 (25 acre site):									
limestone	CY	40333	$ 47.50	$ 1,915,833.33		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	587		$ -	$ 172.98	$ 101,539.26	$ 336.62	$ 197,595.94	
limestone placement	CY	40333		$ -	$ 1.16	$ 46,786.67	$ 2.09	$ 84,296.67	
			MATERIAL SUBTOTAL	$ 1,915,833.33	LABOR SUBTOTAL	$ 153,515.33	EQUIP SUBTOTAL	$ 292,915.51	
			SALES TAX (MATERIALS) 5%	$ 95,791.67	Labor Insurance 32%	$ 49,124.90			
			SUBTOTALS	$ 2,011,625.00		$ 202,640.23		$ 292,915.51	
			TOTAL COST	$ 2,507,180.74					
			CONTIGENCY 20%	$ 501,436.15					
			OVERHEAD 10%	$ 250,718.07					
			PROFIT 8%	$ 260,746.80					
			TOTAL COST						$ 3,520,082
spat	EA	112500000	$ 0.010	$ 1,125,000.00		$ -		$ -	
Mob/Demob	HR	7			$ 172.98	$ 1,210.86	$ 118.83	$ 831.81	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	112500000		$ -	$ 0.001	$ 105,412.50		$ -	
			MATERIAL SUBTOTAL	$ 1,125,000.00	LABOR SUBTOTAL	$ 108,180.18	EQUIP SUBTOTAL	$ 2,194.50	
			SALES TAX (MATERIALS) 5%	$ 56,250.00	Labor Insurance 32%	$ 34,617.66			
			SUBTOTALS	$ 1,181,250.00		$ 142,797.84		$ 2,194.50	
			TOTAL COST	$ 1,326,242.34					
			CONTIGENCY 20%	$ 265,248.47					
			OVERHEAD 10%	$ 132,624.23					
			PROFIT 8%	$ 137,929.20					
			TOTAL COST						$ 1,862,044

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
limestone	CY	80667	$ 47.50	$ 3,831,666.67		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	1174		$ -	$ 172.98	$ 203,078.52	$ 336.62	$ 395,191.88	
limestone placement	CY	80667		$ -	$ 1.16	$ 93,573.33	$ 2.09	$ 168,593.33	
			MATERIAL SUBTOTAL	$ 3,831,666.67	***LABOR SUBTOTAL***	$ 301,841.25	***EQUIP SUBTOTAL***	$ 574,808.11	
			SALES TAX (MATERIALS) 5%	$ 191,583.33	***Labor Insurance 32%***	$ 96,589.20			
			SUBTOTALS	$ 4,023,250.00		$ 398,430.45		$ 574,808.11	
			TOTAL COST	$ 4,996,488.57					
			CONTIGENCY 20%	$ 999,297.71					
			OVERHEAD 10%	$ 499,648.86					
			PROFIT 8%	$ 519,634.81					
			TOTAL COST						$ 7,015,070
spat	EA	225000000	$ 0.010	$ 2,250,000.00		$ -		$ -	
Mob/Demob	HR	7			$ 172.98	$ 1,210.86	$ 118.83	$ 831.81	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	225000000		$ -	$ 0.001	$ 210,825.00		$ -	
			MATERIAL SUBTOTAL	$ 2,250,000.00	***LABOR SUBTOTAL***	$ 213,592.68	***EQUIP SUBTOTAL***	$ 2,194.50	
			SALES TAX (MATERIALS) 5%	$ 112,500.00	***Labor Insurance 32%***	$ 68,349.66			
			SUBTOTALS	$ 2,362,500.00		$ 281,942.34		$ 2,194.50	
			TOTAL COST	$ 2,646,636.84					
			CONTIGENCY 20%	$ 529,327.37					
			OVERHEAD 10%	$ 264,663.68					
			PROFIT 8%	$ 275,250.23					
			TOTAL COST						$ 3,715,878

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
limestone	CY	161333	$ 47.50	$ 7,663,333.33		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	2349		$ -	$ 172.98	$ 406,330.02	$ 336.62	$ 790,720.38	
limestone placement	CY	161333		$ -	$ 1.16	$ 187,146.67	$ 2.09	$ 337,186.67	
			MATERIAL SUBTOTAL	$ 7,663,333.33	***LABOR SUBTOTAL***	$ 598,666.09	***EQUIP SUBTOTAL***	$ 1,138,929.95	
			SALES TAX (MATERIALS) 5%	$ 383,166.67	***Labor Insurance 32%***	$ 191,573.15			
			SUBTOTALS	$ 8,046,500.00		$ 790,239.23		$ 1,138,929.95	
			TOTAL COST	$ 9,975,669.18					
			CONTIGENCY 20%	$ 1,995,133.84					
			OVERHEAD 10%	$ 997,566.92					
			PROFIT 8%	$ 1,037,469.59					
			TOTAL COST						$ 14,005,840
spat	EA	450000000	$ 0.010	$ 4,500,000.00		$ -		$ -	
Mob/Demob	HR	7			$ 172.98	$ 1,210.86	$ 118.83	$ 831.81	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	450000000		$ -	$ 0.001	$ 421,650.00		$ -	
			MATERIAL SUBTOTAL	$ 4,500,000.00	***LABOR SUBTOTAL***	$ 424,417.68	***EQUIP SUBTOTAL***	$ 2,194.50	
			SALES TAX (MATERIALS) 5%	$ 225,000.00	***Labor Insurance 32%***	$ 135,813.66			
			SUBTOTALS	$ 4,725,000.00		$ 560,231.34		$ 2,194.50	
			TOTAL COST	$ 5,287,425.84					
			CONTIGENCY 20%	$ 1,057,485.17					
			OVERHEAD 10%	$ 528,742.58					
			PROFIT 8%	$ 549,892.29					
			TOTAL COST						$ 7,423,546

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 6.75M spat/ac)									
option 1 (25 acre site):									
limestone	CY	40333	$ 47.50	$ 1,915,833.33		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	587		$ -	$ 172.98	$ 101,539.26	$ 336.62	$ 197,595.94	
limestone placement	CY	40333		$ -	$ 1.16	$ 46,786.67	$ 2.09	$ 84,296.67	
			MATERIAL SUBTOTAL	$ 1,915,833.33	***LABOR SUBTOTAL***	$ 153,515.33	***EQUIP SUBTOTAL***	$ 292,915.51	
			SALES TAX (MATERIALS) 5%	$ 95,791.67	***Labor Insurance 32%***	$ 49,124.90			
			SUBTOTALS	$ 2,011,625.00		$ 202,640.23		$ 292,915.51	
			TOTAL COST	$ 2,507,180.74					
			CONTIGENCY 20%	$ 501,436.15					
			OVERHEAD 10%	$ 250,718.07					
			PROFIT 8%	$ 260,746.80					
			TOTAL COST						$ 3,520,082
spat	EA	168750000	$ 0.010	$ 1,687,500.00		$ -		$ -	
Mob/Demob	HR	7			$ 172.98	$ 1,210.86	$ 118.83	$ 831.81	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	168750000		$ -	$ 0.001	$ 158,118.75		$ -	
			MATERIAL SUBTOTAL	$ 1,687,500.00	***LABOR SUBTOTAL***	$ 160,886.43	***EQUIP SUBTOTAL***	$ 2,194.50	
			SALES TAX (MATERIALS) 5%	$ 84,375.00	***Labor Insurance 32%***	$ 51,483.66			
			SUBTOTALS	$ 1,771,875.00		$ 212,370.09		$ 2,194.50	
			TOTAL COST	$ 1,986,439.59					
			CONTIGENCY 20%	$ 397,287.92					
			OVERHEAD 10%	$ 198,643.96					
			PROFIT 8%	$ 206,589.72					
			TOTAL COST						$ 2,788,961

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
limestone	CY	80667	$ 47.50	$ 3,831,666.67		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	1174		$ -	$ 172.98	$ 203,078.52	$ 336.62	$ 395,191.88	
limestone placement	CY	80667		$ -	$ 1.16	$ 93,573.33	$ 2.09	$ 168,593.33	
			MATERIAL SUBTOTAL	$ 3,831,666.67	***LABOR SUBTOTAL***	$ 301,841.25	***EQUIP SUBTOTAL***	$ 574,808.11	
			SALES TAX (MATERIALS) 5%	$ 191,583.33	***Labor Insurance 32%***	$ 96,589.20			
			SUBTOTALS	$ 4,023,250.00		$ 398,430.45		$ 574,808.11	
			TOTAL COST	$ 4,996,488.57					
			CONTIGENCY 20%	$ 999,297.71					
			OVERHEAD 10%	$ 499,648.86					
			PROFIT 8%	$ 519,634.81					
			TOTAL COST						$ 7,015,070
spat	EA	337500000	$ 0.010	$ 3,375,000.00		$ -		$ -	
Mob/Demob	HR	7			$ 172.98	$ 1,210.86	$ 118.83	$ 831.81	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	337500000		$ -	$ 0.001	$ 316,237.50		$ -	
			MATERIAL SUBTOTAL	$ 3,375,000.00	***LABOR SUBTOTAL***	$ 319,005.18	***EQUIP SUBTOTAL***	$ 2,194.50	
			SALES TAX (MATERIALS) 5%	$ 168,750.00	***Labor Insurance 32%***	$ 102,081.66			
			SUBTOTALS	$ 3,543,750.00		$ 421,086.84		$ 2,194.50	
			TOTAL COST	$ 3,967,031.34					
			CONTIGENCY 20%	$ 793,406.27					
			OVERHEAD 10%	$ 396,703.13					
			PROFIT 8%	$ 412,571.26					
			TOTAL COST						$ 5,569,712

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
limestone	CY	161333	$ 47.50	$ 7,663,333.33		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	2349		$ -	$ 172.98	$ 406,330.02	$ 336.62	$ 790,720.38	
limestone placement	CY	161333		$ -	$ 1.16	$ 187,146.67	$ 2.09	$ 337,186.67	
			MATERIAL SUBTOTAL	$ 7,663,333.33	*LABOR SUBTOTAL*	$ 598,666.09	*EQUIP SUBTOTAL*	$ 1,138,929.95	
			SALES TAX (MATERIALS) 5%	$ 383,166.67	*Labor Insurance 32%*	$ 191,573.15			
			SUBTOTALS	$ 8,046,500.00		$ 790,239.23		$ 1,138,929.95	
			TOTAL COST	$ 9,975,669.18					
			CONTIGENCY 20%	$ 1,995,133.84					
			OVERHEAD 10%	$ 997,566.92					
			PROFIT 8%	$ 1,037,469.59					
			TOTAL COST						$ 14,005,840
spat	EA	675000000	$ 0.010	$ 6,750,000.00		$ -		$ -	
Mob/Demob	HR	7			$ 172.98	$ 1,210.86	$ 118.83	$ 831.81	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	675000000		$ -	$ 0.001	$ 632,475.00		$ -	
			MATERIAL SUBTOTAL	$ 6,750,000.00	*LABOR SUBTOTAL*	$ 635,242.68	*EQUIP SUBTOTAL*	$ 2,194.50	
			SALES TAX (MATERIALS) 5%	$ 337,500.00	*Labor Insurance 32%*	$ 203,277.66			
			SUBTOTALS	$ 7,087,500.00		$ 838,520.34		$ 2,194.50	
			TOTAL COST	$ 7,928,214.84					
			CONTIGENCY 20%	$ 1,585,642.97					
			OVERHEAD 10%	$ 792,821.48					
			PROFIT 8%	$ 824,534.34					
			TOTAL COST						$ 11,131,214

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 3.6M spat/ac)									
option 1 (25 acre site):									
granite	CY	40333.3333	$ 48.00	$ 1,936,000.00		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	397		$ -	$ 172.98	$ 68,673.06	$ 336.62	$ 133,638.14	
granite placement	CY	40333.3333		$ -	$ 1.16	$ 46,786.67	$ 2.09	$ 84,296.67	
			MATERIAL SUBTOTAL	$ 1,936,000.00	***LABOR SUBTOTAL***	$ 120,649.13	***EQUIP SUBTOTAL***	$ 228,957.71	
			SALES TAX (MATERIALS) 5%	$ 96,800.00	***Labor Insurance 32%***	$ 38,607.72			
			SUBTOTALS	$ 2,032,800.00		$ 159,256.85		$ 228,957.71	
			TOTAL COST	$ 2,421,014.55					
			CONTIGENCY 20%	$ 484,202.91					
			OVERHEAD 10%	$ 242,101.46					
			PROFIT 8%	$ 251,785.51					
			TOTAL COST						$ 3,399,104
spat	EA	90000000	$ 0.010	$ 900,000.00		$ -		$ -	
Mob/Demob	HR	7			$ 172.98	$ 1,210.86	$ 118.83	$ 831.81	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	90000000		$ -	$ 0.001	$ 84,330.00		$ -	
			MATERIAL SUBTOTAL	$ 900,000.00	***LABOR SUBTOTAL***	$ 87,097.68	***EQUIP SUBTOTAL***	$ 2,194.50	
			SALES TAX (MATERIALS) 5%	$ 45,000.00	***Labor Insurance 32%***	$ 27,871.26			
			SUBTOTALS	$ 945,000.00		$ 114,968.94		$ 2,194.50	
			TOTAL COST	$ 1,062,163.44					
			CONTIGENCY 20%	$ 212,432.69					
			OVERHEAD 10%	$ 106,216.34					
			PROFIT 8%	$ 110,465.00					
			TOTAL COST						$ 1,491,277

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
granite	CY	80666.6667	$ 48.00	$ 3,872,000.00		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	793		$ -	$ 172.98	$ 137,173.14	$ 336.62	$ 266,939.66	
granite placement	CY	80666.6667		$ -	$ 1.16	$ 93,573.33	$ 2.09	$ 168,593.33	
			MATERIAL SUBTOTAL	$ 3,872,000.00	***LABOR SUBTOTAL***	$ 235,935.87	***EQUIP SUBTOTAL***	$ 446,555.89	
			SALES TAX (MATERIALS) 5%	$ 193,600.00	***Labor Insurance 32%***	$ 75,499.48			
			SUBTOTALS	$ 4,065,600.00		$ 311,435.35		$ 446,555.89	
			TOTAL COST	$ 4,823,591.25					
			CONTIGENCY 20%	$ 964,718.25					
			OVERHEAD 10%	$ 482,359.12					
			PROFIT 8%	$ 501,653.49					
			TOTAL COST						$ 6,772,322
spat	EA	180000000	$ 0.010	$ 1,800,000.00		$ -		$ -	
Mob/Demob	HR	7			$ 172.98	$ 1,210.86	$ 118.83	$ 831.81	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	180000000		$ -	$ 0.001	$ 168,660.00		$ -	
			MATERIAL SUBTOTAL	$ 1,800,000.00	***LABOR SUBTOTAL***	$ 171,427.68	***EQUIP SUBTOTAL***	$ 2,194.50	
			SALES TAX (MATERIALS) 5%	$ 90,000.00	***Labor Insurance 32%***	$ 54,856.86			
			SUBTOTALS	$ 1,890,000.00		$ 226,284.54		$ 2,194.50	
			TOTAL COST	$ 2,118,479.04					
			CONTIGENCY 20%	$ 423,695.81					
			OVERHEAD 10%	$ 211,847.90					
			PROFIT 8%	$ 220,321.82					
			TOTAL COST						$ 2,974,345

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
granite	CY	161333.333	$ 48.00	$ 7,744,000.00		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	1587		$ -	$ 172.98	$ 274,519.26	$ 336.62	$ 534,215.94	
granite placement	CY	161333.333		$ -	$ 1.16	$ 187,146.67	$ 2.09	$ 337,186.67	
			MATERIAL SUBTOTAL	$ 7,744,000.00	***LABOR SUBTOTAL***	$ 466,855.33	***EQUIP SUBTOTAL***	$ 882,425.51	
			SALES TAX (MATERIALS) 5%	$ 387,200.00	***Labor Insurance 32%***	$ 149,393.70			
			SUBTOTALS	$ 8,131,200.00		$ 616,249.03		$ 882,425.51	
			TOTAL COST	$ 9,629,874.54					
			CONTIGENCY 20%	$ 1,925,974.91					
			OVERHEAD 10%	$ 962,987.45					
			PROFIT 8%	$ 1,001,506.95					
			TOTAL COST						$ 13,520,344
spat	EA	360000000	$ 0.010	$ 3,600,000.00		$ -		$ -	
Mob/Demob	HR	7			$ 172.98	$ 1,210.86	$ 118.83	$ 831.81	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	360000000		$ -	$ 0.001	$ 337,320.00		$ -	
			MATERIAL SUBTOTAL	$ 3,600,000.00	***LABOR SUBTOTAL***	$ 340,087.68	***EQUIP SUBTOTAL***	$ 2,194.50	
			SALES TAX (MATERIALS) 5%	$ 180,000.00	***Labor Insurance 32%***	$ 108,828.06			
			SUBTOTALS	$ 3,780,000.00		$ 448,915.74		$ 2,194.50	
			TOTAL COST	$ 4,231,110.24					
			CONTIGENCY 20%	$ 846,222.05					
			OVERHEAD 10%	$ 423,111.02					
			PROFIT 8%	$ 440,035.46					
			TOTAL COST						$ 5,940,479

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 4.5M spat/ac)									
option 1 (25 acre site):									
granite	CY	40333.3333	$ 48.00	$ 1,936,000.00		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	397		$ -	$ 172.98	$ 68,673.06	$ 336.62	$ 133,638.14	
granite placement	CY	40333.3333		$ -	$ 1.16	$ 46,786.67	$ 2.09	$ 84,296.67	
			MATERIAL SUBTOTAL	$ 1,936,000.00	***LABOR SUBTOTAL***	$ 120,649.13	***EQUIP SUBTOTAL***	$ 228,957.71	
			SALES TAX (MATERIALS) 5%	$ 96,800.00	***Labor Insurance 32%***	$ 38,607.72			
			SUBTOTALS	$ 2,032,800.00		$ 159,256.85		$ 228,957.71	
			TOTAL COST	$ 2,421,014.55					
			CONTIGENCY 20%	$ 484,202.91					
			OVERHEAD 10%	$ 242,101.46					
			PROFIT 8%	$ 251,785.51					
			TOTAL COST						$ 3,399,104
spat	EA	112500000	$ 0.010	$ 1,125,000.00		$ -		$ -	
Mob/Demob	HR	7			$ 172.98	$ 1,210.86	$ 118.83	$ 831.81	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	112500000		$ -	$ 0.001	$ 105,412.50		$ -	
			MATERIAL SUBTOTAL	$ 1,125,000.00	***LABOR SUBTOTAL***	$ 108,180.18	***EQUIP SUBTOTAL***	$ 2,194.50	
			SALES TAX (MATERIALS) 5%	$ 56,250.00	***Labor Insurance 32%***	$ 34,617.66			
			SUBTOTALS	$ 1,181,250.00		$ 142,797.84		$ 2,194.50	
			TOTAL COST	$ 1,326,242.34					
			CONTIGENCY 20%	$ 265,248.47					
			OVERHEAD 10%	$ 132,624.23					
			PROFIT 8%	$ 137,929.20					
			TOTAL COST						$ 1,862,044

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
granite	CY	80666.6667	$ 48.00	$ 3,872,000.00		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	793		$ -	$ 172.98	$ 137,173.14	$ 336.62	$ 266,939.66	
granite placement	CY	80666.6667		$ -	$ 1.16	$ 93,573.33	$ 2.09	$ 168,593.33	
			MATERIAL SUBTOTAL	$ 3,872,000.00	***LABOR SUBTOTAL***	$ 235,935.87	***EQUIP SUBTOTAL***	$ 446,555.89	
			SALES TAX (MATERIALS) 5%	$ 193,600.00	***Labor Insurance 32%***	$ 75,499.48			
			SUBTOTALS	$ 4,065,600.00		$ 311,435.35		$ 446,555.89	
			TOTAL COST	$ 4,823,591.25					
			CONTIGENCY 20%	$ 964,718.25					
			OVERHEAD 10%	$ 482,359.12					
			PROFIT 8%	$ 501,653.49					
			TOTAL COST						$ 6,772,322
spat	EA	225000000	$ 0.010	$ 2,250,000.00		$ -		$ -	
Mob/Demob	HR	7			$ 172.98	$ 1,210.86	$ 118.83	$ 831.81	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	225000000		$ -	$ 0.001	$ 210,825.00		$ -	
			MATERIAL SUBTOTAL	$ 2,250,000.00	***LABOR SUBTOTAL***	$ 213,592.68	***EQUIP SUBTOTAL***	$ 2,194.50	
			SALES TAX (MATERIALS) 5%	$ 112,500.00	***Labor Insurance 32%***	$ 68,349.66			
			SUBTOTALS	$ 2,362,500.00		$ 281,942.34		$ 2,194.50	
			TOTAL COST	$ 2,646,636.84					
			CONTIGENCY 20%	$ 529,327.37					
			OVERHEAD 10%	$ 264,663.68					
			PROFIT 8%	$ 275,250.23					
			TOTAL COST						$ 3,715,878

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
granite	CY	161333.333	$ 48.00	$ 7,744,000.00		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	1587		$ -	$ 172.98	$ 274,519.26	$ 336.62	$ 534,215.94	
granite placement	CY	161333.333		$ -	$ 1.16	$ 187,146.67	$ 2.09	$ 337,186.67	
			MATERIAL SUBTOTAL	$ 7,744,000.00	***LABOR SUBTOTAL***	$ 466,855.33	***EQUIP SUBTOTAL***	$ 882,425.51	
			SALES TAX (MATERIALS) 5%	$ 387,200.00	***Labor Insurance 32%***	$ 149,393.70			
			SUBTOTALS	$ 8,131,200.00		$ 616,249.03		$ 882,425.51	
			TOTAL COST	$ 9,629,874.54					
			CONTIGENCY 20%	$ 1,925,974.91					
			OVERHEAD 10%	$ 962,987.45					
			PROFIT 8%	$ 1,001,506.95					
			TOTAL COST						$ 13,520,344
spat	EA	450000000	$ 0.010	$ 4,500,000.00		$ -		$ -	
Mob/Demob	HR	7			$ 172.98	$ 1,210.86	$ 118.83	$ 831.81	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	450000000		$ -	$ 0.001	$ 421,650.00		$ -	
			MATERIAL SUBTOTAL	$ 4,500,000.00	***LABOR SUBTOTAL***	$ 424,417.68	***EQUIP SUBTOTAL***	$ 2,194.50	
			SALES TAX (MATERIALS) 5%	$ 225,000.00	***Labor Insurance 32%***	$ 135,813.66			
			SUBTOTALS	$ 4,725,000.00		$ 560,231.34		$ 2,194.50	
			TOTAL COST	$ 5,287,425.84					
			CONTIGENCY 20%	$ 1,057,485.17					
			OVERHEAD 10%	$ 528,742.58					
			PROFIT 8%	$ 549,892.29					
			TOTAL COST						$ 7,423,546

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 6.75M spat/ac)									
option 1 (25 acre site):									
granite	CY	40333.3333	$ 48.00	$ 1,936,000.00		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	397		$ -	$ 172.98	$ 68,673.06	$ 336.62	$ 133,638.14	
granite placement	CY	40333.3333		$ -	$ 1.16	$ 46,786.67	$ 2.09	$ 84,296.67	
			MATERIAL SUBTOTAL	$ 1,936,000.00	***LABOR SUBTOTAL***	$ 120,649.13	***EQUIP SUBTOTAL***	$ 228,957.71	
			SALES TAX (MATERIALS) 5%	$ 96,800.00	***Labor Insurance 32%***	$ 38,607.72			
			SUBTOTALS	$ 2,032,800.00		$ 159,256.85		$ 228,957.71	
			TOTAL COST	$ 2,421,014.55					
			CONTIGENCY 20%	$ 484,202.91					
			OVERHEAD 10%	$ 242,101.46					
			PROFIT 8%	$ 251,785.51					
			TOTAL COST						$ 3,399,104
spat	EA	168750000	$ 0.010	$ 1,687,500.00		$ -		$ -	
Mob/Demob	HR	7			$ 172.98	$ 1,210.86	$ 118.83	$ 831.81	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	168750000		$ -	$ 0.001	$ 158,118.75		$ -	
			MATERIAL SUBTOTAL	$ 1,687,500.00	***LABOR SUBTOTAL***	$ 160,886.43	***EQUIP SUBTOTAL***	$ 2,194.50	
			SALES TAX (MATERIALS) 5%	$ 84,375.00	***Labor Insurance 32%***	$ 51,483.66			
			SUBTOTALS	$ 1,771,875.00		$ 212,370.09		$ 2,194.50	
			TOTAL COST	$ 1,986,439.59					
			CONTIGENCY 20%	$ 397,287.92					
			OVERHEAD 10%	$ 198,643.96					
			PROFIT 8%	$ 206,589.72					
			TOTAL COST						$ 2,788,961

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
granite	CY	80666.6667	$ 48.00	$ 3,872,000.00		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	793		$ -	$ 172.98	$ 137,173.14	$ 336.62	$ 266,939.66	
granite placement	CY	80666.6667		$ -	$ 1.16	$ 93,573.33	$ 2.09	$ 168,593.33	
			MATERIAL SUBTOTAL	$ 3,872,000.00	***LABOR SUBTOTAL***	$ 235,935.87	***EQUIP SUBTOTAL***	$ 446,555.89	
			SALES TAX (MATERIALS) 5%	$ 193,600.00	***Labor Insurance 32%***	$ 75,499.48			
			SUBTOTALS	$ 4,065,600.00		$ 311,435.35		$ 446,555.89	
			TOTAL COST	$ 4,823,591.25					
			CONTIGENCY 20%	$ 964,718.25					
			OVERHEAD 10%	$ 482,359.12					
			PROFIT 8%	$ 501,653.49					
			TOTAL COST						$ 6,772,322
spat	EA	337500000	$ 0.010	$ 3,375,000.00		$ -		$ -	
Mob/Demob	HR	7			$ 172.98	$ 1,210.86	$ 118.83	$ 831.81	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	337500000		$ -	$ 0.001	$ 316,237.50		$ -	
			MATERIAL SUBTOTAL	$ 3,375,000.00	***LABOR SUBTOTAL***	$ 319,005.18	***EQUIP SUBTOTAL***	$ 2,194.50	
			SALES TAX (MATERIALS) 5%	$ 168,750.00	***Labor Insurance 32%***	$ 102,081.66			
			SUBTOTALS	$ 3,543,750.00		$ 421,086.84		$ 2,194.50	
			TOTAL COST	$ 3,967,031.34					
			CONTIGENCY 20%	$ 793,406.27					
			OVERHEAD 10%	$ 396,703.13					
			PROFIT 8%	$ 412,571.26					
			TOTAL COST						$ 5,569,712

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
granite	CY	161333.333	$ 48.00	$ 7,744,000.00		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	1587		$ -	$ 172.98	$ 274,519.26	$ 336.62	$ 534,215.94	
granite placement	CY	161333.333		$ -	$ 1.16	$ 187,146.67	$ 2.09	$ 337,186.67	
			MATERIAL SUBTOTAL	$ 7,744,000.00	***LABOR SUBTOTAL***	$ 466,855.33	***EQUIP SUBTOTAL***	$ 882,425.51	
			SALES TAX (MATERIALS) 5%	$ 387,200.00	***Labor Insurance 32%***	$ 149,393.70			
			SUBTOTALS	$ 8,131,200.00		$ 616,249.03		$ 882,425.51	
			TOTAL COST	$ 9,629,874.54					
			CONTIGENCY 20%	$ 1,925,974.91					
			OVERHEAD 10%	$ 962,987.45					
			PROFIT 8%	$ 1,001,506.95					
			TOTAL COST						$ 13,520,344
spat	EA	675000000	$ 0.010	$ 6,750,000.00		$ -		$ -	
Mob/Demob	HR	7			$ 172.98	$ 1,210.86	$ 118.83	$ 831.81	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	675000000		$ -	$ 0.001	$ 632,475.00		$ -	
			MATERIAL SUBTOTAL	$ 6,750,000.00	***LABOR SUBTOTAL***	$ 635,242.68	***EQUIP SUBTOTAL***	$ 2,194.50	
			SALES TAX (MATERIALS) 5%	$ 337,500.00	***Labor Insurance 32%***	$ 203,277.66			
			SUBTOTALS	$ 7,087,500.00		$ 838,520.34		$ 2,194.50	
			TOTAL COST	$ 7,928,214.84					
			CONTIGENCY 20%	$ 1,585,642.97					
			OVERHEAD 10%	$ 792,821.48					
			PROFIT 8%	$ 824,534.34					
			TOTAL COST						$ 11,131,214

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 3.6M spat/ac)									
option 1 (25 acre site):									
concrete	CY	40333.3333	$ 30.00	$ 1,210,000.00		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	317		$ -	$ 172.98	$ 54,834.66	$ 336.62	$ 106,708.54	
concrete placement	CY	40333.3333		$ -	$ 0.92	$ 37,106.67	$ 1.67	$ 67,356.67	
			MATERIAL SUBTOTAL	$ 1,210,000.00	***LABOR SUBTOTAL***	$ 97,130.73	***EQUIP SUBTOTAL***	$ 185,088.11	
			SALES TAX (MATERIALS) 5%	$ 60,500.00	***Labor Insurance 32%***	$ 31,081.83			
			SUBTOTALS	$ 1,270,500.00		$ 128,212.56		$ 185,088.11	
			TOTAL COST	$ 1,583,800.67					
			CONTIGENCY 20%	$ 316,760.13					
			OVERHEAD 10%	$ 158,380.07					
			PROFIT 8%	$ 164,715.27					
			TOTAL COST						$ 2,223,656
spat	EA	90000000	$ 0.010	$ 900,000.00		$ -		$ -	
Mob/Demob	HR	7			$ 172.98	$ 1,210.86	$ 118.83	$ 831.81	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	90000000		$ -	$ 0.001	$ 84,330.00		$ -	
			MATERIAL SUBTOTAL	$ 900,000.00	***LABOR SUBTOTAL***	$ 87,097.68	***EQUIP SUBTOTAL***	$ 2,194.50	
			SALES TAX (MATERIALS) 5%	$ 45,000.00	***Labor Insurance 32%***	$ 27,871.26			
			SUBTOTALS	$ 945,000.00		$ 114,968.94		$ 2,194.50	
			TOTAL COST	$ 1,062,163.44					
			CONTIGENCY 20%	$ 212,432.69					
			OVERHEAD 10%	$ 106,216.34					
			PROFIT 8%	$ 110,465.00					
			TOTAL COST						$ 1,491,277

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
concrete	CY	80666.6667	$ 30.00	$ 2,420,000.00		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	635		$ -	$ 172.98	$ 109,842.30	$ 336.62	$ 213,753.70	
concrete placement	CY	80666.6667		$ -	$ 0.92	$ 74,213.33	$ 1.67	$ 134,713.33	
			MATERIAL SUBTOTAL	$ 2,420,000.00	***LABOR SUBTOTAL***	$ 189,245.03	***EQUIP SUBTOTAL***	$ 359,489.93	
			SALES TAX (MATERIALS) 5%	$ 121,000.00	***Labor Insurance 32%***	$ 60,558.41			
			SUBTOTALS	$ 2,541,000.00		$ 249,803.44		$ 359,489.93	
			TOTAL COST	$ 3,150,293.38					
			CONTIGENCY 20%	$ 630,058.68					
			OVERHEAD 10%	$ 315,029.34					
			PROFIT 8%	$ 327,630.51					
			TOTAL COST						$ 4,423,012
spat	EA	180000000	$ 0.010	$ 1,800,000.00		$ -		$ -	
Mob/Demob	HR	7			$ 172.98	$ 1,210.86	$ 118.83	$ 831.81	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	180000000		$ -	$ 0.001	$ 168,660.00		$ -	
			MATERIAL SUBTOTAL	$ 1,800,000.00	***LABOR SUBTOTAL***	$ 171,427.68	***EQUIP SUBTOTAL***	$ 2,194.50	
			SALES TAX (MATERIALS) 5%	$ 90,000.00	***Labor Insurance 32%***	$ 54,856.86			
			SUBTOTALS	$ 1,890,000.00		$ 226,284.54		$ 2,194.50	
			TOTAL COST	$ 2,118,479.04					
			CONTIGENCY 20%	$ 423,695.81					
			OVERHEAD 10%	$ 211,847.90					
			PROFIT 8%	$ 220,321.82					
			TOTAL COST						$ 2,974,345

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
concrete	CY	161333.333	$ 30.00	$ 4,840,000.00		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	1270		$ -	$ 172.98	$ 219,684.60	$ 336.62	$ 427,507.40	
concrete placement	CY	161333.333		$ -	$ 0.92	$ 148,426.67	$ 1.67	$ 269,426.67	
			MATERIAL SUBTOTAL	$ 4,840,000.00	***LABOR SUBTOTAL***	$ 373,300.67	***EQUIP SUBTOTAL***	$ 707,956.97	
			SALES TAX (MATERIALS) 5%	$ 242,000.00	***Labor Insurance 32%***	$ 119,456.21			
			SUBTOTALS	$ 5,082,000.00		$ 492,756.88		$ 707,956.97	
			TOTAL COST	$ 6,282,713.85					
			CONTIGENCY 20%	$ 1,256,542.77					
			OVERHEAD 10%	$ 628,271.38					
			PROFIT 8%	$ 653,402.24					
			TOTAL COST						$ 8,820,930
spat	EA	360000000	$ 0.010	$ 3,600,000.00		$ -		$ -	
Mob/Demob	HR	7			$ 172.98	$ 1,210.86	$ 118.83	$ 831.81	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	360000000		$ -	$ 0.001	$ 337,320.00		$ -	
			MATERIAL SUBTOTAL	$ 3,600,000.00	***LABOR SUBTOTAL***	$ 340,087.68	***EQUIP SUBTOTAL***	$ 2,194.50	
			SALES TAX (MATERIALS) 5%	$ 180,000.00	***Labor Insurance 32%***	$ 108,828.06			
			SUBTOTALS	$ 3,780,000.00		$ 448,915.74		$ 2,194.50	
			TOTAL COST	$ 4,231,110.24					
			CONTIGENCY 20%	$ 846,222.05					
			OVERHEAD 10%	$ 423,111.02					
			PROFIT 8%	$ 440,035.46					
			TOTAL COST						$ 5,940,479

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 4.5M spat/ac)									
option 1 (25 acre site):									
concrete	CY	40333.3333	$ 30.00	$ 1,210,000.00		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	317		$ -	$ 172.98	$ 54,834.66	$ 336.62	$ 106,708.54	
concrete placement	CY	40333.3333		$ -	$ 0.92	$ 37,106.67	$ 1.67	$ 67,356.67	
			MATERIAL SUBTOTAL	$ 1,210,000.00	***LABOR SUBTOTAL***	$ 97,130.73	***EQUIP SUBTOTAL***	$ 185,088.11	
			SALES TAX (MATERIALS) 5%	$ 60,500.00	***Labor Insurance 32%***	$ 31,081.83			
			SUBTOTALS	$ 1,270,500.00		$ 128,212.56		$ 185,088.11	
			TOTAL COST	$ 1,583,800.67					
			CONTIGENCY 20%	$ 316,760.13					
			OVERHEAD 10%	$ 158,380.07					
			PROFIT 8%	$ 164,715.27					
			TOTAL COST						$ 2,223,656
spat	EA	112500000	$ 0.010	$ 1,125,000.00		$ -		$ -	
Mob/Demob	HR	7			$ 172.98	$ 1,210.86	$ 118.83	$ 831.81	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	112500000		$ -	$ 0.001	$ 105,412.50		$ -	
			MATERIAL SUBTOTAL	$ 1,125,000.00	***LABOR SUBTOTAL***	$ 108,180.18	***EQUIP SUBTOTAL***	$ 2,194.50	
			SALES TAX (MATERIALS) 5%	$ 56,250.00	***Labor Insurance 32%***	$ 34,617.66			
			SUBTOTALS	$ 1,181,250.00		$ 142,797.84		$ 2,194.50	
			TOTAL COST	$ 1,326,242.34					
			CONTIGENCY 20%	$ 265,248.47					
			OVERHEAD 10%	$ 132,624.23					
			PROFIT 8%	$ 137,929.20					
			TOTAL COST						$ 1,862,044

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
concrete	CY	80666.6667	$ 30.00	$ 2,420,000.00		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	635		$ -	$ 172.98	$ 109,842.30	$ 336.62	$ 213,753.70	
concrete placement	CY	80666.6667		$ -	$ 0.92	$ 74,213.33	$ 1.67	$ 134,713.33	
			MATERIAL SUBTOTAL	$ 2,420,000.00	***LABOR SUBTOTAL***	$ 189,245.03	***EQUIP SUBTOTAL***	$ 359,489.93	
			SALES TAX (MATERIALS) 5%	$ 121,000.00	***Labor Insurance 32%***	$ 60,558.41			
			SUBTOTALS	$ 2,541,000.00		$ 249,803.44		$ 359,489.93	
			TOTAL COST	$ 3,150,293.38					
			CONTIGENCY 20%	$ 630,058.68					
			OVERHEAD 10%	$ 315,029.34					
			PROFIT 8%	$ 327,630.51					
			TOTAL COST						$ 4,423,012
spat	EA	225000000	$ 0.010	$ 2,250,000.00		$ -		$ -	
Mob/Demob	HR	7			$ 172.98	$ 1,210.86	$ 118.83	$ 831.81	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	225000000		$ -	$ 0.001	$ 210,825.00		$ -	
			MATERIAL SUBTOTAL	$ 2,250,000.00	***LABOR SUBTOTAL***	$ 213,592.68	***EQUIP SUBTOTAL***	$ 2,194.50	
			SALES TAX (MATERIALS) 5%	$ 112,500.00	***Labor Insurance 32%***	$ 68,349.66			
			SUBTOTALS	$ 2,362,500.00		$ 281,942.34		$ 2,194.50	
			TOTAL COST	$ 2,646,636.84					
			CONTIGENCY 20%	$ 529,327.37					
			OVERHEAD 10%	$ 264,663.68					
			PROFIT 8%	$ 275,250.23					
			TOTAL COST						$ 3,715,878

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
concrete	CY	161333.333	$ 30.00	$ 4,840,000.00		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	1270		$ -	$ 172.98	$ 219,684.60	$ 336.62	$ 427,507.40	
concrete placement	CY	161333.333		$ -	$ 0.92	$ 148,426.67	$ 1.67	$ 269,426.67	
			MATERIAL SUBTOTAL	$ 4,840,000.00	***LABOR SUBTOTAL***	$ 373,300.67	***EQUIP SUBTOTAL***	$ 707,956.97	
			SALES TAX (MATERIALS) 5%	$ 242,000.00	***Labor Insurance 32%***	$ 119,456.21			
			SUBTOTALS	$ 5,082,000.00		$ 492,756.88		$ 707,956.97	
			TOTAL COST	$ 6,282,713.85					
			CONTIGENCY 20%	$ 1,256,542.77					
			OVERHEAD 10%	$ 628,271.38					
			PROFIT 8%	$ 653,402.24					
			TOTAL COST						$ 8,820,930
spat	EA	450000000	$ 0.010	$ 4,500,000.00		$ -		$ -	
Mob/Demob	HR	7			$ 172.98	$ 1,210.86	$ 118.83	$ 831.81	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	450000000		$ -	$ 0.001	$ 421,650.00		$ -	
			MATERIAL SUBTOTAL	$ 4,500,000.00	***LABOR SUBTOTAL***	$ 424,417.68	***EQUIP SUBTOTAL***	$ 2,194.50	
			SALES TAX (MATERIALS) 5%	$ 225,000.00	***Labor Insurance 32%***	$ 135,813.66			
			SUBTOTALS	$ 4,725,000.00		$ 560,231.34		$ 2,194.50	
			TOTAL COST	$ 5,287,425.84					
			CONTIGENCY 20%	$ 1,057,485.17					
			OVERHEAD 10%	$ 528,742.58					
			PROFIT 8%	$ 549,892.29					
			TOTAL COST						$ 7,423,546

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 6.75M spat/ac)									
option 1 (25 acre site):									
concrete	CY	40333.3333	$ 30.00	$ 1,210,000.00		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	317		$ -	$ 172.98	$ 54,834.66	$ 336.62	$ 106,708.54	
concrete placement	CY	40333.3333		$ -	$ 0.92	$ 37,106.67	$ 1.67	$ 67,356.67	
			MATERIAL SUBTOTAL	$ 1,210,000.00	***LABOR SUBTOTAL***	$ 97,130.73	***EQUIP SUBTOTAL***	$ 185,088.11	
			SALES TAX (MATERIALS) 5%	$ 60,500.00	***Labor Insurance 32%***	$ 31,081.83			
			SUBTOTALS	$ 1,270,500.00		$ 128,212.56		$ 185,088.11	
			TOTAL COST	$ 1,583,800.67					
			CONTIGENCY 20%	$ 316,760.13					
			OVERHEAD 10%	$ 158,380.07					
			PROFIT 8%	$ 164,715.27					
			TOTAL COST						$ 2,223,656
spat	EA	168750000	$ 0.010	$ 1,687,500.00		$ -		$ -	
Mob/Demob	HR	7			$ 172.98	$ 1,210.86	$ 118.83	$ 831.81	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	168750000		$ -	$ 0.001	$ 158,118.75		$ -	
			MATERIAL SUBTOTAL	$ 1,687,500.00	***LABOR SUBTOTAL***	$ 160,886.43	***EQUIP SUBTOTAL***	$ 2,194.50	
			SALES TAX (MATERIALS) 5%	$ 84,375.00	***Labor Insurance 32%***	$ 51,483.66			
			SUBTOTALS	$ 1,771,875.00		$ 212,370.09		$ 2,194.50	
			TOTAL COST	$ 1,986,439.59					
			CONTIGENCY 20%	$ 397,287.92					
			OVERHEAD 10%	$ 198,643.96					
			PROFIT 8%	$ 206,589.72					
			TOTAL COST						$ 2,788,961

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
concrete	CY	80666.6667	$ 30.00	$ 2,420,000.00		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	635		$ -	$ 172.98	$ 109,842.30	$ 336.62	$ 213,753.70	
concrete placement	CY	80666.6667		$ -	$ 0.92	$ 74,213.33	$ 1.67	$ 134,713.33	
			MATERIAL SUBTOTAL	$ 2,420,000.00	***LABOR SUBTOTAL***	$ 189,245.03	***EQUIP SUBTOTAL***	$ 359,489.93	
			SALES TAX (MATERIALS) 5%	$ 121,000.00	***Labor Insurance 32%***	$ 60,558.41			
			SUBTOTALS	$ 2,541,000.00		$ 249,803.44		$ 359,489.93	
			TOTAL COST	$ 3,150,293.38					
			CONTIGENCY 20%	$ 630,058.68					
			OVERHEAD 10%	$ 315,029.34					
			PROFIT 8%	$ 327,630.51					
			TOTAL COST						$ 4,423,012
spat	EA	337500000	$ 0.010	$ 3,375,000.00		$ -		$ -	
Mob/Demob	HR	7			$ 172.98	$ 1,210.86	$ 118.83	$ 831.81	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	337500000		$ -	$ 0.001	$ 316,237.50		$ -	
			MATERIAL SUBTOTAL	$ 3,375,000.00	***LABOR SUBTOTAL***	$ 319,005.18	***EQUIP SUBTOTAL***	$ 2,194.50	
			SALES TAX (MATERIALS) 5%	$ 168,750.00	***Labor Insurance 32%***	$ 102,081.66			
			SUBTOTALS	$ 3,543,750.00		$ 421,086.84		$ 2,194.50	
			TOTAL COST	$ 3,967,031.34					
			CONTIGENCY 20%	$ 793,406.27					
			OVERHEAD 10%	$ 396,703.13					
			PROFIT 8%	$ 412,571.26					
			TOTAL COST						$ 5,569,712

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
concrete	CY	161333.333	$ 30.00	$ 4,840,000.00		$ -		$ -	
Mob/Demob	HR	30		$ -	$ 172.98	$ 5,189.40	$ 367.43	$ 11,022.90	
barge delivery	HR	1270		$ -	$ 172.98	$ 219,684.60	$ 336.62	$ 427,507.40	
concrete placement	CY	161333.333		$ -	$ 0.92	$ 148,426.67	$ 1.67	$ 269,426.67	
			MATERIAL SUBTOTAL	$ 4,840,000.00	***LABOR SUBTOTAL***	$ 373,300.67	***EQUIP SUBTOTAL***	$ 707,956.97	
			SALES TAX (MATERIALS) 5%	$ 242,000.00	***Labor Insurance 32%***	$ 119,456.21			
			SUBTOTALS	$ 5,082,000.00		$ 492,756.88		$ 707,956.97	
			TOTAL COST	$ 6,282,713.85					
			CONTIGENCY 20%	$ 1,256,542.77					
			OVERHEAD 10%	$ 628,271.38					
			PROFIT 8%	$ 653,402.24					
			TOTAL COST						$ 8,820,930
spat	EA	675000000	$ 0.010	$ 6,750,000.00		$ -		$ -	
Mob/Demob	HR	7			$ 172.98	$ 1,210.86	$ 118.83	$ 831.81	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	675000000		$ -	$ 0.001	$ 632,475.00		$ -	
			MATERIAL SUBTOTAL	$ 6,750,000.00	***LABOR SUBTOTAL***	$ 635,242.68	***EQUIP SUBTOTAL***	$ 2,194.50	
			SALES TAX (MATERIALS) 5%	$ 337,500.00	***Labor Insurance 32%***	$ 203,277.66			
			SUBTOTALS	$ 7,087,500.00		$ 838,520.34		$ 2,194.50	
			TOTAL COST	$ 7,928,214.84					
			CONTIGENCY 20%	$ 1,585,642.97					
			OVERHEAD 10%	$ 792,821.48					
			PROFIT 8%	$ 824,534.34					
			TOTAL COST						$ 11,131,214

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 3.6M spat/ac)									
option 1 (25 acre site):									
oyster shell dredging	CY	40333	$ 15.85	$ 639,283.33		$ -		$ -	
Mob/Demob	HR	7		$ -	$ 172.98	$ 1,210.86	$ 367.43	$ 2,572.01	
barge delivery	HR	30		$ -	$ 172.98	$ 5,189.40	$ 336.62	$ 10,098.60	
oyster placement	CY	40333		$ -	$ 6.27	$ 252,890.00		$ -	
			SUBTOTAL	$ 639,283.33	***SUBTOTAL***	$ 259,290.26	***SUBTOTAL***	$ 12,670.61	
			(MATERIALS) 5%	$ 31,964.17	***Insurance 32%***	$ 82,972.88			
			SUBTOTALS	$ 671,247.50		$ 342,263.14		$ 12,670.61	
			TOTAL COST	$ 1,026,181.25					
			CONTIGENCY 20%	$ 205,236.25					
			OVERHEAD 10%	$ 102,618.13					
			PROFIT 8%	$ 106,722.85					
			TOTAL COST						$ 1,440,758
spat	EA	90000000	$ 0.010	$ 900,000.00		$ -		$ -	
Mob/Demob	HR	7			$ 172.98	$ 1,210.86	$ 118.83	$ 831.81	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	90000000		$ -	$ 0.001	$ 84,330.00		$ -	
Turbidity control	LF	4200	$ 0.69	$ 2,898.00	$ 0.15	$ 630.00	$ 0.39	$ 1,638.00	
			MATERIAL SUBTOTAL	$ 902,898.00	***LABOR SUBTOTAL***	$ 87,727.68	***EQUIP SUBTOTAL***	$ 3,832.50	
			SALES TAX (MATERIALS) 5%	$ 45,144.90	***Labor Insurance 32%***	$ 28,072.86			
			SUBTOTALS	$ 948,042.90		$ 115,800.54		$ 3,832.50	
			TOTAL COST	$ 1,067,675.94					
			CONTIGENCY 20%	$ 213,535.19					
			OVERHEAD 10%	$ 106,767.59					
			PROFIT 8%	$ 111,038.30					
			TOTAL COST						$ 1,499,017

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
oyster shell dredging	CY	80667	$ 15.85	$ 1,278,566.67		$ -		$ -	
Mob/Demob	HR	7		$ -	$ 172.98	$ 1,210.86	$ 367.43	$ 2,572.01	
barge delivery	HR	61		$ -	$ 172.98	$ 10,551.78	$ 336.62	$ 20,533.82	
oyster placement	CY	80667		$ -	$ 6.27	$ 505,780.00		$ -	
			MATERIAL SUBTOTAL	$ 1,278,566.67	***LABOR SUBTOTAL***	$ 517,542.64	***EQUIP SUBTOTAL***	$ 23,105.83	
			SALES TAX (MATERIALS) 5%	$ 63,928.33	***Labor Insurance 32%***	$ 165,613.64			
			SUBTOTALS	$ 1,342,495.00		$ 683,156.28		$ 23,105.83	
			TOTAL COST	$ 2,048,757.11					
			CONTIGENCY 20%	$ 409,751.42					
			OVERHEAD 10%	$ 204,875.71					
			PROFIT 8%	$ 213,070.74					
			TOTAL COST						$ 2,876,455
spat	EA	180000000	$ 0.010	$ 1,800,000.00		$ -		$ -	
Mob/Demob	HR	7			$ 172.98	$ 1,210.86	$ 118.83	$ 831.81	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	180000000		$ -	$ 0.001	$ 168,660.00		$ -	
Turbidity control	LF	5900	$ 0.69	$ 4,071.00	$ 0.15	$ 885.00	$ 0.39	$ 2,301.00	
			MATERIAL SUBTOTAL	$ 1,804,071.00	***LABOR SUBTOTAL***	$ 172,312.68	***EQUIP SUBTOTAL***	$ 4,495.50	
			SALES TAX (MATERIALS) 5%	$ 90,203.55	***Labor Insurance 32%***	$ 55,140.06			
			SUBTOTALS	$ 1,894,274.55		$ 227,452.74		$ 4,495.50	
			TOTAL COST	$ 2,126,222.79					
			CONTIGENCY 20%	$ 425,244.56					
			OVERHEAD 10%	$ 212,622.28					
			PROFIT 8%	$ 221,127.17					
			TOTAL COST						$ 2,985,217

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
oyster shell dredging	CY	161333	$ 15.85	$ 2,557,133.33		$ -		$ -	
Mob/Demob	HR	7		$ -	$ 172.98	$ 1,210.86	$ 367.43	$ 2,572.01	
barge delivery	HR	121		$ -	$ 172.98	$ 20,930.58	$ 336.62	$ 40,731.02	
oyster placement	CY	161333		$ -	$ 6.27	$ 1,011,560.00		$ -	
			MATERIAL SUBTOTAL	$ 2,557,133.33	***LABOR SUBTOTAL***	$ 1,033,701.44	***EQUIP SUBTOTAL***	$ 43,303.03	
			SALES TAX (MATERIALS) 5%	$ 127,856.67	***Labor Insurance 32%***	$ 330,784.46			
			SUBTOTALS	$ 2,684,990.00		$ 1,364,485.90		$ 43,303.03	
			TOTAL COST	$ 4,092,778.93					
			CONTIGENCY 20%	$ 818,555.79					
			OVERHEAD 10%	$ 409,277.89					
			PROFIT 8%	$ 425,649.01					
			TOTAL COST						$ 5,746,262
spat	EA	360000000	$ 0.010	$ 3,600,000.00		$ -		$ -	
Mob/Demob	HR	7			$ 172.98	$ 1,210.86	$ 118.83	$ 831.81	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	360000000		$ -	$ 0.001	$ 337,320.00		$ -	
Turbidity control	LF	8350	$ 0.69	$ 5,761.50	$ 0.15	$ 1,252.50	$ 0.39	$ 3,256.50	
			SUBTOTAL	$ 3,605,761.50	***SUBTOTAL***	$ 341,340.18	***SUBTOTAL***	$ 5,451.00	
			(MATERIALS) 5%	$ 180,288.08	***Insurance 32%***	$ 109,228.86			
			SUBTOTALS	$ 3,786,049.58		$ 450,569.04		$ 5,451.00	
			TOTAL COST	$ 4,242,069.61					
			CONTIGENCY 20%	$ 848,413.92					
			OVERHEAD 10%	$ 424,206.96					
			PROFIT 8%	$ 441,175.24					
			TOTAL COST						$ 5,955,866

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 4.5M spat/ac)									
option 1 (25 acre site):									
oyster shell dredging	CY	40333	$ 15.85	$ 639,283.33		$ -		$ -	
Mob/Demob	HR	7		$ -	$ 172.98	$ 1,210.86	$ 367.43	$ 2,572.01	
barge delivery	HR	30		$ -	$ 172.98	$ 5,189.40	$ 336.62	$ 10,098.60	
oyster placement	CY	40333		$ -	$ 6.27	$ 252,890.00		$ -	
			SUBTOTAL	$ 639,283.33	***SUBTOTAL***	$ 259,290.26	***SUBTOTAL***	$ 12,670.61	
			(MATERIALS) 5%	$ 31,964.17	***Insurance 32%***	$ 82,972.88			
			SUBTOTALS	$ 671,247.50		$ 342,263.14		$ 12,670.61	
			TOTAL COST	$ 1,026,181.25					
			CONTIGENCY 20%	$ 205,236.25					
			OVERHEAD 10%	$ 102,618.13					
			PROFIT 8%	$ 106,722.85					
			TOTAL COST						$ 1,440,758
spat	EA	112500000	$ 0.010	$ 1,125,000.00		$ -		$ -	
Mob/Demob	HR	7			$ 172.98	$ 1,210.86	$ 118.83	$ 831.81	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	112500000		$ -	$ 0.001	$ 105,412.50		$ -	
Turbidity control	LF	4200	$ 0.69	$ 2,898.00	$ 0.15	$ 630.00	$ 0.39	$ 1,638.00	
			SUBTOTAL	$ 1,127,898.00	***SUBTOTAL***	$ 108,810.18	***SUBTOTAL***	$ 3,832.50	
			(MATERIALS) 5%	$ 56,394.90	***Insurance 32%***	$ 34,819.26			
			SUBTOTALS	$ 1,184,292.90		$ 143,629.44		$ 3,832.50	
			TOTAL COST	$ 1,331,754.84					
			CONTIGENCY 20%	$ 266,350.97					
			OVERHEAD 10%	$ 133,175.48					
			PROFIT 8%	$ 138,502.50					
			TOTAL COST						$ 1,869,784

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
oyster shell dredging	CY	80667	$ 15.85	$ 1,278,566.67		$ -		$ -	
Mob/Demob	HR	7		$ -	$ 172.98	$ 1,210.86	$ 367.43	$ 2,572.01	
barge delivery	HR	61		$ -	$ 172.98	$ 10,551.78	$ 336.62	$ 20,533.82	
oyster placement	CY	80667		$ -	$ 6.27	$ 505,780.00		$ -	
			MATERIAL SUBTOTAL	$ 1,278,566.67	***LABOR SUBTOTAL***	$ 517,542.64	***EQUIP SUBTOTAL***	$ 23,105.83	
			SALES TAX (MATERIALS) 5%	$ 63,928.33	***Labor Insurance 32%***	$ 165,613.64			
			SUBTOTALS	$ 1,342,495.00		$ 683,156.28		$ 23,105.83	
			TOTAL COST	$ 2,048,757.11					
			CONTIGENCY 20%	$ 409,751.42					
			OVERHEAD 10%	$ 204,875.71					
			PROFIT 8%	$ 213,070.74					
			TOTAL COST						$ 2,876,455
spat	EA	225000000	$ 0.010	$ 2,250,000.00		$ -		$ -	
Mob/Demob	HR	7			$ 172.98	$ 1,210.86	$ 118.83	$ 831.81	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	225000000		$ -	$ 0.001	$ 210,825.00		$ -	
Turbidity control	LF	5900	$ 0.69	$ 4,071.00	$ 0.15	$ 885.00	$ 0.39	$ 2,301.00	
			MATERIAL SUBTOTAL	$ 2,254,071.00	***LABOR SUBTOTAL***	$ 214,477.68	***EQUIP SUBTOTAL***	$ 4,495.50	
			SALES TAX (MATERIALS) 5%	$ 112,703.55	***Labor Insurance 32%***	$ 68,632.86			
			SUBTOTALS	$ 2,366,774.55		$ 283,110.54		$ 4,495.50	
			TOTAL COST	$ 2,654,380.59					
			CONTIGENCY 20%	$ 530,876.12					
			OVERHEAD 10%	$ 265,438.06					
			PROFIT 8%	$ 276,055.58					
			TOTAL COST						$ 3,726,750

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
oyster shell dredging	CY	161333	$ 15.85	$ 2,557,133.33		$ -		$ -	
Mob/Demob	HR	7		$ -	$ 172.98	$ 1,210.86	$ 367.43	$ 2,572.01	
barge delivery	HR	121		$ -	$ 172.98	$ 20,930.58	$ 336.62	$ 40,731.02	
oyster placement	CY	161333		$ -	$ 6.27	$ 1,011,560.00		$ -	
			MATERIAL SUBTOTAL	$ 2,557,133.33	***LABOR SUBTOTAL***	$ 1,033,701.44	***EQUIP SUBTOTAL***	$ 43,303.03	
			SALES TAX (MATERIALS) 5%	$ 127,856.67	***Labor Insurance 32%***	$ 330,784.46			
			SUBTOTALS	$ 2,684,990.00		$ 1,364,485.90		$ 43,303.03	
			TOTAL COST	$ 4,092,778.93					
			CONTIGENCY 20%	$ 818,555.79					
			OVERHEAD 10%	$ 409,277.89					
			PROFIT 8%	$ 425,649.01					
			TOTAL COST						$ 5,746,262
spat	EA	450000000	$ 0.010	$ 4,500,000.00		$ -		$ -	
Mob/Demob	HR	7			$ 172.98	$ 1,210.86	$ 118.83	$ 831.81	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	450000000		$ -	$ 0.001	$ 421,650.00		$ -	
Turbidity control	LF	8350	$ 0.69	$ 5,761.50	$ 0.15	$ 1,252.50	$ 0.39	$ 3,256.50	
			MATERIAL SUBTOTAL	$ 4,505,761.50	***LABOR SUBTOTAL***	$ 425,670.18	***EQUIP SUBTOTAL***	$ 5,451.00	
			SALES TAX (MATERIALS) 5%	$ 225,288.08	***Labor Insurance 32%***	$ 136,214.46			
			SUBTOTALS	$ 4,731,049.58		$ 561,884.64		$ 5,451.00	
			TOTAL COST	$ 5,298,385.21					
			CONTIGENCY 20%	$ 1,059,677.04					
			OVERHEAD 10%	$ 529,838.52					
			PROFIT 8%	$ 551,032.06					
			TOTAL COST						$ 7,438,933

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 6.75M spat/ac)									
option 1 (25 acre site):									
oyster shell dredging	CY	40333	$ 15.85	$ 639,283.33		$ -		$ -	
Mob/Demob	HR	7		$ -	$ 172.98	$ 1,210.86	$ 367.43	$ 2,572.01	
barge delivery	HR	30		$ -	$ 172.98	$ 5,189.40	$ 336.62	$ 10,098.60	
oyster placement	CY	40333		$ -	$ 6.27	$ 252,890.00		$ -	
			MATERIAL SUBTOTAL	$ 639,283.33	***LABOR SUBTOTAL***	$ 259,290.26	***EQUIP SUBTOTAL***	$ 12,670.61	
			SALES TAX (MATERIALS) 5%	$ 31,964.17	***Labor Insurance 32%***	$ 82,972.88			
			SUBTOTALS	$ 671,247.50		$ 342,263.14		$ 12,670.61	
			TOTAL COST	$ 1,026,181.25					
			CONTIGENCY 20%	$ 205,236.25					
			OVERHEAD 10%	$ 102,618.13					
			PROFIT 8%	$ 106,722.85					
			TOTAL COST						$ 1,440,758
spat	EA	168750000	$ 0.010	$ 1,687,500.00		$ -		$ -	
Mob/Demob	HR	7			$ 172.98	$ 1,210.86	$ 118.83	$ 831.81	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	168750000		$ -	$ 0.001	$ 158,118.75		$ -	
Turbidity control	LF	4200	$ 0.69	$ 2,898.00	$ 0.15	$ 630.00	$ 0.39	$ 1,638.00	
			MATERIAL SUBTOTAL	$ 1,690,398.00	***LABOR SUBTOTAL***	$ 161,516.43	***EQUIP SUBTOTAL***	$ 3,832.50	
			SALES TAX (MATERIALS) 5%	$ 84,519.90	***Labor Insurance 32%***	$ 51,685.26			
			SUBTOTALS	$ 1,774,917.90		$ 213,201.69		$ 3,832.50	
			TOTAL COST	$ 1,991,952.09					
			CONTIGENCY 20%	$ 398,390.42					
			OVERHEAD 10%	$ 199,195.21					
			PROFIT 8%	$ 207,163.02					
			TOTAL COST						$ 2,796,701

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
oyster shell dredging	CY	80667	$ 15.85	$ 1,278,566.67		$ -		$ -	
Mob/Demob	HR	7		$ -	$ 172.98	$ 1,210.86	$ 367.43	$ 2,572.01	
barge delivery	HR	61		$ -	$ 172.98	$ 10,551.78	$ 336.62	$ 20,533.82	
oyster placement	CY	80667		$ -	$ 6.27	$ 505,780.00		$ -	
			MATERIAL SUBTOTAL	$ 1,278,566.67	***LABOR SUBTOTAL***	$ 517,542.64	***EQUIP SUBTOTAL***	$ 23,105.83	
			SALES TAX (MATERIALS) 5%	$ 63,928.33	***Labor Insurance 32%***	$ 165,613.64			
			SUBTOTALS	$ 1,342,495.00		$ 683,156.28		$ 23,105.83	
			TOTAL COST	$ 2,048,757.11					
			CONTIGENCY 20%	$ 409,751.42					
			OVERHEAD 10%	$ 204,875.71					
			PROFIT 8%	$ 213,070.74					
			TOTAL COST						$ 2,876,455
spat	EA	337500000	$ 0.010	$ 3,375,000.00		$ -		$ -	
Mob/Demob	HR	7			$ 172.98	$ 1,210.86	$ 118.83	$ 831.81	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	337500000		$ -	$ 0.001	$ 316,237.50		$ -	
Turbidity control	LF	5900	$ 0.69	$ 4,071.00	$ 0.15	$ 885.00	$ 0.39	$ 2,301.00	
			MATERIAL SUBTOTAL	$ 3,379,071.00	***LABOR SUBTOTAL***	$ 319,890.18	***EQUIP SUBTOTAL***	$ 4,495.50	
			SALES TAX (MATERIALS) 5%	$ 168,953.55	***Labor Insurance 32%***	$ 102,364.86			
			SUBTOTALS	$ 3,548,024.55		$ 422,255.04		$ 4,495.50	
			TOTAL COST	$ 3,974,775.09					
			CONTIGENCY 20%	$ 794,955.02					
			OVERHEAD 10%	$ 397,477.51					
			PROFIT 8%	$ 413,376.61					
			TOTAL COST						$ 5,580,584

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
oyster shell dredging	CY	161333	$ 15.85	$ 2,557,133.33		$ -		$ -	
Mob/Demob	HR	7		$ -	$ 172.98	$ 1,210.86	$ 367.43	$ 2,572.01	
barge delivery	HR	121		$ -	$ 172.98	$ 20,930.58	$ 336.62	$ 40,731.02	
oyster placement	CY	161333		$ -	$ 6.27	$ 1,011,560.00		$ -	
			MATERIAL SUBTOTAL	$ 2,557,133.33	***LABOR SUBTOTAL***	$ 1,033,701.44	***EQUIP SUBTOTAL***	$ 43,303.03	
			SALES TAX (MATERIALS) 5%	$ 127,856.67	***Labor Insurance 32%***	$ 330,784.46			
			SUBTOTALS	$ 2,684,990.00		$ 1,364,485.90		$ 43,303.03	
			TOTAL COST	$ 4,092,778.93					
			CONTIGENCY 20%	$ 818,555.79					
			OVERHEAD 10%	$ 409,277.89					
			PROFIT 8%	$ 425,649.01					
			TOTAL COST						$ 5,746,262
spat	EA	675000000	$ 0.010	$ 6,750,000.00		$ -		$ -	
Mob/Demob	HR	7			$ 172.98	$ 1,210.86	$ 118.83	$ 831.81	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	675000000		$ -	$ 0.001	$ 632,475.00		$ -	
Turbidity control	LF	8350	$ 0.69	$ 5,761.50	$ 0.15	$ 1,252.50	$ 0.39	$ 3,256.50	
			MATERIAL SUBTOTAL	$ 6,755,761.50	***LABOR SUBTOTAL***	$ 636,495.18	***EQUIP SUBTOTAL***	$ 5,451.00	
			SALES TAX (MATERIALS) 5%	$ 337,788.08	***Labor Insurance 32%***	$ 203,678.46			
			SUBTOTALS	$ 7,093,549.58		$ 840,173.64		$ 5,451.00	
			TOTAL COST	$ 7,939,174.21					
			CONTIGENCY 20%	$ 1,587,834.84					
			OVERHEAD 10%	$ 793,917.42					
			PROFIT 8%	$ 825,674.12					
			TOTAL COST						$ 11,146,601

Piankatank River

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 3.6M spat/ac)									
option 1 (25 acre site):									
limestone	CY	40333	$ 47.50	$ 1,915,833.33		$ -		$ -	
Mob/Demob	HR	35		$ -	$ 172.98	$ 6,054.30	$ 367.43	$ 12,860.05	
barge delivery	HR	886		$ -	$ 172.98	$ 153,260.28	$ 336.62	$ 298,245.32	
limestone placement	CY	40333		$ -	$ 1.16	$ 46,786.67	$ 2.09	$ 84,296.67	
			MATERIAL SUBTOTAL	$ 1,915,833.33	***LABOR SUBTOTAL***	$ 206,101.25	***EQUIP SUBTOTAL***	$ 395,402.04	
			SALES TAX (MATERIALS) 5%	$ 95,791.67	***Labor Insurance 32%***	$ 65,952.40			
			SUBTOTALS	$ 2,011,625.00		$ 272,053.65		$ 395,402.04	
			TOTAL COST	$ 2,679,080.68					
			CONTIGENCY 20%	$ 535,816.14					
			OVERHEAD 10%	$ 267,908.07					
			PROFIT 8%	$ 278,624.39					
			TOTAL COST						$ 3,761,429
spat	EA	90000000	$ 0.010	$ 900,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	90000000		$ -	$ 0.001	$ 84,330.00		$ -	
			MATERIAL SUBTOTAL	$ 900,000.00	***LABOR SUBTOTAL***	$ 87,443.64	***EQUIP SUBTOTAL***	$ 2,432.16	
			SALES TAX (MATERIALS) 5%	$ 45,000.00	***Labor Insurance 32%***	$ 27,981.96			
			SUBTOTALS	$ 945,000.00		$ 115,425.60		$ 2,432.16	
			TOTAL COST	$ 1,062,857.76					
			CONTIGENCY 20%	$ 212,571.55					
			OVERHEAD 10%	$ 106,285.78					
			PROFIT 8%	$ 110,537.21					
			TOTAL COST						$ 1,492,252

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
limestone	CY	80667	$ 47.50	$ 3,831,666.67		$ -		$ -	
Mob/Demob	HR	35		$ -	$ 172.98	$ 6,054.30	$ 367.43	$ 12,860.05	
barge delivery	HR	1772		$ -	$ 172.98	$ 306,520.56	$ 336.62	$ 596,490.64	
limestone placement	CY	80667		$ -	$ 1.16	$ 93,573.33	$ 2.09	$ 168,593.33	
			MATERIAL SUBTOTAL	$ 3,831,666.67	***LABOR SUBTOTAL***	$ 406,148.19	***EQUIP SUBTOTAL***	$ 777,944.02	
			SALES TAX (MATERIALS) 5%	$ 191,583.33	***Labor Insurance 32%***	$ 129,967.42			
			SUBTOTALS	$ 4,023,250.00		$ 536,115.62		$ 777,944.02	
			TOTAL COST	$ 5,337,309.64					
			CONTIGENCY 20%	$ 1,067,461.93					
			OVERHEAD 10%	$ 533,730.96					
			PROFIT 8%	$ 555,080.20					
			TOTAL COST						$ 7,493,583
spat	EA	180000000	$ 0.010	$ 1,800,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	180000000		$ -	$ 0.001	$ 168,660.00		$ -	
			MATERIAL SUBTOTAL	$ 1,800,000.00	***LABOR SUBTOTAL***	$ 171,773.64	***EQUIP SUBTOTAL***	$ 2,432.16	
			SALES TAX (MATERIALS) 5%	$ 90,000.00	***Labor Insurance 32%***	$ 54,967.56			
			SUBTOTALS	$ 1,890,000.00		$ 226,741.20		$ 2,432.16	
			TOTAL COST	$ 2,119,173.36					
			CONTIGENCY 20%	$ 423,834.67					
			OVERHEAD 10%	$ 211,917.34					
			PROFIT 8%	$ 220,394.03					
			TOTAL COST						$ 2,975,319

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
limestone	CY	161333	$ 47.50	$ 7,663,333.33		$ -		$ -	
Mob/Demob	HR	35		$ -	$ 172.98	$ 6,054.30	$ 367.43	$ 12,860.05	
barge delivery	HR	3544		$ -	$ 172.98	$ 613,041.12	$ 336.62	$ 1,192,981.28	
limestone placement	CY	161333		$ -	$ 1.16	$ 187,146.67	$ 2.09	$ 337,186.67	
			MATERIAL SUBTOTAL	$ 7,663,333.33	***LABOR SUBTOTAL***	$ 806,242.09	***EQUIP SUBTOTAL***	$ 1,543,028.00	
			SALES TAX (MATERIALS) 5%	$ 383,166.67	***Labor Insurance 32%***	$ 257,997.47			
			SUBTOTALS	$ 8,046,500.00		$ 1,064,239.55		$ 1,543,028.00	
			TOTAL COST	$ 10,653,767.55					
			CONTIGENCY 20%	$ 2,130,753.51					
			OVERHEAD 10%	$ 1,065,376.76					
			PROFIT 8%	$ 1,107,991.83					
			TOTAL COST						$ 14,957,890
spat	EA	360000000	$ 0.010	$ 3,600,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	360000000		$ -	$ 0.001	$ 337,320.00		$ -	
			MATERIAL SUBTOTAL	$ 3,600,000.00	***LABOR SUBTOTAL***	$ 340,433.64	***EQUIP SUBTOTAL***	$ 2,432.16	
			SALES TAX (MATERIALS) 5%	$ 180,000.00	***Labor Insurance 32%***	$ 108,938.76			
			SUBTOTALS	$ 3,780,000.00		$ 449,372.40		$ 2,432.16	
			TOTAL COST	$ 4,231,804.56					
			CONTIGENCY 20%	$ 846,360.91					
			OVERHEAD 10%	$ 423,180.46					
			PROFIT 8%	$ 440,107.67					
			TOTAL COST						$ 5,941,454

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 4.5M spat/ac)									
option 1 (25 acre site):									
limestone	CY	40333	$ 47.50	$ 1,915,833.33		$ -		$ -	
Mob/Demob	HR	35		$ -	$ 172.98	$ 6,054.30	$ 367.43	$ 12,860.05	
barge delivery	HR	886		$ -	$ 172.98	$ 153,260.28	$ 336.62	$ 298,245.32	
limestone placement	CY	40333		$ -	$ 1.16	$ 46,786.67	$ 2.09	$ 84,296.67	
			MATERIAL SUBTOTAL	$ 1,915,833.33	***LABOR SUBTOTAL***	$ 206,101.25	***EQUIP SUBTOTAL***	$ 395,402.04	
			SALES TAX (MATERIALS) 5%	$ 95,791.67	***Labor Insurance 32%***	$ 65,952.40			
			SUBTOTALS	$ 2,011,625.00		$ 272,053.65		$ 395,402.04	
			TOTAL COST	$ 2,679,080.68					
			CONTIGENCY 20%	$ 535,816.14					
			OVERHEAD 10%	$ 267,908.07					
			PROFIT 8%	$ 278,624.39					
			TOTAL COST						$ 3,761,429
spat	EA	112500000	$ 0.010	$ 1,125,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	112500000		$ -	$ 0.001	$ 105,412.50		$ -	
			MATERIAL SUBTOTAL	$ 1,125,000.00	***LABOR SUBTOTAL***	$ 108,526.14	***EQUIP SUBTOTAL***	$ 2,432.16	
			SALES TAX (MATERIALS) 5%	$ 56,250.00	***Labor Insurance 32%***	$ 34,728.36			
			SUBTOTALS	$ 1,181,250.00		$ 143,254.50		$ 2,432.16	
			TOTAL COST	$ 1,326,936.66					
			CONTIGENCY 20%	$ 265,387.33					
			OVERHEAD 10%	$ 132,693.67					
			PROFIT 8%	$ 138,001.41					
			TOTAL COST						$ 1,863,019

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
limestone	CY	80667	$ 47.50	$ 3,831,666.67		$ -		$ -	
Mob/Demob	HR	35		$ -	$ 172.98	$ 6,054.30	$ 367.43	$ 12,860.05	
barge delivery	HR	1772		$ -	$ 172.98	$ 306,520.56	$ 336.62	$ 596,490.64	
limestone placement	CY	80667		$ -	$ 1.16	$ 93,573.33	$ 2.09	$ 168,593.33	
			MATERIAL SUBTOTAL	$ 3,831,666.67	***LABOR SUBTOTAL***	$ 406,148.19	***EQUIP SUBTOTAL***	$ 777,944.02	
			SALES TAX (MATERIALS) 5%	$ 191,583.33	***Labor Insurance 32%***	$ 129,967.42			
			SUBTOTALS	$ 4,023,250.00		$ 536,115.62		$ 777,944.02	
			TOTAL COST	$ 5,337,309.64					
			CONTIGENCY 20%	$ 1,067,461.93					
			OVERHEAD 10%	$ 533,730.96					
			PROFIT 8%	$ 555,080.20					
			TOTAL COST						$ 7,493,583
spat	EA	225000000	$ 0.010	$ 2,250,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	225000000		$ -	$ 0.001	$ 210,825.00		$ -	
			MATERIAL SUBTOTAL	$ 2,250,000.00	***LABOR SUBTOTAL***	$ 213,938.64	***EQUIP SUBTOTAL***	$ 2,432.16	
			SALES TAX (MATERIALS) 5%	$ 112,500.00	***Labor Insurance 32%***	$ 68,460.36			
			SUBTOTALS	$ 2,362,500.00		$ 282,399.00		$ 2,432.16	
			TOTAL COST	$ 2,647,331.16					
			CONTIGENCY 20%	$ 529,466.23					
			OVERHEAD 10%	$ 264,733.12					
			PROFIT 8%	$ 275,322.44					
			TOTAL COST						$ 3,716,853

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
limestone	CY	161333	$ 47.50	$ 7,663,333.33		$ -		$ -	
Mob/Demob	HR	35		$ -	$ 172.98	$ 6,054.30	$ 367.43	$ 12,860.05	
barge delivery	HR	3544		$ -	$ 172.98	$ 613,041.12	$ 336.62	$ 1,192,981.28	
limestone placement	CY	161333		$ -	$ 1.16	$ 187,146.67	$ 2.09	$ 337,186.67	
			MATERIAL SUBTOTAL	$ 7,663,333.33	***LABOR SUBTOTAL***	$ 806,242.09	***EQUIP SUBTOTAL***	$ 1,543,028.00	
			SALES TAX (MATERIALS) 5%	$ 383,166.67	***Labor Insurance 32%***	$ 257,997.47			
			SUBTOTALS	$ 8,046,500.00		$ 1,064,239.55		$ 1,543,028.00	
			TOTAL COST	$ 10,653,767.55					
			CONTIGENCY 20%	$ 2,130,753.51					
			OVERHEAD 10%	$ 1,065,376.76					
			PROFIT 8%	$ 1,107,991.83					
			TOTAL COST						$ 14,957,890
spat	EA	450000000	$ 0.010	$ 4,500,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	450000000		$ -	$ 0.001	$ 421,650.00		$ -	
			MATERIAL SUBTOTAL	$ 4,500,000.00	***LABOR SUBTOTAL***	$ 424,763.64	***EQUIP SUBTOTAL***	$ 2,432.16	
			SALES TAX (MATERIALS) 5%	$ 225,000.00	***Labor Insurance 32%***	$ 135,924.36			
			SUBTOTALS	$ 4,725,000.00		$ 560,688.00		$ 2,432.16	
			TOTAL COST	$ 5,288,120.16					
			CONTIGENCY 20%	$ 1,057,624.03					
			OVERHEAD 10%	$ 528,812.02					
			PROFIT 8%	$ 549,964.50					
			TOTAL COST						$ 7,424,521

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 6.75M spat/ac)									
option 1 (25 acre site):									
limestone	CY	40333	$ 47.50	$ 1,915,833.33		$ -		$ -	
Mob/Demob	HR	35		$ -	$ 172.98	$ 6,054.30	$ 367.43	$ 12,860.05	
barge delivery	HR	886		$ -	$ 172.98	$ 153,260.28	$ 336.62	$ 298,245.32	
limestone placement	CY	40333		$ -	$ 1.16	$ 46,786.67	$ 2.09	$ 84,296.67	
			MATERIAL SUBTOTAL	$ 1,915,833.33	***LABOR SUBTOTAL***	$ 206,101.25	***EQUIP SUBTOTAL***	$ 395,402.04	
			SALES TAX (MATERIALS) 5%	$ 95,791.67	***Labor Insurance 32%***	$ 65,952.40			
			SUBTOTALS	$ 2,011,625.00		$ 272,053.65		$ 395,402.04	
			TOTAL COST	$ 2,679,080.68					
			CONTIGENCY 20%	$ 535,816.14					
			OVERHEAD 10%	$ 267,908.07					
			PROFIT 8%	$ 278,624.39					
			TOTAL COST						$ 3,761,429
spat	EA	168750000	$ 0.010	$ 1,687,500.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	168750000		$ -	$ 0.001	$ 158,118.75		$ -	
			MATERIAL SUBTOTAL	$ 1,687,500.00	***LABOR SUBTOTAL***	$ 161,232.39	***EQUIP SUBTOTAL***	$ 2,432.16	
			SALES TAX (MATERIALS) 5%	$ 84,375.00	***Labor Insurance 32%***	$ 51,594.36			
			SUBTOTALS	$ 1,771,875.00		$ 212,826.75		$ 2,432.16	
			TOTAL COST	$ 1,987,133.91					
			CONTIGENCY 20%	$ 397,426.78					
			OVERHEAD 10%	$ 198,713.39					
			PROFIT 8%	$ 206,661.93					
			TOTAL COST						$ 2,789,936

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
limestone	CY	80667	$ 47.50	$ 3,831,666.67		$ -		$ -	
Mob/Demob	HR	35		$ -	$ 172.98	$ 6,054.30	$ 367.43	$ 12,860.05	
barge delivery	HR	1772		$ -	$ 172.98	$ 306,520.56	$ 336.62	$ 596,490.64	
limestone placement	CY	80667		$ -	$ 1.16	$ 93,573.33	$ 2.09	$ 168,593.33	
			MATERIAL SUBTOTAL	$ 3,831,666.67	***LABOR SUBTOTAL***	$ 406,148.19	***EQUIP SUBTOTAL***	$ 777,944.02	
			SALES TAX (MATERIALS) 5%	$ 191,583.33	***Labor Insurance 32%***	$ 129,967.42			
			SUBTOTALS	$ 4,023,250.00		$ 536,115.62		$ 777,944.02	
			TOTAL COST	$ 5,337,309.64					
			CONTIGENCY 20%	$ 1,067,461.93					
			OVERHEAD 10%	$ 533,730.96					
			PROFIT 8%	$ 555,080.20					
			TOTAL COST						$ 7,493,583
spat	EA	337500000	$ 0.010	$ 3,375,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	337500000		$ -	$ 0.001	$ 316,237.50		$ -	
			MATERIAL SUBTOTAL	$ 3,375,000.00	***LABOR SUBTOTAL***	$ 319,351.14	***EQUIP SUBTOTAL***	$ 2,432.16	
			SALES TAX (MATERIALS) 5%	$ 168,750.00	***Labor Insurance 32%***	$ 102,192.36			
			SUBTOTALS	$ 3,543,750.00		$ 421,543.50		$ 2,432.16	
			TOTAL COST	$ 3,967,725.66					
			CONTIGENCY 20%	$ 793,545.13					
			OVERHEAD 10%	$ 396,772.57					
			PROFIT 8%	$ 412,643.47					
			TOTAL COST						$ 5,570,687

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
limestone	CY	161333	$ 47.50	$ 7,663,333.33		$ -		$ -	
Mob/Demob	HR	35		$ -	$ 172.98	$ 6,054.30	$ 367.43	$ 12,860.05	
barge delivery	HR	3544		$ -	$ 172.98	$ 613,041.12	$ 336.62	$ 1,192,981.28	
limestone placement	CY	161333		$ -	$ 1.16	$ 187,146.67	$ 2.09	$ 337,186.67	
			MATERIAL SUBTOTAL	$ 7,663,333.33	***LABOR SUBTOTAL***	$ 806,242.09	***EQUIP SUBTOTAL***	$ 1,543,028.00	
			SALES TAX (MATERIALS) 5%	$ 383,166.67	***Labor Insurance 32%***	$ 257,997.47			
			SUBTOTALS	$ 8,046,500.00		$ 1,064,239.55		$ 1,543,028.00	
			TOTAL COST	$ 10,653,767.55					
			CONTIGENCY 20%	$ 2,130,753.51					
			OVERHEAD 10%	$ 1,065,376.76					
			PROFIT 8%	$ 1,107,991.83					
			TOTAL COST						$ 14,957,890
spat	EA	675000000	$ 0.010	$ 6,750,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	675000000		$ -	$ 0.001	$ 632,475.00		$ -	
			MATERIAL SUBTOTAL	$ 6,750,000.00	***LABOR SUBTOTAL***	$ 635,588.64	***EQUIP SUBTOTAL***	$ 2,432.16	
			SALES TAX (MATERIALS) 5%	$ 337,500.00	***Labor Insurance 32%***	$ 203,388.36			
			SUBTOTALS	$ 7,087,500.00		$ 838,977.00		$ 2,432.16	
			TOTAL COST	$ 7,928,909.16					
			CONTIGENCY 20%	$ 1,585,781.83					
			OVERHEAD 10%	$ 792,890.92					
			PROFIT 8%	$ 824,606.55					
			TOTAL COST						$ 11,132,188

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 3.6M spat/ac)									
option 1 (25 acre site):									
granite	CY	40333.3333	$ 48.00	$ 1,936,000.00		$ -		$ -	
Mob/Demob	HR	35		$ -	$ 172.98	$ 6,054.30	$ 367.43	$ 12,860.05	
barge delivery	HR	599		$ -	$ 172.98	$ 103,615.02	$ 336.62	$ 201,635.38	
granite placement	CY	40333.3333		$ -	$ 1.16	$ 46,786.67	$ 2.09	$ 84,296.67	
			MATERIAL SUBTOTAL	$ 1,936,000.00	***LABOR SUBTOTAL***	$ 156,455.99	***EQUIP SUBTOTAL***	$ 298,792.10	
			SALES TAX (MATERIALS) 5%	$ 96,800.00	***Labor Insurance 32%***	$ 50,065.92			
			SUBTOTALS	$ 2,032,800.00		$ 206,521.90		$ 298,792.10	
			TOTAL COST	$ 2,538,114.00					
			CONTIGENCY 20%	$ 507,622.80					
			OVERHEAD 10%	$ 253,811.40					
			PROFIT 8%	$ 263,963.86					
			TOTAL COST						$ 3,563,512
spat	EA	90000000	$ 0.010	$ 900,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	90000000		$ -	$ 0.001	$ 84,330.00		$ -	
			MATERIAL SUBTOTAL	$ 900,000.00	***LABOR SUBTOTAL***	$ 87,443.64	***EQUIP SUBTOTAL***	$ 2,432.16	
			SALES TAX (MATERIALS) 5%	$ 45,000.00	***Labor Insurance 32%***	$ 27,981.96			
			SUBTOTALS	$ 945,000.00		$ 115,425.60		$ 2,432.16	
			TOTAL COST	$ 1,062,857.76					
			CONTIGENCY 20%	$ 212,571.55					
			OVERHEAD 10%	$ 106,285.78					
			PROFIT 8%	$ 110,537.21					
			TOTAL COST						$ 1,492,252

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
granite	CY	80666.6667	$ 48.00	$ 3,872,000.00		$ -		$ -	
Mob/Demob	HR	35		$ -	$ 172.98	$ 6,054.30	$ 367.43	$ 12,860.05	
barge delivery	HR	1197		$ -	$ 172.98	$ 207,057.06	$ 336.62	$ 402,934.14	
granite placement	CY	80666.6667		$ -	$ 1.16	$ 93,573.33	$ 2.09	$ 168,593.33	
			MATERIAL SUBTOTAL	$ 3,872,000.00	***LABOR SUBTOTAL***	$ 306,684.69	***EQUIP SUBTOTAL***	$ 584,387.52	
			SALES TAX (MATERIALS) 5%	$ 193,600.00	***Labor Insurance 32%***	$ 98,139.10			
			SUBTOTALS	$ 4,065,600.00		$ 404,823.80		$ 584,387.52	
			TOTAL COST	$ 5,054,811.32					
			CONTIGENCY 20%	$ 1,010,962.26					
			OVERHEAD 10%	$ 505,481.13					
			PROFIT 8%	$ 525,700.38					
			TOTAL COST						$ 7,096,955
spat	EA	180000000	$ 0.010	$ 1,800,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	180000000		$ -	$ 0.001	$ 168,660.00		$ -	
			MATERIAL SUBTOTAL	$ 1,800,000.00	***LABOR SUBTOTAL***	$ 171,773.64	***EQUIP SUBTOTAL***	$ 2,432.16	
			SALES TAX (MATERIALS) 5%	$ 90,000.00	***Labor Insurance 32%***	$ 54,967.56			
			SUBTOTALS	$ 1,890,000.00		$ 226,741.20		$ 2,432.16	
			TOTAL COST	$ 2,119,173.36					
			CONTIGENCY 20%	$ 423,834.67					
			OVERHEAD 10%	$ 211,917.34					
			PROFIT 8%	$ 220,394.03					
			TOTAL COST						$ 2,975,319

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
granite	CY	161333.333	$ 48.00	$ 7,744,000.00		$ -		$ -	
Mob/Demob	HR	35		$ -	$ 172.98	$ 6,054.30	$ 367.43	$ 12,860.05	
barge delivery	HR	2395		$ -	$ 172.98	$ 414,287.10	$ 336.62	$ 806,204.90	
granite placement	CY	161333.333		$ -	$ 1.16	$ 187,146.67	$ 2.09	$ 337,186.67	
			MATERIAL SUBTOTAL	$ 7,744,000.00	***LABOR SUBTOTAL***	$ 607,488.07	***EQUIP SUBTOTAL***	$ 1,156,251.62	
			SALES TAX (MATERIALS) 5%	$ 387,200.00	***Labor Insurance 32%***	$ 194,396.18			
			SUBTOTALS	$ 8,131,200.00		$ 801,884.25		$ 1,156,251.62	
			TOTAL COST	$ 10,089,335.86					
			CONTIGENCY 20%	$ 2,017,867.17					
			OVERHEAD 10%	$ 1,008,933.59					
			PROFIT 8%	$ 1,049,290.93					
			TOTAL COST						$ 14,165,428
spat	EA	360000000	$ 0.010	$ 3,600,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	360000000		$ -	$ 0.001	$ 337,320.00		$ -	
			MATERIAL SUBTOTAL	$ 3,600,000.00	***LABOR SUBTOTAL***	$ 340,433.64	***EQUIP SUBTOTAL***	$ 2,432.16	
			SALES TAX (MATERIALS) 5%	$ 180,000.00	***Labor Insurance 32%***	$ 108,938.76			
			SUBTOTALS	$ 3,780,000.00		$ 449,372.40		$ 2,432.16	
			TOTAL COST	$ 4,231,804.56					
			CONTIGENCY 20%	$ 846,360.91					
			OVERHEAD 10%	$ 423,180.46					
			PROFIT 8%	$ 440,107.67					
			TOTAL COST						$ 5,941,454

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 4.5M spat/ac)									
option 1 (25 acre site):									
granite	CY	40333.3333	$ 48.00	$ 1,936,000.00		$ -		$ -	
Mob/Demob	HR	35		$ -	$ 172.98	$ 6,054.30	$ 367.43	$ 12,860.05	
barge delivery	HR	599		$ -	$ 172.98	$ 103,615.02	$ 336.62	$ 201,635.38	
granite placement	CY	40333.3333		$ -	$ 1.16	$ 46,786.67	$ 2.09	$ 84,296.67	
			MATERIAL SUBTOTAL	$ 1,936,000.00	***LABOR SUBTOTAL***	$ 156,455.99	***EQUIP SUBTOTAL***	$ 298,792.10	
			SALES TAX (MATERIALS) 5%	$ 96,800.00	***Labor Insurance 32%***	$ 50,065.92			
			SUBTOTALS	$ 2,032,800.00		$ 206,521.90		$ 298,792.10	
			TOTAL COST	$ 2,538,114.00					
			CONTIGENCY 20%	$ 507,622.80					
			OVERHEAD 10%	$ 253,811.40					
			PROFIT 8%	$ 263,963.86					
			TOTAL COST						$ 3,563,512
spat	EA	112500000	$ 0.010	$ 1,125,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	112500000		$ -	$ 0.001	$ 105,412.50		$ -	
			MATERIAL SUBTOTAL	$ 1,125,000.00	***LABOR SUBTOTAL***	$ 108,526.14	***EQUIP SUBTOTAL***	$ 2,432.16	
			SALES TAX (MATERIALS) 5%	$ 56,250.00	***Labor Insurance 32%***	$ 34,728.36			
			SUBTOTALS	$ 1,181,250.00		$ 143,254.50		$ 2,432.16	
			TOTAL COST	$ 1,326,936.66					
			CONTIGENCY 20%	$ 265,387.33					
			OVERHEAD 10%	$ 132,693.67					
			PROFIT 8%	$ 138,001.41					
			TOTAL COST						$ 1,863,019

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
granite	CY	80666.6667	$ 48.00	$ 3,872,000.00		$ -		$ -	
Mob/Demob	HR	35		$ -	$ 172.98	$ 6,054.30	$ 367.43	$ 12,860.05	
barge delivery	HR	1197		$ -	$ 172.98	$ 207,057.06	$ 336.62	$ 402,934.14	
granite placement	CY	80666.6667		$ -	$ 1.16	$ 93,573.33	$ 2.09	$ 168,593.33	
			MATERIAL SUBTOTAL	$ 3,872,000.00	***LABOR SUBTOTAL***	$ 306,684.69	***EQUIP SUBTOTAL***	$ 584,387.52	
			SALES TAX (MATERIALS) 5%	$ 193,600.00	***Labor Insurance 32%***	$ 98,139.10			
			SUBTOTALS	$ 4,065,600.00		$ 404,823.80		$ 584,387.52	
			TOTAL COST	$ 5,054,811.32					
			CONTIGENCY 20%	$ 1,010,962.26					
			OVERHEAD 10%	$ 505,481.13					
			PROFIT 8%	$ 525,700.38					
			TOTAL COST						$ 7,096,955
spat	EA	225000000	$ 0.010	$ 2,250,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	225000000		$ -	$ 0.001	$ 210,825.00		$ -	
			MATERIAL SUBTOTAL	$ 2,250,000.00	***LABOR SUBTOTAL***	$ 213,938.64	***EQUIP SUBTOTAL***	$ 2,432.16	
			SALES TAX (MATERIALS) 5%	$ 112,500.00	***Labor Insurance 32%***	$ 68,460.36			
			SUBTOTALS	$ 2,362,500.00		$ 282,399.00		$ 2,432.16	
			TOTAL COST	$ 2,647,331.16					
			CONTIGENCY 20%	$ 529,466.23					
			OVERHEAD 10%	$ 264,733.12					
			PROFIT 8%	$ 275,322.44					
			TOTAL COST						$ 3,716,853

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
granite	CY	161333.333	$ 48.00	$ 7,744,000.00		$ -		$ -	
Mob/Demob	HR	35		$ -	$ 172.98	$ 6,054.30	$ 367.43	$ 12,860.05	
barge delivery	HR	2395		$ -	$ 172.98	$ 414,287.10	$ 336.62	$ 806,204.90	
granite placement	CY	161333.333		$ -	$ 1.16	$ 187,146.67	$ 2.09	$ 337,186.67	
			MATERIAL SUBTOTAL	$ 7,744,000.00	***LABOR SUBTOTAL***	$ 607,488.07	***EQUIP SUBTOTAL***	$ 1,156,251.62	
			SALES TAX (MATERIALS) 5%	$ 387,200.00	***Labor Insurance 32%***	$ 194,396.18			
			SUBTOTALS	$ 8,131,200.00		$ 801,884.25		$ 1,156,251.62	
			TOTAL COST	$ 10,089,335.86					
			CONTIGENCY 20%	$ 2,017,867.17					
			OVERHEAD 10%	$ 1,008,933.59					
			PROFIT 8%	$ 1,049,290.93					
			TOTAL COST						$ 14,165,428
spat	EA	450000000	$ 0.010	$ 4,500,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	450000000		$ -	$ 0.001	$ 421,650.00		$ -	
			MATERIAL SUBTOTAL	$ 4,500,000.00	***LABOR SUBTOTAL***	$ 424,763.64	***EQUIP SUBTOTAL***	$ 2,432.16	
			SALES TAX (MATERIALS) 5%	$ 225,000.00	***Labor Insurance 32%***	$ 135,924.36			
			SUBTOTALS	$ 4,725,000.00		$ 560,688.00		$ 2,432.16	
			TOTAL COST	$ 5,288,120.16					
			CONTIGENCY 20%	$ 1,057,624.03					
			OVERHEAD 10%	$ 528,812.02					
			PROFIT 8%	$ 549,964.50					
			TOTAL COST						$ 7,424,521

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 6.75M spat/ac)									
option 1 (25 acre site):									
granite	CY	40333.3333	$ 48.00	$ 1,936,000.00		$ -		$ -	
Mob/Demob	HR	35		$ -	$ 172.98	$ 6,054.30	$ 367.43	$ 12,860.05	
barge delivery	HR	599		$ -	$ 172.98	$ 103,615.02	$ 336.62	$ 201,635.38	
granite placement	CY	40333.3333		$ -	$ 1.16	$ 46,786.67	$ 2.09	$ 84,296.67	
			MATERIAL SUBTOTAL	$ 1,936,000.00	***LABOR SUBTOTAL***	$ 156,455.99	***EQUIP SUBTOTAL***	$ 298,792.10	
			SALES TAX (MATERIALS) 5%	$ 96,800.00	***Labor Insurance 32%***	$ 50,065.92			
			SUBTOTALS	$ 2,032,800.00		$ 206,521.90		$ 298,792.10	
			TOTAL COST	$ 2,538,114.00					
			CONTIGENCY 20%	$ 507,622.80					
			OVERHEAD 10%	$ 253,811.40					
			PROFIT 8%	$ 263,963.86					
			TOTAL COST						$ 3,563,512
spat	EA	168750000	$ 0.010	$ 1,687,500.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	168750000		$ -	$ 0.001	$ 158,118.75		$ -	
			MATERIAL SUBTOTAL	$ 1,687,500.00	***LABOR SUBTOTAL***	$ 161,232.39	***EQUIP SUBTOTAL***	$ 2,432.16	
			SALES TAX (MATERIALS) 5%	$ 84,375.00	***Labor Insurance 32%***	$ 51,594.36			
			SUBTOTALS	$ 1,771,875.00		$ 212,826.75		$ 2,432.16	
			TOTAL COST	$ 1,987,133.91					
			CONTIGENCY 20%	$ 397,426.78					
			OVERHEAD 10%	$ 198,713.39					
			PROFIT 8%	$ 206,661.93					
			TOTAL COST						$ 2,789,936

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
granite	CY	80666.6667	$ 48.00	$ 3,872,000.00		$ -		$ -	
Mob/Demob	HR	35		$ -	$ 172.98	$ 6,054.30	$ 367.43	$ 12,860.05	
barge delivery	HR	1197		$ -	$ 172.98	$ 207,057.06	$ 336.62	$ 402,934.14	
granite placement	CY	80666.6667		$ -	$ 1.16	$ 93,573.33	$ 2.09	$ 168,593.33	
			MATERIAL SUBTOTAL	$ 3,872,000.00	***LABOR SUBTOTAL***	$ 306,684.69	***EQUIP SUBTOTAL***	$ 584,387.52	
			SALES TAX (MATERIALS) 5%	$ 193,600.00	***Labor Insurance 32%***	$ 98,139.10			
			SUBTOTALS	$ 4,065,600.00		$ 404,823.80		$ 584,387.52	
			TOTAL COST	$ 5,054,811.32					
			CONTIGENCY 20%	$ 1,010,962.26					
			OVERHEAD 10%	$ 505,481.13					
			PROFIT 8%	$ 525,700.38					
			TOTAL COST						$ 7,096,955
spat	EA	337500000	$ 0.010	$ 3,375,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	337500000		$ -	$ 0.001	$ 316,237.50		$ -	
			MATERIAL SUBTOTAL	$ 3,375,000.00	***LABOR SUBTOTAL***	$ 319,351.14	***EQUIP SUBTOTAL***	$ 2,432.16	
			SALES TAX (MATERIALS) 5%	$ 168,750.00	***Labor Insurance 32%***	$ 102,192.36			
			SUBTOTALS	$ 3,543,750.00		$ 421,543.50		$ 2,432.16	
			TOTAL COST	$ 3,967,725.66					
			CONTIGENCY 20%	$ 793,545.13					
			OVERHEAD 10%	$ 396,772.57					
			PROFIT 8%	$ 412,643.47					
			TOTAL COST						$ 5,570,687

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
granite	CY	161333.333	$ 48.00	$ 7,744,000.00		$ -		$ -	
Mob/Demob	HR	35		$ -	$ 172.98	$ 6,054.30	$ 367.43	$ 12,860.05	
barge delivery	HR	2395		$ -	$ 172.98	$ 414,287.10	$ 336.62	$ 806,204.90	
granite placement	CY	161333.333		$ -	$ 1.16	$ 187,146.67	$ 2.09	$ 337,186.67	
			MATERIAL SUBTOTAL	$ 7,744,000.00	***LABOR SUBTOTAL***	$ 607,488.07	***EQUIP SUBTOTAL***	$ 1,156,251.62	
			SALES TAX (MATERIALS) 5%	$ 387,200.00	***Labor Insurance 32%***	$ 194,396.18			
			SUBTOTALS	$ 8,131,200.00		$ 801,884.25		$ 1,156,251.62	
			TOTAL COST	$ 10,089,335.86					
			CONTIGENCY 20%	$ 2,017,867.17					
			OVERHEAD 10%	$ 1,008,933.59					
			PROFIT 8%	$ 1,049,290.93					
			TOTAL COST						$ 14,165,428
spat	EA	675000000	$ 0.010	$ 6,750,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	675000000		$ -	$ 0.001	$ 632,475.00		$ -	
			MATERIAL SUBTOTAL	$ 6,750,000.00	***LABOR SUBTOTAL***	$ 635,588.64	***EQUIP SUBTOTAL***	$ 2,432.16	
			SALES TAX (MATERIALS) 5%	$ 337,500.00	***Labor Insurance 32%***	$ 203,388.36			
			SUBTOTALS	$ 7,087,500.00		$ 838,977.00		$ 2,432.16	
			TOTAL COST	$ 7,928,909.16					
			CONTIGENCY 20%	$ 1,585,781.83					
			OVERHEAD 10%	$ 792,890.92					
			PROFIT 8%	$ 824,606.55					
			TOTAL COST						$ 11,132,188

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 3.6M spat/ac)									
option 1 (25 acre site):									
concrete	CY	40333.3333	$ 30.00	$ 1,210,000.00		$ -		$ -	
Mob/Demob	HR	35		$ -	$ 172.98	$ 6,054.30	$ 367.43	$ 12,860.05	
barge delivery	HR	479		$ -	$ 172.98	$ 82,857.42	$ 336.62	$ 161,240.98	
concrete placement	CY	40333.3333		$ -	$ 0.92	$ 37,106.67	$ 1.67	$ 67,356.67	
			MATERIAL SUBTOTAL	$ 1,210,000.00	***LABOR SUBTOTAL***	$ 126,018.39	***EQUIP SUBTOTAL***	$ 241,457.70	
			SALES TAX (MATERIALS) 5%	$ 60,500.00	***Labor Insurance 32%***	$ 40,325.88			
			SUBTOTALS	$ 1,270,500.00		$ 166,344.27		$ 241,457.70	
			TOTAL COST	$ 1,678,301.97					
			CONTIGENCY 20%	$ 335,660.39					
			OVERHEAD 10%	$ 167,830.20					
			PROFIT 8%	$ 174,543.40					
			TOTAL COST						$ 2,356,336
spat	EA	90000000	$ 0.010	$ 900,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	90000000		$ -	$ 0.001	$ 84,330.00		$ -	
			MATERIAL SUBTOTAL	$ 900,000.00	***LABOR SUBTOTAL***	$ 87,443.64	***EQUIP SUBTOTAL***	$ 2,432.16	
			SALES TAX (MATERIALS) 5%	$ 45,000.00	***Labor Insurance 32%***	$ 27,981.96			
			SUBTOTALS	$ 945,000.00		$ 115,425.60		$ 2,432.16	
			TOTAL COST	$ 1,062,857.76					
			CONTIGENCY 20%	$ 212,571.55					
			OVERHEAD 10%	$ 106,285.78					
			PROFIT 8%	$ 110,537.21					
			TOTAL COST						$ 1,492,252

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
concrete	CY	80666.6667	$ 30.00	$ 2,420,000.00		$ -		$ -	
Mob/Demob	HR	35		$ -	$ 172.98	$ 6,054.30	$ 367.43	$ 12,860.05	
barge delivery	HR	958		$ -	$ 172.98	$ 165,714.84	$ 336.62	$ 322,481.96	
concrete placement	CY	80666.6667		$ -	$ 0.92	$ 74,213.33	$ 1.67	$ 134,713.33	
			MATERIAL SUBTOTAL	$ 2,420,000.00	***LABOR SUBTOTAL***	$ 245,982.47	***EQUIP SUBTOTAL***	$ 470,055.34	
			SALES TAX (MATERIALS) 5%	$ 121,000.00	***Labor Insurance 32%***	$ 78,714.39			
			SUBTOTALS	$ 2,541,000.00		$ 324,696.86		$ 470,055.34	
			TOTAL COST	$ 3,335,752.21					
			CONTIGENCY 20%	$ 667,150.44					
			OVERHEAD 10%	$ 333,575.22					
			PROFIT 8%	$ 346,918.23					
			TOTAL COST						$ 4,683,396
spat	EA	180000000	$ 0.010	$ 1,800,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	180000000		$ -	$ 0.001	$ 168,660.00		$ -	
			MATERIAL SUBTOTAL	$ 1,800,000.00	***LABOR SUBTOTAL***	$ 171,773.64	***EQUIP SUBTOTAL***	$ 2,432.16	
			SALES TAX (MATERIALS) 5%	$ 90,000.00	***Labor Insurance 32%***	$ 54,967.56			
			SUBTOTALS	$ 1,890,000.00		$ 226,741.20		$ 2,432.16	
			TOTAL COST	$ 2,119,173.36					
			CONTIGENCY 20%	$ 423,834.67					
			OVERHEAD 10%	$ 211,917.34					
			PROFIT 8%	$ 220,394.03					
			TOTAL COST						$ 2,975,319

DESCRIPTION	***UOM***	***QTY***	***MATERIAL UNIT COST***	***TOTAL MATERIAL***	***LABOR UNIT COST LABOR***	***TOTAL LABOR***	***EQUIP UNIT COST***	***TOTAL EQUIP***	
option 3 (100 acre site):									
concrete	CY	161333.333	$ 30.00	$ 4,840,000.00		$ -		$ -	
Mob/Demob	HR	35		$ -	$ 172.98	$ 6,054.30	$ 367.43	$ 12,860.05	
barge delivery	HR	1916		$ -	$ 172.98	$ 331,429.68	$ 336.62	$ 644,963.92	
concrete placement	CY	161333.333		$ -	$ 0.92	$ 148,426.67	$ 1.67	$ 269,426.67	
			MATERIAL SUBTOTAL	$ 4,840,000.00	***LABOR SUBTOTAL***	$ 485,910.65	***EQUIP SUBTOTAL***	$ 927,250.64	
			SALES TAX (MATERIALS) 5%	$ 242,000.00	***Labor Insurance 32%***	$ 155,491.41			
			SUBTOTALS	$ 5,082,000.00		$ 641,402.05		$ 927,250.64	
			TOTAL COST	$ 6,650,652.69					
			CONTIGENCY 20%	$ 1,330,130.54					
			OVERHEAD 10%	$ 665,065.27					
			PROFIT 8%	$ 691,667.88					
			TOTAL COST						$ 9,337,516
spat	EA	360000000	$ 0.010	$ 3,600,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	360000000		$ -	$ 0.001	$ 337,320.00		$ -	
			MATERIAL SUBTOTAL	$ 3,600,000.00	***LABOR SUBTOTAL***	$ 340,433.64	***EQUIP SUBTOTAL***	$ 2,432.16	
			SALES TAX (MATERIALS) 5%	$ 180,000.00	***Labor Insurance 32%***	$ 108,938.76			
			SUBTOTALS	$ 3,780,000.00		$ 449,372.40		$ 2,432.16	
			TOTAL COST	$ 4,231,804.56					
			CONTIGENCY 20%	$ 846,360.91					
			OVERHEAD 10%	$ 423,180.46					
			PROFIT 8%	$ 440,107.67					
			TOTAL COST						$ 5,941,454

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 4.5M spat/ac)									
option 1 (25 acre site):									
concrete	CY	40333.3333	$ 30.00	$ 1,210,000.00		$ -		$ -	
Mob/Demob	HR	35		$ -	$ 172.98	$ 6,054.30	$ 367.43	$ 12,860.05	
barge delivery	HR	479		$ -	$ 172.98	$ 82,857.42	$ 336.62	$ 161,240.98	
concrete placement	CY	40333.3333		$ -	$ 0.92	$ 37,106.67	$ 1.67	$ 67,356.67	
			MATERIAL SUBTOTAL	$ 1,210,000.00	***LABOR SUBTOTAL***	$ 126,018.39	***EQUIP SUBTOTAL***	$ 241,457.70	
			SALES TAX (MATERIALS) 5%	$ 60,500.00	***Labor Insurance 32%***	$ 40,325.88			
			SUBTOTALS	$ 1,270,500.00		$ 166,344.27		$ 241,457.70	
			TOTAL COST	$ 1,678,301.97					
			CONTIGENCY 20%	$ 335,660.39					
			OVERHEAD 10%	$ 167,830.20					
			PROFIT 8%	$ 174,543.40					
			TOTAL COST						$ 2,356,336
spat	EA	112500000	$ 0.010	$ 1,125,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	112500000		$ -	$ 0.001	$ 105,412.50		$ -	
			MATERIAL SUBTOTAL	$ 1,125,000.00	***LABOR SUBTOTAL***	$ 108,526.14	***EQUIP SUBTOTAL***	$ 2,432.16	
			SALES TAX (MATERIALS) 5%	$ 56,250.00	***Labor Insurance 32%***	$ 34,728.36			
			SUBTOTALS	$ 1,181,250.00		$ 143,254.50		$ 2,432.16	
			TOTAL COST	$ 1,326,936.66					
			CONTIGENCY 20%	$ 265,387.33					
			OVERHEAD 10%	$ 132,693.67					
			PROFIT 8%	$ 138,001.41					
			TOTAL COST						$ 1,863,019

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
concrete	CY	80666.6667	$ 30.00	$ 2,420,000.00		$ -		$ -	
Mob/Demob	HR	35		$ -	$ 172.98	$ 6,054.30	$ 367.43	$ 12,860.05	
barge delivery	HR	958		$ -	$ 172.98	$ 165,714.84	$ 336.62	$ 322,481.96	
concrete placement	CY	80666.6667		$ -	$ 0.92	$ 74,213.33	$ 1.67	$ 134,713.33	
			MATERIAL SUBTOTAL	$ 2,420,000.00	***LABOR SUBTOTAL***	$ 245,982.47	***EQUIP SUBTOTAL***	$ 470,055.34	
			SALES TAX (MATERIALS) 5%	$ 121,000.00	***Labor Insurance 32%***	$ 78,714.39			
			SUBTOTALS	$ 2,541,000.00		$ 324,696.86		$ 470,055.34	
			TOTAL COST	$ 3,335,752.21					
			CONTIGENCY 20%	$ 667,150.44					
			OVERHEAD 10%	$ 333,575.22					
			PROFIT 8%	$ 346,918.23					
			TOTAL COST						$ 4,683,396
spat	EA	225000000	$ 0.010	$ 2,250,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	225000000		$ -	$ 0.001	$ 210,825.00		$ -	
			MATERIAL SUBTOTAL	$ 2,250,000.00	***LABOR SUBTOTAL***	$ 213,938.64	***EQUIP SUBTOTAL***	$ 2,432.16	
			SALES TAX (MATERIALS) 5%	$ 112,500.00	***Labor Insurance 32%***	$ 68,460.36			
			SUBTOTALS	$ 2,362,500.00		$ 282,399.00		$ 2,432.16	
			TOTAL COST	$ 2,647,331.16					
			CONTIGENCY 20%	$ 529,466.23					
			OVERHEAD 10%	$ 264,733.12					
			PROFIT 8%	$ 275,322.44					
			TOTAL COST						$ 3,716,853

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
concrete	CY	161333.333	$ 30.00	$ 4,840,000.00		$ -		$ -	
Mob/Demob	HR	35		$ -	$ 172.98	$ 6,054.30	$ 367.43	$ 12,860.05	
barge delivery	HR	1916		$ -	$ 172.98	$ 331,429.68	$ 336.62	$ 644,963.92	
concrete placement	CY	161333.333		$ -	$ 0.92	$ 148,426.67	$ 1.67	$ 269,426.67	
			MATERIAL SUBTOTAL	$ 4,840,000.00	***LABOR SUBTOTAL***	$ 485,910.65	***EQUIP SUBTOTAL***	$ 927,250.64	
			SALES TAX (MATERIALS) 5%	$ 242,000.00	***Labor Insurance 32%***	$ 155,491.41			
			SUBTOTALS	$ 5,082,000.00		$ 641,402.05		$ 927,250.64	
			TOTAL COST	$ 6,650,652.69					
			CONTIGENCY 20%	$ 1,330,130.54					
			OVERHEAD 10%	$ 665,065.27					
			PROFIT 8%	$ 691,667.88					
			TOTAL COST						$ 9,337,516
spat	EA	450000000	$ 0.010	$ 4,500,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	450000000		$ -	$ 0.001	$ 421,650.00		$ -	
			MATERIAL SUBTOTAL	$ 4,500,000.00	***LABOR SUBTOTAL***	$ 424,763.64	***EQUIP SUBTOTAL***	$ 2,432.16	
			SALES TAX (MATERIALS) 5%	$ 225,000.00	***Labor Insurance 32%***	$ 135,924.36			
			SUBTOTALS	$ 4,725,000.00		$ 560,688.00		$ 2,432.16	
			TOTAL COST	$ 5,288,120.16					
			CONTIGENCY 20%	$ 1,057,624.03					
			OVERHEAD 10%	$ 528,812.02					
			PROFIT 8%	$ 549,964.50					
			TOTAL COST						$ 7,424,521

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 6.75M spat/ac)									
option 1 (25 acre site):									
concrete	CY	40333.3333	$ 30.00	$ 1,210,000.00		$ -		$ -	
Mob/Demob	HR	35		$ -	$ 172.98	$ 6,054.30	$ 367.43	$ 12,860.05	
barge delivery	HR	479		$ -	$ 172.98	$ 82,857.42	$ 336.62	$ 161,240.98	
concrete placement	CY	40333.3333		$ -	$ 0.92	$ 37,106.67	$ 1.67	$ 67,356.67	
			MATERIAL SUBTOTAL	$ 1,210,000.00	***LABOR SUBTOTAL***	$ 126,018.39	***EQUIP SUBTOTAL***	$ 241,457.70	
			SALES TAX (MATERIALS) 5%	$ 60,500.00	***Labor Insurance 32%***	$ 40,325.88			
			SUBTOTALS	$ 1,270,500.00		$ 166,344.27		$ 241,457.70	
			TOTAL COST	$ 1,678,301.97					
			CONTIGENCY 20%	$ 335,660.39					
			OVERHEAD 10%	$ 167,830.20					
			PROFIT 8%	$ 174,543.40					
			TOTAL COST						$ 2,356,336
spat	EA	168750000	$ 0.010	$ 1,687,500.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	168750000		$ -	$ 0.001	$ 158,118.75		$ -	
			MATERIAL SUBTOTAL	$ 1,687,500.00	***LABOR SUBTOTAL***	$ 161,232.39	***EQUIP SUBTOTAL***	$ 2,432.16	
			SALES TAX (MATERIALS) 5%	$ 84,375.00	***Labor Insurance 32%***	$ 51,594.36			
			SUBTOTALS	$ 1,771,875.00		$ 212,826.75		$ 2,432.16	
			TOTAL COST	$ 1,987,133.91					
			CONTIGENCY 20%	$ 397,426.78					
			OVERHEAD 10%	$ 198,713.39					
			PROFIT 8%	$ 206,661.93					
			TOTAL COST						$ 2,789,936

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
concrete	CY	80666.6667	$ 30.00	$ 2,420,000.00		$ -		$ -	
Mob/Demob	HR	35		$ -	$ 172.98	$ 6,054.30	$ 367.43	$ 12,860.05	
barge delivery	HR	958		$ -	$ 172.98	$ 165,714.84	$ 336.62	$ 322,481.96	
concrete placement	CY	80666.6667		$ -	$ 0.92	$ 74,213.33	$ 1.67	$ 134,713.33	
			MATERIAL SUBTOTAL	$ 2,420,000.00	***LABOR SUBTOTAL***	$ 245,982.47	***EQUIP SUBTOTAL***	$ 470,055.34	
			SALES TAX (MATERIALS) 5%	$ 121,000.00	***Labor Insurance 32%***	$ 78,714.39			
			SUBTOTALS	$ 2,541,000.00		$ 324,696.86		$ 470,055.34	
			TOTAL COST	$ 3,335,752.21					
			CONTIGENCY 20%	$ 667,150.44					
			OVERHEAD 10%	$ 333,575.22					
			PROFIT 8%	$ 346,918.23					
			TOTAL COST						$ 4,683,396
spat	EA	337500000	$ 0.010	$ 3,375,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	337500000		$ -	$ 0.001	$ 316,237.50		$ -	
			MATERIAL SUBTOTAL	$ 3,375,000.00	***LABOR SUBTOTAL***	$ 319,351.14	***EQUIP SUBTOTAL***	$ 2,432.16	
			SALES TAX (MATERIALS) 5%	$ 168,750.00	***Labor Insurance 32%***	$ 102,192.36			
			SUBTOTALS	$ 3,543,750.00		$ 421,543.50		$ 2,432.16	
			TOTAL COST	$ 3,967,725.66					
			CONTIGENCY 20%	$ 793,545.13					
			OVERHEAD 10%	$ 396,772.57					
			PROFIT 8%	$ 412,643.47					
			TOTAL COST						$ 5,570,687

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
concrete	CY	161333.333	$ 30.00	$ 4,840,000.00		$ -		$ -	
Mob/Demob	HR	35		$ -	$ 172.98	$ 6,054.30	$ 367.43	$ 12,860.05	
barge delivery	HR	1916		$ -	$ 172.98	$ 331,429.68	$ 336.62	$ 644,963.92	
concrete placement	CY	161333.333		$ -	$ 0.92	$ 148,426.67	$ 1.67	$ 269,426.67	
			MATERIAL SUBTOTAL	$ 4,840,000.00	***LABOR SUBTOTAL***	$ 485,910.65	***EQUIP SUBTOTAL***	$ 927,250.64	
			SALES TAX (MATERIALS) 5%	$ 242,000.00	***Labor Insurance 32%***	$ 155,491.41			
			SUBTOTALS	$ 5,082,000.00		$ 641,402.05		$ 927,250.64	
			TOTAL COST	$ 6,650,652.69					
			CONTIGENCY 20%	$ 1,330,130.54					
			OVERHEAD 10%	$ 665,065.27					
			PROFIT 8%	$ 691,667.88					
			TOTAL COST						$ 9,337,516
spat	EA	675000000	$ 0.010	$ 6,750,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	675000000		$ -	$ 0.001	$ 632,475.00		$ -	
			MATERIAL SUBTOTAL	$ 6,750,000.00	***LABOR SUBTOTAL***	$ 635,588.64	***EQUIP SUBTOTAL***	$ 2,432.16	
			SALES TAX (MATERIALS) 5%	$ 337,500.00	***Labor Insurance 32%***	$ 203,388.36			
			SUBTOTALS	$ 7,087,500.00		$ 838,977.00		$ 2,432.16	
			TOTAL COST	$ 7,928,909.16					
			CONTIGENCY 20%	$ 1,585,781.83					
			OVERHEAD 10%	$ 792,890.92					
			PROFIT 8%	$ 824,606.55					
			TOTAL COST						$ 11,132,188

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 3.6M spat/ac)									
option 1 (25 acre site):									
oyster shell dredging	CY	40333	$ 15.85	$ 639,283.33		$ -		$ -	
Mob/Demob	HR	12		$ -	$ 172.98	$ 2,075.76	$ 367.43	$ 4,409.16	
barge delivery	HR	116		$ -	$ 172.98	$ 20,065.68	$ 336.62	$ 39,047.92	
oyster placement	CY	40333		$ -	$ 6.27	$ 252,890.00		$ -	
			MATERIAL SUBTOTAL	$ 639,283.33	***LABOR SUBTOTAL***	$ 275,031.44	***EQUIP SUBTOTAL***	$ 43,457.08	
			SALES TAX (MATERIALS) 5%	$ 31,964.17	***Labor Insurance 32%***	$ 88,010.06			
			SUBTOTALS	$ 671,247.50		$ 363,041.50		$ 43,457.08	
			TOTAL COST	$ 1,077,746.08					
			CONTIGENCY 20%	$ 215,549.22					
			OVERHEAD 10%	$ 107,774.61					
			PROFIT 8%	$ 112,085.59					
			TOTAL COST						$ 1,513,155
spat	EA	90000000	$ 0.010	$ 900,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	90000000		$ -	$ 0.001	$ 84,330.00		$ -	
Turbidity control	LF	4200	$ 0.69	$ 2,898.00	$ 0.15	$ 630.00	$ 0.39	$ 1,638.00	
			MATERIAL SUBTOTAL	$ 902,898.00	***LABOR SUBTOTAL***	$ 88,073.64	***EQUIP SUBTOTAL***	$ 4,070.16	
			SALES TAX (MATERIALS) 5%	$ 45,144.90	***Labor Insurance 32%***	$ 28,183.56			
			SUBTOTALS	$ 948,042.90		$ 116,257.20		$ 4,070.16	
			TOTAL COST	$ 1,068,370.26					
			CONTIGENCY 20%	$ 213,674.05					
			OVERHEAD 10%	$ 106,837.03					
			PROFIT 8%	$ 111,110.51					
			TOTAL COST						$ 1,499,992

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
oyster shell dredging	CY	80667	$ 15.85	$ 1,278,566.67		$ -		$ -	
Mob/Demob	HR	12		$ -	$ 172.98	$ 2,075.76	$ 367.43	$ 4,409.16	
barge delivery	HR	232		$ -	$ 172.98	$ 40,131.36	$ 336.62	$ 78,095.84	
oyster placement	CY	80667		$ -	$ 6.27	$ 505,780.00		$ -	
			MATERIAL SUBTOTAL	$ 1,278,566.67	***LABOR SUBTOTAL***	$ 547,987.12	***EQUIP SUBTOTAL***	$ 82,505.00	
			SALES TAX (MATERIALS) 5%	$ 63,928.33	***Labor Insurance 32%***	$ 175,355.88			
			SUBTOTALS	$ 1,342,495.00		$ 723,343.00		$ 82,505.00	
			TOTAL COST	$ 2,148,343.00					
			CONTIGENCY 20%	$ 429,668.60					
			OVERHEAD 10%	$ 214,834.30					
			PROFIT 8%	$ 223,427.67					
			TOTAL COST						$ 3,016,274
spat	EA	180000000	$ 0.010	$ 1,800,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	180000000		$ -	$ 0.001	$ 168,660.00		$ -	
Turbidity control	LF	5900	$ 0.69	$ 4,071.00	$ 0.15	$ 885.00	$ 0.39	$ 2,301.00	
			MATERIAL SUBTOTAL	$ 1,804,071.00	***LABOR SUBTOTAL***	$ 172,658.64	***EQUIP SUBTOTAL***	$ 4,733.16	
			SALES TAX (MATERIALS) 5%	$ 90,203.55	***Labor Insurance 32%***	$ 55,250.76			
			SUBTOTALS	$ 1,894,274.55		$ 227,909.40		$ 4,733.16	
			TOTAL COST	$ 2,126,917.11					
			CONTIGENCY 20%	$ 425,383.42					
			OVERHEAD 10%	$ 212,691.71					
			PROFIT 8%	$ 221,199.38					
			TOTAL COST						$ 2,986,192

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
oyster shell dredging	CY	161333	$ 15.85	$ 2,557,133.33		$ -		$ -	
Mob/Demob	HR	12		$ -	$ 172.98	$ 2,075.76	$ 367.43	$ 4,409.16	
barge delivery	HR	464		$ -	$ 172.98	$ 80,262.72	$ 336.62	$ 156,191.68	
oyster placement	CY	161333		$ -	$ 6.27	$ 1,011,560.00		$ -	
			MATERIAL SUBTOTAL	$ 2,557,133.33	***LABOR SUBTOTAL***	$ 1,093,898.48	***EQUIP SUBTOTAL***	$ 160,600.84	
			SALES TAX (MATERIALS) 5%	$ 127,856.67	***Labor Insurance 32%***	$ 350,047.51			
			SUBTOTALS	$ 2,684,990.00		$ 1,443,945.99		$ 160,600.84	
			TOTAL COST	$ 4,289,536.83					
			CONTIGENCY 20%	$ 857,907.37					
			OVERHEAD 10%	$ 428,953.68					
			PROFIT 8%	$ 446,111.83					
			TOTAL COST						$ 6,022,510
spat	EA	360000000	$ 0.010	$ 3,600,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	360000000		$ -	$ 0.001	$ 337,320.00		$ -	
Turbidity control	LF	8350	$ 0.69	$ 5,761.50	$ 0.15	$ 1,252.50	$ 0.39	$ 3,256.50	
			MATERIAL SUBTOTAL	$ 3,605,761.50	***LABOR SUBTOTAL***	$ 341,686.14	***EQUIP SUBTOTAL***	$ 5,688.66	
			SALES TAX (MATERIALS) 5%	$ 180,288.08	***Labor Insurance 32%***	$ 109,339.56			
			SUBTOTALS	$ 3,786,049.58		$ 451,025.70		$ 5,688.66	
			TOTAL COST	$ 4,242,763.94					
			CONTIGENCY 20%	$ 848,552.79					
			OVERHEAD 10%	$ 424,276.39					
			PROFIT 8%	$ 441,247.45					
			TOTAL COST						$ 5,956,841

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 4.5M spat/ac)									
option 1 (25 acre site):									
oyster shell dredging	CY	40333	$ 15.85	$ 639,283.33		$ -		$ -	
Mob/Demob	HR	12		$ -	$ 172.98	$ 2,075.76	$ 367.43	$ 4,409.16	
barge delivery	HR	116		$ -	$ 172.98	$ 20,065.68	$ 336.62	$ 39,047.92	
oyster placement	CY	40333		$ -	$ 6.27	$ 252,890.00		$ -	
			MATERIAL SUBTOTAL	$ 639,283.33	***LABOR SUBTOTAL***	$ 275,031.44	***EQUIP SUBTOTAL***	$ 43,457.08	
			SALES TAX (MATERIALS) 5%	$ 31,964.17	***Labor Insurance 32%***	$ 88,010.06			
			SUBTOTALS	$ 671,247.50		$ 363,041.50		$ 43,457.08	
			TOTAL COST	$ 1,077,746.08					
			CONTIGENCY 20%	$ 215,549.22					
			OVERHEAD 10%	$ 107,774.61					
			PROFIT 8%	$ 112,085.59					
			TOTAL COST						$ 1,513,155
spat	EA	112500000	$ 0.010	$ 1,125,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	112500000		$ -	$ 0.001	$ 105,412.50		$ -	
Turbidity control	LF	4200	$ 0.69	$ 2,898.00	$ 0.15	$ 630.00	$ 0.39	$ 1,638.00	
			MATERIAL SUBTOTAL	$ 1,127,898.00	***LABOR SUBTOTAL***	$ 109,156.14	***EQUIP SUBTOTAL***	$ 4,070.16	
			SALES TAX (MATERIALS) 5%	$ 56,394.90	***Labor Insurance 32%***	$ 34,929.96			
			SUBTOTALS	$ 1,184,292.90		$ 144,086.10		$ 4,070.16	
			TOTAL COST	$ 1,332,449.16					
			CONTIGENCY 20%	$ 266,489.83					
			OVERHEAD 10%	$ 133,244.92					
			PROFIT 8%	$ 138,574.71					
			TOTAL COST						$ 1,870,759

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
oyster shell dredging	CY	80667	$ 15.85	$ 1,278,566.67		$ -		$ -	
Mob/Demob	HR	12		$ -	$ 172.98	$ 2,075.76	$ 367.43	$ 4,409.16	
barge delivery	HR	232		$ -	$ 172.98	$ 40,131.36	$ 336.62	$ 78,095.84	
oyster placement	CY	80667		$ -	$ 6.27	$ 505,780.00		$ -	
			MATERIAL SUBTOTAL	$ 1,278,566.67	***LABOR SUBTOTAL***	$ 547,987.12	***EQUIP SUBTOTAL***	$ 82,505.00	
			SALES TAX (MATERIALS) 5%	$ 63,928.33	***Labor Insurance 32%***	$ 175,355.88			
			SUBTOTALS	$ 1,342,495.00		$ 723,343.00		$ 82,505.00	
			TOTAL COST	$ 2,148,343.00					
			CONTIGENCY 20%	$ 429,668.60					
			OVERHEAD 10%	$ 214,834.30					
			PROFIT 8%	$ 223,427.67					
			TOTAL COST						$ 3,016,274
spat	EA	225000000	$ 0.010	$ 2,250,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	225000000		$ -	$ 0.001	$ 210,825.00		$ -	
Turbidity control	LF	5900	$ 0.69	$ 4,071.00	$ 0.15	$ 885.00	$ 0.39	$ 2,301.00	
			SUBTOTAL	$ 2,254,071.00	***SUBTOTAL***	$ 214,823.64	***SUBTOTAL***	$ 4,733.16	
			(MATERIALS) 5%	$ 112,703.55	***Insurance 32%***	$ 68,743.56			
			SUBTOTALS	$ 2,366,774.55		$ 283,567.20		$ 4,733.16	
			TOTAL COST	$ 2,655,074.91					
			CONTIGENCY 20%	$ 531,014.98					
			OVERHEAD 10%	$ 265,507.49					
			PROFIT 8%	$ 276,127.79					
			TOTAL COST						$ 3,727,725

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
oyster shell dredging	CY	161333	$ 15.85	$ 2,557,133.33		$ -		$ -	
Mob/Demob	HR	12		$ -	$ 172.98	$ 2,075.76	$ 367.43	$ 4,409.16	
barge delivery	HR	464		$ -	$ 172.98	$ 80,262.72	$ 336.62	$ 156,191.68	
oyster placement	CY	161333		$ -	$ 6.27	$ 1,011,560.00		$ -	
			MATERIAL SUBTOTAL	$ 2,557,133.33	***LABOR SUBTOTAL***	$ 1,093,898.48	***EQUIP SUBTOTAL***	$ 160,600.84	
			SALES TAX (MATERIALS) 5%	$ 127,856.67	***Labor Insurance 32%***	$ 350,047.51			
			SUBTOTALS	$ 2,684,990.00		$ 1,443,945.99		$ 160,600.84	
			TOTAL COST	$ 4,289,536.83					
			CONTIGENCY 20%	$ 857,907.37					
			OVERHEAD 10%	$ 428,953.68					
			PROFIT 8%	$ 446,111.83					
			TOTAL COST						$ 6,022,510
spat	EA	450000000	$ 0.010	$ 4,500,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	450000000		$ -	$ 0.001	$ 421,650.00		$ -	
Turbidity control	LF	8350	$ 0.69	$ 5,761.50	$ 0.15	$ 1,252.50	$ 0.39	$ 3,256.50	
			MATERIAL SUBTOTAL	$ 4,505,761.50	***LABOR SUBTOTAL***	$ 426,016.14	***EQUIP SUBTOTAL***	$ 5,688.66	
			SALES TAX (MATERIALS) 5%	$ 225,288.08	***Labor Insurance 32%***	$ 136,325.16			
			SUBTOTALS	$ 4,731,049.58		$ 562,341.30		$ 5,688.66	
			TOTAL COST	$ 5,299,079.54					
			CONTIGENCY 20%	$ 1,059,815.91					
			OVERHEAD 10%	$ 529,907.95					
			PROFIT 8%	$ 551,104.27					
			TOTAL COST						$ 7,439,908

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 6.75M spat/ac)									
option 1 (25 acre site):									
oyster shell dredging	CY	40333	$ 15.85	$ 639,283.33		$ -		$ -	
Mob/Demob	HR	12		$ -	$ 172.98	$ 2,075.76	$ 367.43	$ 4,409.16	
barge delivery	HR	116		$ -	$ 172.98	$ 20,065.68	$ 336.62	$ 39,047.92	
oyster placement	CY	40333		$ -	$ 6.27	$ 252,890.00		$ -	
			MATERIAL SUBTOTAL	$ 639,283.33	***LABOR SUBTOTAL***	$ 275,031.44	***EQUIP SUBTOTAL***	$ 43,457.08	
			SALES TAX (MATERIALS) 5%	$ 31,964.17	***Labor Insurance 32%***	$ 88,010.06			
			SUBTOTALS	$ 671,247.50		$ 363,041.50		$ 43,457.08	
			TOTAL COST	$ 1,077,746.08					
			CONTIGENCY 20%	$ 215,549.22					
			OVERHEAD 10%	$ 107,774.61					
			PROFIT 8%	$ 112,085.59					
			TOTAL COST						$ 1,513,155
spat	EA	168750000	$ 0.010	$ 1,687,500.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	168750000		$ -	$ 0.001	$ 158,118.75		$ -	
Turbidity control	LF	4200	$ 0.69	$ 2,898.00	$ 0.15	$ 630.00	$ 0.39	$ 1,638.00	
			MATERIAL SUBTOTAL	$ 1,690,398.00	***LABOR SUBTOTAL***	$ 161,862.39	***EQUIP SUBTOTAL***	$ 4,070.16	
			SALES TAX (MATERIALS) 5%	$ 84,519.90	***Labor Insurance 32%***	$ 51,795.96			
			SUBTOTALS	$ 1,774,917.90		$ 213,658.35		$ 4,070.16	
			TOTAL COST	$ 1,992,646.41					
			CONTIGENCY 20%	$ 398,529.28					
			OVERHEAD 10%	$ 199,264.64					
			PROFIT 8%	$ 207,235.23					
			TOTAL COST						$ 2,797,676

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
oyster shell dredging	CY	80667	$ 15.85	$ 1,278,566.67		$ -		$ -	
Mob/Demob	HR	12		$ -	$ 172.98	$ 2,075.76	$ 367.43	$ 4,409.16	
barge delivery	HR	232		$ -	$ 172.98	$ 40,131.36	$ 336.62	$ 78,095.84	
oyster placement	CY	80667		$ -	$ 6.27	$ 505,780.00		$ -	
			MATERIAL SUBTOTAL	$ 1,278,566.67	***LABOR SUBTOTAL***	$ 547,987.12	***EQUIP SUBTOTAL***	$ 82,505.00	
			SALES TAX (MATERIALS) 5%	$ 63,928.33	***Labor Insurance 32%***	$ 175,355.88			
			SUBTOTALS	$ 1,342,495.00		$ 723,343.00		$ 82,505.00	
			TOTAL COST	$ 2,148,343.00					
			CONTIGENCY 20%	$ 429,668.60					
			OVERHEAD 10%	$ 214,834.30					
			PROFIT 8%	$ 223,427.67					
			TOTAL COST						$ 3,016,274
spat	EA	337500000	$ 0.010	$ 3,375,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	337500000		$ -	$ 0.001	$ 316,237.50		$ -	
Turbidity control	LF	5900	$ 0.69	$ 4,071.00	$ 0.15	$ 885.00	$ 0.39	$ 2,301.00	
			MATERIAL SUBTOTAL	$ 3,379,071.00	***LABOR SUBTOTAL***	$ 320,236.14	***EQUIP SUBTOTAL***	$ 4,733.16	
			SALES TAX (MATERIALS) 5%	$ 168,953.55	***Labor Insurance 32%***	$ 102,475.56			
			SUBTOTALS	$ 3,548,024.55		$ 422,711.70		$ 4,733.16	
			TOTAL COST	$ 3,975,469.41					
			CONTIGENCY 20%	$ 795,093.88					
			OVERHEAD 10%	$ 397,546.94					
			PROFIT 8%	$ 413,448.82					
			TOTAL COST						$ 5,581,559

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
oyster shell dredging	CY	161333	$ 15.85	$ 2,557,133.33		$ -		$ -	
Mob/Demob	HR	12		$ -	$ 172.98	$ 2,075.76	$ 367.43	$ 4,409.16	
barge delivery	HR	464		$ -	$ 172.98	$ 80,262.72	$ 336.62	$ 156,191.68	
oyster placement	CY	161333		$ -	$ 6.27	$ 1,011,560.00		$ -	
			MATERIAL SUBTOTAL	$ 2,557,133.33	***LABOR SUBTOTAL***	$ 1,093,898.48	***EQUIP SUBTOTAL***	$ 160,600.84	
			SALES TAX (MATERIALS) 5%	$ 127,856.67	***Labor Insurance 32%***	$ 350,047.51			
			SUBTOTALS	$ 2,684,990.00		$ 1,443,945.99		$ 160,600.84	
			TOTAL COST	$ 4,289,536.83					
			CONTIGENCY 20%	$ 857,907.37					
			OVERHEAD 10%	$ 428,953.68					
			PROFIT 8%	$ 446,111.83					
			TOTAL COST						$ 6,022,510
spat	EA	675000000	$ 0.010	$ 6,750,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	675000000		$ -	$ 0.001	$ 632,475.00		$ -	
Turbidity control	LF	8350	$ 0.69	$ 5,761.50	$ 0.15	$ 1,252.50	$ 0.39	$ 3,256.50	
			MATERIAL SUBTOTAL	$ 6,755,761.50	***LABOR SUBTOTAL***	$ 636,841.14	***EQUIP SUBTOTAL***	$ 5,688.66	
			SALES TAX (MATERIALS) 5%	$ 337,788.08	***Labor Insurance 32%***	$ 203,789.16			
			SUBTOTALS	$ 7,093,549.58		$ 840,630.30		$ 5,688.66	
			TOTAL COST	$ 7,939,868.54					
			CONTIGENCY 20%	$ 1,587,973.71					
			OVERHEAD 10%	$ 793,986.85					
			PROFIT 8%	$ 825,746.33					
			TOTAL COST						$ 11,147,575

Little Wicomico River

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 3.6M spat/ac)									
option 1 (25 acre site):									
limestone	CY	40333	$ 47.50	$ 1,915,833.33		$ -		$ -	
Mob/Demob	HR	39		$ -	$ 172.98	$ 6,746.22	$ 367.43	$ 14,329.77	
barge delivery	HR	1019		$ -	$ 172.98	$ 176,266.62	$ 336.62	$ 343,015.78	
limestone placement	CY	40333		$ -	$ 1.16	$ 46,786.67	$ 2.09	$ 84,296.67	
			MATERIAL SUBTOTAL	$ 1,915,833.33	***LABOR SUBTOTAL***	$ 229,799.51	***EQUIP SUBTOTAL***	$ 441,642.22	
			SALES TAX (MATERIALS) 5%	$ 95,791.67	***Labor Insurance 32%***	$ 73,535.84			
			SUBTOTALS	$ 2,011,625.00		$ 303,335.35		$ 441,642.22	
			TOTAL COST	$ 2,756,602.57					
			CONTIGENCY 20%	$ 551,320.51					
			OVERHEAD 10%	$ 275,660.26					
			PROFIT 8%	$ 286,686.67					
			TOTAL COST						$ 3,870,270
spat	EA	90000000	$ 0.010	$ 900,000.00		$ -		$ -	
Mob/Demob	HR	11			$ 172.98	$ 1,902.78	$ 118.83	$ 1,307.13	
barge delivery	HR	13		$ -	$ 172.98	$ 2,248.74	$ 151.41	$ 1,968.33	
spat planting	EA	90000000		$ -	$ 0.001	$ 84,330.00		$ -	
			MATERIAL SUBTOTAL	$ 900,000.00	***LABOR SUBTOTAL***	$ 88,481.52	***EQUIP SUBTOTAL***	$ 3,275.46	
			SALES TAX (MATERIALS) 5%	$ 45,000.00	***Labor Insurance 32%***	$ 28,314.09			
			SUBTOTALS	$ 945,000.00		$ 116,795.61		$ 3,275.46	
			TOTAL COST	$ 1,065,071.07					
			CONTIGENCY 20%	$ 213,014.21					
			OVERHEAD 10%	$ 106,507.11					
			PROFIT 8%	$ 110,767.39					
			TOTAL COST						$ 1,495,360

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
limestone	CY	80667	$ 47.50	$ 3,831,666.67		$ -		$ -	
Mob/Demob	HR	39		$ -	$ 172.98	$ 6,746.22	$ 367.43	$ 14,329.77	
barge delivery	HR	2038		$ -	$ 172.98	$ 352,533.24	$ 336.62	$ 686,031.56	
limestone placement	CY	80667		$ -	$ 1.16	$ 93,573.33	$ 2.09	$ 168,593.33	
			MATERIAL SUBTOTAL	$ 3,831,666.67	***LABOR SUBTOTAL***	$ 452,852.79	***EQUIP SUBTOTAL***	$ 868,954.66	
			SALES TAX (MATERIALS) 5%	$ 191,583.33	***Labor Insurance 32%***	$ 144,912.89			
			SUBTOTALS	$ 4,023,250.00		$ 597,765.69		$ 868,954.66	
			TOTAL COST	$ 5,489,970.35					
			CONTIGENCY 20%	$ 1,097,994.07					
			OVERHEAD 10%	$ 548,997.04					
			PROFIT 8%	$ 570,956.92					
			TOTAL COST						$ 7,707,918
spat	EA	180000000	$ 0.010	$ 1,800,000.00		$ -		$ -	
Mob/Demob	HR	11			$ 172.98	$ 1,902.78	$ 118.83	$ 1,307.13	
barge delivery	HR	13		$ -	$ 172.98	$ 2,248.74	$ 151.41	$ 1,968.33	
spat planting	EA	180000000		$ -	$ 0.001	$ 168,660.00		$ -	
			MATERIAL SUBTOTAL	$ 1,800,000.00	***SUBTOTAL***	$ 172,811.52	***SUBTOTAL***	$ 3,275.46	
			(MATERIALS) 5%	$ 90,000.00	***32%***	$ 55,299.69			
			SUBTOTALS	$ 1,890,000.00		$ 228,111.21		$ 3,275.46	
			TOTAL COST	$ 2,121,386.67					
			CONTIGENCY 20%	$ 424,277.33					
			OVERHEAD 10%	$ 212,138.67					
			PROFIT 8%	$ 220,624.21					
			TOTAL COST						$ 2,978,427

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
limestone	CY	161333	$ 47.50	$ 7,663,333.33		$ -		$ -	
Mob/Demob	HR	39		$ -	$ 172.98	$ 6,746.22	$ 367.43	$ 14,329.77	
barge delivery	HR	4077		$ -	$ 172.98	$ 705,239.46	$ 336.62	$ 1,372,399.74	
limestone placement	CY	161333		$ -	$ 1.16	$ 187,146.67	$ 2.09	$ 337,186.67	
			MATERIAL SUBTOTAL	$ 7,663,333.33	***LABOR SUBTOTAL***	$ 899,132.35	***EQUIP SUBTOTAL***	$ 1,723,916.18	
			SALES TAX (MATERIALS) 5%	$ 383,166.67	***Labor Insurance 32%***	$ 287,722.35			
			SUBTOTALS	$ 8,046,500.00		$ 1,186,854.70		$ 1,723,916.18	
			TOTAL COST	$ 10,957,270.87					
			CONTIGENCY 20%	$ 2,191,454.17					
			OVERHEAD 10%	$ 1,095,727.09					
			PROFIT 8%	$ 1,139,556.17					
			TOTAL COST						$ 15,384,008
spat	EA	360000000	$ 0.010	$ 3,600,000.00		$ -		$ -	
Mob/Demob	HR	11			$ 172.98	$ 1,902.78	$ 118.83	$ 1,307.13	
barge delivery	HR	13		$ -	$ 172.98	$ 2,248.74	$ 151.41	$ 1,968.33	
spat planting	EA	360000000		$ -	$ 0.001	$ 337,320.00		$ -	
			MATERIAL SUBTOTAL	$ 3,600,000.00	***LABOR SUBTOTAL***	$ 341,471.52	***EQUIP SUBTOTAL***	$ 3,275.46	
			SALES TAX (MATERIALS) 5%	$ 180,000.00	***Labor Insurance 32%***	$ 109,270.89			
			SUBTOTALS	$ 3,780,000.00		$ 450,742.41		$ 3,275.46	
			TOTAL COST	$ 4,234,017.87					
			CONTIGENCY 20%	$ 846,803.57					
			OVERHEAD 10%	$ 423,401.79					
			PROFIT 8%	$ 440,337.86					
			TOTAL COST						$ 5,944,561

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 4.5M spat/ac)									
option 1 (25 acre site):									
limestone	CY	40333	$ 47.50	$ 1,915,833.33		$ -		$ -	
Mob/Demob	HR	39		$ -	$ 172.98	$ 6,746.22	$ 367.43	$ 14,329.77	
barge delivery	HR	1019		$ -	$ 172.98	$ 176,266.62	$ 336.62	$ 343,015.78	
limestone placement	CY	40333		$ -	$ 1.16	$ 46,786.67	$ 2.09	$ 84,296.67	
			MATERIAL SUBTOTAL	$ 1,915,833.33	***LABOR SUBTOTAL***	$ 229,799.51	***EQUIP SUBTOTAL***	$ 441,642.22	
			SALES TAX (MATERIALS) 5%	$ 95,791.67	***Labor Insurance 32%***	$ 73,535.84			
			SUBTOTALS	$ 2,011,625.00		$ 303,335.35		$ 441,642.22	
			TOTAL COST	$ 2,756,602.57					
			CONTIGENCY 20%	$ 551,320.51					
			OVERHEAD 10%	$ 275,660.26					
			PROFIT 8%	$ 286,686.67					
			TOTAL COST						$ 3,870,270
spat	EA	112500000	$ 0.010	$ 1,125,000.00		$ -		$ -	
Mob/Demob	HR	11			$ 172.98	$ 1,902.78	$ 118.83	$ 1,307.13	
barge delivery	HR	13		$ -	$ 172.98	$ 2,248.74	$ 151.41	$ 1,968.33	
spat planting	EA	112500000		$ -	$ 0.001	$ 105,412.50		$ -	
			MATERIAL SUBTOTAL	$ 1,125,000.00	***LABOR SUBTOTAL***	$ 109,564.02	***EQUIP SUBTOTAL***	$ 3,275.46	
			SALES TAX (MATERIALS) 5%	$ 56,250.00	***Labor Insurance 32%***	$ 35,060.49			
			SUBTOTALS	$ 1,181,250.00		$ 144,624.51		$ 3,275.46	
			TOTAL COST	$ 1,329,149.97					
			CONTIGENCY 20%	$ 265,829.99					
			OVERHEAD 10%	$ 132,915.00					
			PROFIT 8%	$ 138,231.60					
			TOTAL COST						$ 1,866,127

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
limestone	CY	80667	$ 47.50	$ 3,831,666.67		$ -		$ -	
Mob/Demob	HR	39		$ -	$ 172.98	$ 6,746.22	$ 367.43	$ 14,329.77	
barge delivery	HR	2038		$ -	$ 172.98	$ 352,533.24	$ 336.62	$ 686,031.56	
limestone placement	CY	80667		$ -	$ 1.16	$ 93,573.33	$ 2.09	$ 168,593.33	
			MATERIAL SUBTOTAL	$ 3,831,666.67	***LABOR SUBTOTAL***	$ 452,852.79	***EQUIP SUBTOTAL***	$ 868,954.66	
			SALES TAX (MATERIALS) 5%	$ 191,583.33	***Labor Insurance 32%***	$ 144,912.89			
			SUBTOTALS	$ 4,023,250.00		$ 597,765.69		$ 868,954.66	
			TOTAL COST	$ 5,489,970.35					
			CONTIGENCY 20%	$ 1,097,994.07					
			OVERHEAD 10%	$ 548,997.04					
			PROFIT 8%	$ 570,956.92					
			TOTAL COST						$ 7,707,918
spat	EA	225000000	$ 0.010	$ 2,250,000.00		$ -		$ -	
Mob/Demob	HR	11			$ 172.98	$ 1,902.78	$ 118.83	$ 1,307.13	
barge delivery	HR	13		$ -	$ 172.98	$ 2,248.74	$ 151.41	$ 1,968.33	
spat planting	EA	225000000		$ -	$ 0.001	$ 210,825.00		$ -	
			MATERIAL SUBTOTAL	$ 2,250,000.00	***LABOR SUBTOTAL***	$ 214,976.52	***EQUIP SUBTOTAL***	$ 3,275.46	
			SALES TAX (MATERIALS) 5%	$ 112,500.00	***Labor Insurance 32%***	$ 68,792.49			
			SUBTOTALS	$ 2,362,500.00		$ 283,769.01		$ 3,275.46	
			TOTAL COST	$ 2,649,544.47					
			CONTIGENCY 20%	$ 529,908.89					
			OVERHEAD 10%	$ 264,954.45					
			PROFIT 8%	$ 275,552.62					
			TOTAL COST						$ 3,719,960

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
limestone	CY	161333	$ 47.50	$ 7,663,333.33		$ -		$ -	
Mob/Demob	HR	39		$ -	$ 172.98	$ 6,746.22	$ 367.43	$ 14,329.77	
barge delivery	HR	4077		$ -	$ 172.98	$ 705,239.46	$ 336.62	$ 1,372,399.74	
limestone placement	CY	161333		$ -	$ 1.16	$ 187,146.67	$ 2.09	$ 337,186.67	
			MATERIAL SUBTOTAL	$ 7,663,333.33	***LABOR SUBTOTAL***	$ 899,132.35	***EQUIP SUBTOTAL***	$ 1,723,916.18	
			SALES TAX (MATERIALS) 5%	$ 383,166.67	***Labor Insurance 32%***	$ 287,722.35			
			SUBTOTALS	$ 8,046,500.00		$ 1,186,854.70		$ 1,723,916.18	
			TOTAL COST	$ 10,957,270.87					
			CONTIGENCY 20%	$ 2,191,454.17					
			OVERHEAD 10%	$ 1,095,727.09					
			PROFIT 8%	$ 1,139,556.17					
			TOTAL COST						$ 15,384,008
spat	EA	450000000	$ 0.010	$ 4,500,000.00		$ -		$ -	
Mob/Demob	HR	11			$ 172.98	$ 1,902.78	$ 118.83	$ 1,307.13	
barge delivery	HR	13		$ -	$ 172.98	$ 2,248.74	$ 151.41	$ 1,968.33	
spat planting	EA	450000000		$ -	$ 0.001	$ 421,650.00		$ -	
			MATERIAL SUBTOTAL	$ 4,500,000.00	***LABOR SUBTOTAL***	$ 425,801.52	***EQUIP SUBTOTAL***	$ 3,275.46	
			SALES TAX (MATERIALS) 5%	$ 225,000.00	***Labor Insurance 32%***	$ 136,256.49			
			SUBTOTALS	$ 4,725,000.00		$ 562,058.01		$ 3,275.46	
			TOTAL COST	$ 5,290,333.47					
			CONTIGENCY 20%	$ 1,058,066.69					
			OVERHEAD 10%	$ 529,033.35					
			PROFIT 8%	$ 550,194.68					
			TOTAL COST						$ 7,427,628

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 6.75M spat/ac)									
option 1 (25 acre site):									
limestone	CY	40333	$ 47.50	$ 1,915,833.33		$ -		$ -	
Mob/Demob	HR	39		$ -	$ 172.98	$ 6,746.22	$ 367.43	$ 14,329.77	
barge delivery	HR	1019		$ -	$ 172.98	$ 176,266.62	$ 336.62	$ 343,015.78	
limestone placement	CY	40333		$ -	$ 1.16	$ 46,786.67	$ 2.09	$ 84,296.67	
			MATERIAL SUBTOTAL	$ 1,915,833.33	***LABOR SUBTOTAL***	$ 229,799.51	***EQUIP SUBTOTAL***	$ 441,642.22	
			SALES TAX (MATERIALS) 5%	$ 95,791.67	***Labor Insurance 32%***	$ 73,535.84			
			SUBTOTALS	$ 2,011,625.00		$ 303,335.35		$ 441,642.22	
			TOTAL COST	$ 2,756,602.57					
			CONTIGENCY 20%	$ 551,320.51					
			OVERHEAD 10%	$ 275,660.26					
			PROFIT 8%	$ 286,686.67					
			TOTAL COST						$ 3,870,270
spat	EA	168750000	$ 0.010	$ 1,687,500.00		$ -		$ -	
Mob/Demob	HR	11			$ 172.98	$ 1,902.78	$ 118.83	$ 1,307.13	
barge delivery	HR	13		$ -	$ 172.98	$ 2,248.74	$ 151.41	$ 1,968.33	
spat planting	EA	168750000		$ -	$ 0.001	$ 158,118.75		$ -	
			MATERIAL SUBTOTAL	$ 1,687,500.00	***LABOR SUBTOTAL***	$ 162,270.27	***EQUIP SUBTOTAL***	$ 3,275.46	
			SALES TAX (MATERIALS) 5%	$ 84,375.00	***Labor Insurance 32%***	$ 51,926.49			
			SUBTOTALS	$ 1,771,875.00		$ 214,196.76		$ 3,275.46	
			TOTAL COST	$ 1,989,347.22					
			CONTIGENCY 20%	$ 397,869.44					
			OVERHEAD 10%	$ 198,934.72					
			PROFIT 8%	$ 206,892.11					
			TOTAL COST						$ 2,793,043

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
limestone	CY	80667	$ 47.50	$ 3,831,666.67		$ -		$ -	
Mob/Demob	HR	39		$ -	$ 172.98	$ 6,746.22	$ 367.43	$ 14,329.77	
barge delivery	HR	2038		$ -	$ 172.98	$ 352,533.24	$ 336.62	$ 686,031.56	
limestone placement	CY	80667		$ -	$ 1.16	$ 93,573.33	$ 2.09	$ 168,593.33	
			MATERIAL SUBTOTAL	$ 3,831,666.67	***LABOR SUBTOTAL***	$ 452,852.79	***EQUIP SUBTOTAL***	$ 868,954.66	
			SALES TAX (MATERIALS) 5%	$ 191,583.33	***Labor Insurance 32%***	$ 144,912.89			
			SUBTOTALS	$ 4,023,250.00		$ 597,765.69		$ 868,954.66	
			TOTAL COST	$ 5,489,970.35					
			CONTIGENCY 20%	$ 1,097,994.07					
			OVERHEAD 10%	$ 548,997.04					
			PROFIT 8%	$ 570,956.92					
			TOTAL COST						$ 7,707,918
spat	EA	337500000	$ 0.010	$ 3,375,000.00		$ -		$ -	
Mob/Demob	HR	11			$ 172.98	$ 1,902.78	$ 118.83	$ 1,307.13	
barge delivery	HR	13		$ -	$ 172.98	$ 2,248.74	$ 151.41	$ 1,968.33	
spat planting	EA	337500000		$ -	$ 0.001	$ 316,237.50		$ -	
			MATERIAL SUBTOTAL	$ 3,375,000.00	***LABOR SUBTOTAL***	$ 320,389.02	***EQUIP SUBTOTAL***	$ 3,275.46	
			SALES TAX (MATERIALS) 5%	$ 168,750.00	***Labor Insurance 32%***	$ 102,524.49			
			SUBTOTALS	$ 3,543,750.00		$ 422,913.51		$ 3,275.46	
			TOTAL COST	$ 3,969,938.97					
			CONTIGENCY 20%	$ 793,987.79					
			OVERHEAD 10%	$ 396,993.90					
			PROFIT 8%	$ 412,873.65					
			TOTAL COST						$ 5,573,794

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
limestone	CY	161333	$ 47.50	$ 7,663,333.33		$ -		$ -	
Mob/Demob	HR	39		$ -	$ 172.98	$ 6,746.22	$ 367.43	$ 14,329.77	
barge delivery	HR	4077		$ -	$ 172.98	$ 705,239.46	$ 336.62	$ 1,372,399.74	
limestone placement	CY	161333		$ -	$ 1.16	$ 187,146.67	$ 2.09	$ 337,186.67	
			MATERIAL SUBTOTAL	$ 7,663,333.33	***LABOR SUBTOTAL***	$ 899,132.35	***EQUIP SUBTOTAL***	$ 1,723,916.18	
			SALES TAX (MATERIALS) 5%	$ 383,166.67	***Labor Insurance 32%***	$ 287,722.35			
			SUBTOTALS	$ 8,046,500.00		$ 1,186,854.70		$ 1,723,916.18	
			TOTAL COST	$ 10,957,270.87					
			CONTIGENCY 20%	$ 2,191,454.17					
			OVERHEAD 10%	$ 1,095,727.09					
			PROFIT 8%	$ 1,139,556.17					
			TOTAL COST						$ 15,384,008
spat	EA	675000000	$ 0.010	$ 6,750,000.00		$ -		$ -	
Mob/Demob	HR	11			$ 172.98	$ 1,902.78	$ 118.83	$ 1,307.13	
barge delivery	HR	13		$ -	$ 172.98	$ 2,248.74	$ 151.41	$ 1,968.33	
spat planting	EA	675000000		$ -	$ 0.001	$ 632,475.00		$ -	
			MATERIAL SUBTOTAL	$ 6,750,000.00	***LABOR SUBTOTAL***	$ 636,626.52	***EQUIP SUBTOTAL***	$ 3,275.46	
			SALES TAX (MATERIALS) 5%	$ 337,500.00	***Labor Insurance 32%***	$ 203,720.49			
			SUBTOTALS	$ 7,087,500.00		$ 840,347.01		$ 3,275.46	
			TOTAL COST	$ 7,931,122.47					
			CONTIGENCY 20%	$ 1,586,224.49					
			OVERHEAD 10%	$ 793,112.25					
			PROFIT 8%	$ 824,836.74					
			TOTAL COST						$ 11,135,296

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 3.6M spat/ac)									
option 1 (25 acre site):									
granite	CY	40333.3333	$ 48.00	$ 1,936,000.00		$ -		$ -	
Mob/Demob	HR	39		$ -	$ 172.98	$ 6,746.22	$ 367.43	$ 14,329.77	
barge delivery	HR	689		$ -	$ 172.98	$ 119,183.22	$ 336.62	$ 231,931.18	
granite placement	CY	40333.3333		$ -	$ 1.16	$ 46,786.67	$ 2.09	$ 84,296.67	
			MATERIAL SUBTOTAL	$ 1,936,000.00	***LABOR SUBTOTAL***	$ 172,716.11	***EQUIP SUBTOTAL***	$ 330,557.62	
			SALES TAX (MATERIALS) 5%	$ 96,800.00	***Labor Insurance 32%***	$ 55,269.15			
			SUBTOTALS	$ 2,032,800.00		$ 227,985.26		$ 330,557.62	
			TOTAL COST	$ 2,591,342.88					
			CONTIGENCY 20%	$ 518,268.58					
			OVERHEAD 10%	$ 259,134.29					
			PROFIT 8%	$ 269,499.66					
			TOTAL COST						$ 3,638,245
spat	EA	90000000	$ 0.010	$ 900,000.00		$ -		$ -	
Mob/Demob	HR	11			$ 172.98	$ 1,902.78	$ 118.83	$ 1,307.13	
barge delivery	HR	13		$ -	$ 172.98	$ 2,248.74	$ 151.41	$ 1,968.33	
spat planting	EA	90000000		$ -	$ 0.001	$ 84,330.00		$ -	
			MATERIAL SUBTOTAL	$ 900,000.00	***LABOR SUBTOTAL***	$ 88,481.52	***EQUIP SUBTOTAL***	$ 3,275.46	
			SALES TAX (MATERIALS) 5%	$ 45,000.00	***Labor Insurance 32%***	$ 28,314.09			
			SUBTOTALS	$ 945,000.00		$ 116,795.61		$ 3,275.46	
			TOTAL COST	$ 1,065,071.07					
			CONTIGENCY 20%	$ 213,014.21					
			OVERHEAD 10%	$ 106,507.11					
			PROFIT 8%	$ 110,767.39					
			TOTAL COST						$ 1,495,360

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
granite	CY	80666.6667	$ 48.00	$ 3,872,000.00		$ -		$ -	
Mob/Demob	HR	39		$ -	$ 172.98	$ 6,746.22	$ 367.43	$ 14,329.77	
barge delivery	HR	1377		$ -	$ 172.98	$ 238,193.46	$ 336.62	$ 463,525.74	
granite placement	CY	80666.6667		$ -	$ 1.16	$ 93,573.33	$ 2.09	$ 168,593.33	
			MATERIAL SUBTOTAL	$ 3,872,000.00	***LABOR SUBTOTAL***	$ 338,513.01	***EQUIP SUBTOTAL***	$ 646,448.84	
			SALES TAX (MATERIALS) 5%	$ 193,600.00	***Labor Insurance 32%***	$ 108,324.16			
			SUBTOTALS	$ 4,065,600.00		$ 446,837.18		$ 646,448.84	
			TOTAL COST	$ 5,158,886.02					
			CONTIGENCY 20%	$ 1,031,777.20					
			OVERHEAD 10%	$ 515,888.60					
			PROFIT 8%	$ 536,524.15					
			TOTAL COST						$ 7,243,076
spat	EA	180000000	$ 0.010	$ 1,800,000.00		$ -		$ -	
Mob/Demob	HR	11			$ 172.98	$ 1,902.78	$ 118.83	$ 1,307.13	
barge delivery	HR	13		$ -	$ 172.98	$ 2,248.74	$ 151.41	$ 1,968.33	
spat planting	EA	180000000		$ -	$ 0.001	$ 168,660.00		$ -	
			SUBTOTAL	$ 1,800,000.00	***SUBTOTAL***	$ 172,811.52	***SUBTOTAL***	$ 3,275.46	
			(MATERIALS) 5%	$ 90,000.00	***32%***	$ 55,299.69			
			SUBTOTALS	$ 1,890,000.00		$ 228,111.21		$ 3,275.46	
			TOTAL COST	$ 2,121,386.67					
			CONTIGENCY 20%	$ 424,277.33					
			OVERHEAD 10%	$ 212,138.67					
			PROFIT 8%	$ 220,624.21					
			TOTAL COST						$ 2,978,427

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
granite	CY	161333.333	$ 48.00	$ 7,744,000.00		$ -		$ -	
Mob/Demob	HR	39		$ -	$ 172.98	$ 6,746.22	$ 367.43	$ 14,329.77	
barge delivery	HR	2754		$ -	$ 172.98	$ 476,386.92	$ 336.62	$ 927,051.48	
granite placement	CY	161333.333		$ -	$ 1.16	$ 187,146.67	$ 2.09	$ 337,186.67	
			MATERIAL SUBTOTAL	$ 7,744,000.00	***LABOR SUBTOTAL***	$ 670,279.81	***EQUIP SUBTOTAL***	$ 1,278,567.92	
			SALES TAX (MATERIALS) 5%	$ 387,200.00	***Labor Insurance 32%***	$ 214,489.54			
			SUBTOTALS	$ 8,131,200.00		$ 884,769.34		$ 1,278,567.92	
			TOTAL COST	$ 10,294,537.26					
			CONTIGENCY 20%	$ 2,058,907.45					
			OVERHEAD 10%	$ 1,029,453.73					
			PROFIT 8%	$ 1,070,631.88					
			TOTAL COST						$ 14,453,530
spat	EA	360000000	$ 0.010	$ 3,600,000.00		$ -		$ -	
Mob/Demob	HR	11			$ 172.98	$ 1,902.78	$ 118.83	$ 1,307.13	
barge delivery	HR	13		$ -	$ 172.98	$ 2,248.74	$ 151.41	$ 1,968.33	
spat planting	EA	360000000		$ -	$ 0.001	$ 337,320.00		$ -	
			MATERIAL SUBTOTAL	$ 3,600,000.00	***LABOR SUBTOTAL***	$ 341,471.52	***EQUIP SUBTOTAL***	$ 3,275.46	
			SALES TAX (MATERIALS) 5%	$ 180,000.00	***Labor Insurance 32%***	$ 109,270.89			
			SUBTOTALS	$ 3,780,000.00		$ 450,742.41		$ 3,275.46	
			TOTAL COST	$ 4,234,017.87					
			CONTIGENCY 20%	$ 846,803.57					
			OVERHEAD 10%	$ 423,401.79					
			PROFIT 8%	$ 440,337.86					
			TOTAL COST						$ 5,944,561

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 4.5M spat/ac)									
option 1 (25 acre site):									
granite	CY	40333.3333	$ 48.00	$ 1,936,000.00		$ -		$ -	
Mob/Demob	HR	39		$ -	$ 172.98	$ 6,746.22	$ 367.43	$ 14,329.77	
barge delivery	HR	689		$ -	$ 172.98	$ 119,183.22	$ 336.62	$ 231,931.18	
granite placement	CY	40333.3333		$ -	$ 1.16	$ 46,786.67	$ 2.09	$ 84,296.67	
			MATERIAL SUBTOTAL	$ 1,936,000.00	***LABOR SUBTOTAL***	$ 172,716.11	***EQUIP SUBTOTAL***	$ 330,557.62	
			SALES TAX (MATERIALS) 5%	$ 96,800.00	***Labor Insurance 32%***	$ 55,269.15			
			SUBTOTALS	$ 2,032,800.00		$ 227,985.26		$ 330,557.62	
			TOTAL COST	$ 2,591,342.88					
			CONTIGENCY 20%	$ 518,268.58					
			OVERHEAD 10%	$ 259,134.29					
			PROFIT 8%	$ 269,499.66					
			TOTAL COST						$ 3,638,245
spat	EA	112500000	$ 0.010	$ 1,125,000.00		$ -		$ -	
Mob/Demob	HR	11			$ 172.98	$ 1,902.78	$ 118.83	$ 1,307.13	
barge delivery	HR	13		$ -	$ 172.98	$ 2,248.74	$ 151.41	$ 1,968.33	
spat planting	EA	112500000		$ -	$ 0.001	$ 105,412.50		$ -	
			MATERIAL SUBTOTAL	$ 1,125,000.00	***LABOR SUBTOTAL***	$ 109,564.02	***EQUIP SUBTOTAL***	$ 3,275.46	
			SALES TAX (MATERIALS) 5%	$ 56,250.00	***Labor Insurance 32%***	$ 35,060.49			
			SUBTOTALS	$ 1,181,250.00		$ 144,624.51		$ 3,275.46	
			TOTAL COST	$ 1,329,149.97					
			CONTIGENCY 20%	$ 265,829.99					
			OVERHEAD 10%	$ 132,915.00					
			PROFIT 8%	$ 138,231.60					
			TOTAL COST						$ 1,866,127

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
granite	CY	80666.6667	$ 48.00	$ 3,872,000.00		$ -		$ -	
Mob/Demob	HR	39		$ -	$ 172.98	$ 6,746.22	$ 367.43	$ 14,329.77	
barge delivery	HR	1377		$ -	$ 172.98	$ 238,193.46	$ 336.62	$ 463,525.74	
granite placement	CY	80666.6667		$ -	$ 1.16	$ 93,573.33	$ 2.09	$ 168,593.33	
			MATERIAL SUBTOTAL	$ 3,872,000.00	***LABOR SUBTOTAL***	$ 338,513.01	***EQUIP SUBTOTAL***	$ 646,448.84	
			SALES TAX (MATERIALS) 5%	$ 193,600.00	***Labor Insurance 32%***	$ 108,324.16			
			SUBTOTALS	$ 4,065,600.00		$ 446,837.18		$ 646,448.84	
			TOTAL COST	$ 5,158,886.02					
			CONTIGENCY 20%	$ 1,031,777.20					
			OVERHEAD 10%	$ 515,888.60					
			PROFIT 8%	$ 536,524.15					
			TOTAL COST						$ 7,243,076
spat	EA	225000000	$ 0.010	$ 2,250,000.00		$ -		$ -	
Mob/Demob	HR	11			$ 172.98	$ 1,902.78	$ 118.83	$ 1,307.13	
barge delivery	HR	13		$ -	$ 172.98	$ 2,248.74	$ 151.41	$ 1,968.33	
spat planting	EA	225000000		$ -	$ 0.001	$ 210,825.00		$ -	
			MATERIAL SUBTOTAL	$ 2,250,000.00	***LABOR SUBTOTAL***	$ 214,976.52	***EQUIP SUBTOTAL***	$ 3,275.46	
			SALES TAX (MATERIALS) 5%	$ 112,500.00	***Labor Insurance 32%***	$ 68,792.49			
			SUBTOTALS	$ 2,362,500.00		$ 283,769.01		$ 3,275.46	
			TOTAL COST	$ 2,649,544.47					
			CONTIGENCY 20%	$ 529,908.89					
			OVERHEAD 10%	$ 264,954.45					
			PROFIT 8%	$ 275,552.62					
			TOTAL COST						$ 3,719,960

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
granite	CY	161333.333	$ 48.00	$ 7,744,000.00		$ -		$ -	
Mob/Demob	HR	39		$ -	$ 172.98	$ 6,746.22	$ 367.43	$ 14,329.77	
barge delivery	HR	2754		$ -	$ 172.98	$ 476,386.92	$ 336.62	$ 927,051.48	
granite placement	CY	161333.333		$ -	$ 1.16	$ 187,146.67	$ 2.09	$ 337,186.67	
			MATERIAL SUBTOTAL	$ 7,744,000.00	***LABOR SUBTOTAL***	$ 670,279.81	***EQUIP SUBTOTAL***	$ 1,278,567.92	
			SALES TAX (MATERIALS) 5%	$ 387,200.00	***Labor Insurance 32%***	$ 214,489.54			
			SUBTOTALS	$ 8,131,200.00		$ 884,769.34		$ 1,278,567.92	
			TOTAL COST	$ 10,294,537.26					
			CONTIGENCY 20%	$ 2,058,907.45					
			OVERHEAD 10%	$ 1,029,453.73					
			PROFIT 8%	$ 1,070,631.88					
			TOTAL COST						$ 14,453,530
spat	EA	450000000	$ 0.010	$ 4,500,000.00		$ -		$ -	
Mob/Demob	HR	11			$ 172.98	$ 1,902.78	$ 118.83	$ 1,307.13	
barge delivery	HR	13		$ -	$ 172.98	$ 2,248.74	$ 151.41	$ 1,968.33	
spat planting	EA	450000000		$ -	$ 0.001	$ 421,650.00		$ -	
			MATERIAL SUBTOTAL	$ 4,500,000.00	***LABOR SUBTOTAL***	$ 425,801.52	***EQUIP SUBTOTAL***	$ 3,275.46	
			SALES TAX (MATERIALS) 5%	$ 225,000.00	***Labor Insurance 32%***	$ 136,256.49			
			SUBTOTALS	$ 4,725,000.00		$ 562,058.01		$ 3,275.46	
			TOTAL COST	$ 5,290,333.47					
			CONTIGENCY 20%	$ 1,058,066.69					
			OVERHEAD 10%	$ 529,033.35					
			PROFIT 8%	$ 550,194.68					
			TOTAL COST						$ 7,427,628

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 6.75M spat/ac)									
option 1 (25 acre site):									
granite	CY	40333.3333	$ 48.00	$ 1,936,000.00		$ -		$ -	
Mob/Demob	HR	39		$ -	$ 172.98	$ 6,746.22	$ 367.43	$ 14,329.77	
barge delivery	HR	689		$ -	$ 172.98	$ 119,183.22	$ 336.62	$ 231,931.18	
granite placement	CY	40333.3333		$ -	$ 1.16	$ 46,786.67	$ 2.09	$ 84,296.67	
			MATERIAL SUBTOTAL	$ 1,936,000.00	***LABOR SUBTOTAL***	$ 172,716.11	***EQUIP SUBTOTAL***	$ 330,557.62	
			SALES TAX (MATERIALS) 5%	$ 96,800.00	***Labor Insurance 32%***	$ 55,269.15			
			SUBTOTALS	$ 2,032,800.00		$ 227,985.26		$ 330,557.62	
			TOTAL COST	$ 2,591,342.88					
			CONTIGENCY 20%	$ 518,268.58					
			OVERHEAD 10%	$ 259,134.29					
			PROFIT 8%	$ 269,499.66					
			TOTAL COST						$ 3,638,245
spat	EA	168750000	$ 0.010	$ 1,687,500.00		$ -		$ -	
Mob/Demob	HR	11			$ 172.98	$ 1,902.78	$ 118.83	$ 1,307.13	
barge delivery	HR	13		$ -	$ 172.98	$ 2,248.74	$ 151.41	$ 1,968.33	
spat planting	EA	168750000		$ -	$ 0.001	$ 158,118.75		$ -	
			MATERIAL SUBTOTAL	$ 1,687,500.00	***LABOR SUBTOTAL***	$ 162,270.27	***EQUIP SUBTOTAL***	$ 3,275.46	
			SALES TAX (MATERIALS) 5%	$ 84,375.00	***Labor Insurance 32%***	$ 51,926.49			
			SUBTOTALS	$ 1,771,875.00		$ 214,196.76		$ 3,275.46	
			TOTAL COST	$ 1,989,347.22					
			CONTIGENCY 20%	$ 397,869.44					
			OVERHEAD 10%	$ 198,934.72					
			PROFIT 8%	$ 206,892.11					
			TOTAL COST						$ 2,793,043

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
granite	CY	80666.6667	$ 48.00	$ 3,872,000.00		$ -		$ -	
Mob/Demob	HR	39		$ -	$ 172.98	$ 6,746.22	$ 367.43	$ 14,329.77	
barge delivery	HR	1377		$ -	$ 172.98	$ 238,193.46	$ 336.62	$ 463,525.74	
granite placement	CY	80666.6667		$ -	$ 1.16	$ 93,573.33	$ 2.09	$ 168,593.33	
			MATERIAL SUBTOTAL	$ 3,872,000.00	***LABOR SUBTOTAL***	$ 338,513.01	***EQUIP SUBTOTAL***	$ 646,448.84	
			SALES TAX (MATERIALS) 5%	$ 193,600.00	***Labor Insurance 32%***	$ 108,324.16			
			SUBTOTALS	$ 4,065,600.00		$ 446,837.18		$ 646,448.84	
			TOTAL COST	$ 5,158,886.02					
			CONTIGENCY 20%	$ 1,031,777.20					
			OVERHEAD 10%	$ 515,888.60					
			PROFIT 8%	$ 536,524.15					
			TOTAL COST						$ 7,243,076
spat	EA	337500000	$ 0.010	$ 3,375,000.00		$ -		$ -	
Mob/Demob	HR	11			$ 172.98	$ 1,902.78	$ 118.83	$ 1,307.13	
barge delivery	HR	13		$ -	$ 172.98	$ 2,248.74	$ 151.41	$ 1,968.33	
spat planting	EA	337500000		$ -	$ 0.001	$ 316,237.50		$ -	
			MATERIAL SUBTOTAL	$ 3,375,000.00	***LABOR SUBTOTAL***	$ 320,389.02	***EQUIP SUBTOTAL***	$ 3,275.46	
			SALES TAX (MATERIALS) 5%	$ 168,750.00	***Labor Insurance 32%***	$ 102,524.49			
			SUBTOTALS	$ 3,543,750.00		$ 422,913.51		$ 3,275.46	
			TOTAL COST	$ 3,969,938.97					
			CONTIGENCY 20%	$ 793,987.79					
			OVERHEAD 10%	$ 396,993.90					
			PROFIT 8%	$ 412,873.65					
			TOTAL COST						$ 5,573,794

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
granite	CY	161333.333	$ 48.00	$ 7,744,000.00		$ -		$ -	
Mob/Demob	HR	39		$ -	$ 172.98	$ 6,746.22	$ 367.43	$ 14,329.77	
barge delivery	HR	2754		$ -	$ 172.98	$ 476,386.92	$ 336.62	$ 927,051.48	
granite placement	CY	161333.333		$ -	$ 1.16	$ 187,146.67	$ 2.09	$ 337,186.67	
			MATERIAL SUBTOTAL	$ 7,744,000.00	***LABOR SUBTOTAL***	$ 670,279.81	***EQUIP SUBTOTAL***	$ 1,278,567.92	
			SALES TAX (MATERIALS) 5%	$ 387,200.00	***Labor Insurance 32%***	$ 214,489.54			
			SUBTOTALS	$ 8,131,200.00		$ 884,769.34		$ 1,278,567.92	
			TOTAL COST	$ 10,294,537.26					
			CONTIGENCY 20%	$ 2,058,907.45					
			OVERHEAD 10%	$ 1,029,453.73					
			PROFIT 8%	$ 1,070,631.88					
			TOTAL COST						$ 14,453,530
spat	EA	675000000	$ 0.010	$ 6,750,000.00		$ -		$ -	
Mob/Demob	HR	11			$ 172.98	$ 1,902.78	$ 118.83	$ 1,307.13	
barge delivery	HR	13		$ -	$ 172.98	$ 2,248.74	$ 151.41	$ 1,968.33	
spat planting	EA	675000000		$ -	$ 0.001	$ 632,475.00		$ -	
			MATERIAL SUBTOTAL	$ 6,750,000.00	***LABOR SUBTOTAL***	$ 636,626.52	***EQUIP SUBTOTAL***	$ 3,275.46	
			SALES TAX (MATERIALS) 5%	$ 337,500.00	***Labor Insurance 32%***	$ 203,720.49			
			SUBTOTALS	$ 7,087,500.00		$ 840,347.01		$ 3,275.46	
			TOTAL COST	$ 7,931,122.47					
			CONTIGENCY 20%	$ 1,586,224.49					
			OVERHEAD 10%	$ 793,112.25					
			PROFIT 8%	$ 824,836.74					
			TOTAL COST						$ 11,135,296

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 3.6M spat/ac)									
option 1 (25 acre site):									
concrete	CY	40333.3333	$ 30.00	$ 1,210,000.00		$ -		$ -	
Mob/Demob	HR	39		$ -	$ 172.98	$ 6,746.22	$ 367.43	$ 14,329.77	
barge delivery	HR	551		$ -	$ 172.98	$ 95,311.98	$ 336.62	$ 185,477.62	
concrete placement	CY	40333.3333		$ -	$ 0.92	$ 37,106.67	$ 1.67	$ 67,356.67	
			MATERIAL SUBTOTAL	$ 1,210,000.00	***LABOR SUBTOTAL***	$ 139,164.87	***EQUIP SUBTOTAL***	$ 267,164.06	
			SALES TAX (MATERIALS) 5%	$ 60,500.00	***Labor Insurance 32%***	$ 44,532.76			
			SUBTOTALS	$ 1,270,500.00		$ 183,697.62		$ 267,164.06	
			TOTAL COST	$ 1,721,361.68					
			CONTIGENCY 20%	$ 344,272.34					
			OVERHEAD 10%	$ 172,136.17					
			PROFIT 8%	$ 179,021.61					
			TOTAL COST						$ 2,416,792
spat	EA	90000000	$ 0.010	$ 900,000.00		$ -		$ -	
Mob/Demob	HR	11			$ 172.98	$ 1,902.78	$ 118.83	$ 1,307.13	
barge delivery	HR	13		$ -	$ 172.98	$ 2,248.74	$ 151.41	$ 1,968.33	
spat planting	EA	90000000		$ -	$ 0.001	$ 84,330.00		$ -	
			MATERIAL SUBTOTAL	$ 900,000.00	***LABOR SUBTOTAL***	$ 88,481.52	***EQUIP SUBTOTAL***	$ 3,275.46	
			SALES TAX (MATERIALS) 5%	$ 45,000.00	***Labor Insurance 32%***	$ 28,314.09			
			SUBTOTALS	$ 945,000.00		$ 116,795.61		$ 3,275.46	
			TOTAL COST	$ 1,065,071.07					
			CONTIGENCY 20%	$ 213,014.21					
			OVERHEAD 10%	$ 106,507.11					
			PROFIT 8%	$ 110,767.39					
			TOTAL COST						$ 1,495,360

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
concrete	CY	80666.6667	$ 30.00	$ 2,420,000.00		$ -		$ -	
Mob/Demob	HR	39		$ -	$ 172.98	$ 6,746.22	$ 367.43	$ 14,329.77	
barge delivery	HR	1102		$ -	$ 172.98	$ 190,623.96	$ 336.62	$ 370,955.24	
concrete placement	CY	80666.6667		$ -	$ 0.92	$ 74,213.33	$ 1.67	$ 134,713.33	
			MATERIAL SUBTOTAL	$ 2,420,000.00	***LABOR SUBTOTAL***	$ 271,583.51	***EQUIP SUBTOTAL***	$ 519,998.34	
			SALES TAX (MATERIALS) 5%	$ 121,000.00	***Labor Insurance 32%***	$ 86,906.72			
			SUBTOTALS	$ 2,541,000.00		$ 358,490.24		$ 519,998.34	
			TOTAL COST	$ 3,419,488.58					
			CONTIGENCY 20%	$ 683,897.72					
			OVERHEAD 10%	$ 341,948.86					
			PROFIT 8%	$ 355,626.81					
			TOTAL COST						$ 4,800,962
spat	EA	180000000	$ 0.010	$ 1,800,000.00		$ -		$ -	
Mob/Demob	HR	11			$ 172.98	$ 1,902.78	$ 118.83	$ 1,307.13	
barge delivery	HR	13		$ -	$ 172.98	$ 2,248.74	$ 151.41	$ 1,968.33	
spat planting	EA	180000000		$ -	$ 0.001	$ 168,660.00		$ -	
			SUBTOTAL	$ 1,800,000.00	***SUBTOTAL***	$ 172,811.52	***SUBTOTAL***	$ 3,275.46	
			(MATERIALS) 5%	$ 90,000.00	***32%***	$ 55,299.69			
			SUBTOTALS	$ 1,890,000.00		$ 228,111.21		$ 3,275.46	
			TOTAL COST	$ 2,121,386.67					
			CONTIGENCY 20%	$ 424,277.33					
			OVERHEAD 10%	$ 212,138.67					
			PROFIT 8%	$ 220,624.21					
			TOTAL COST						$ 2,978,427

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
concrete	CY	161333.333	$ 30.00	$ 4,840,000.00		$ -		$ -	
Mob/Demob	HR	39		$ -	$ 172.98	$ 6,746.22	$ 367.43	$ 14,329.77	
barge delivery	HR	2204		$ -	$ 172.98	$ 381,247.92	$ 336.62	$ 741,910.48	
concrete placement	CY	161333.333		$ -	$ 0.92	$ 148,426.67	$ 1.67	$ 269,426.67	
			MATERIAL SUBTOTAL	$ 4,840,000.00	***LABOR SUBTOTAL***	$ 536,420.81	***EQUIP SUBTOTAL***	$ 1,025,666.92	
			SALES TAX (MATERIALS) 5%	$ 242,000.00	***Labor Insurance 32%***	$ 171,654.66			
			SUBTOTALS	$ 5,082,000.00		$ 708,075.46		$ 1,025,666.92	
			TOTAL COST	$ 6,815,742.38					
			CONTIGENCY 20%	$ 1,363,148.48					
			OVERHEAD 10%	$ 681,574.24					
			PROFIT 8%	$ 708,837.21					
			TOTAL COST						$ 9,569,302
spat	EA	360000000	$ 0.010	$ 3,600,000.00		$ -		$ -	
Mob/Demob	HR	11			$ 172.98	$ 1,902.78	$ 118.83	$ 1,307.13	
barge delivery	HR	13		$ -	$ 172.98	$ 2,248.74	$ 151.41	$ 1,968.33	
spat planting	EA	360000000		$ -	$ 0.001	$ 337,320.00		$ -	
			MATERIAL SUBTOTAL	$ 3,600,000.00	***LABOR SUBTOTAL***	$ 341,471.52	***EQUIP SUBTOTAL***	$ 3,275.46	
			SALES TAX (MATERIALS) 5%	$ 180,000.00	***Labor Insurance 32%***	$ 109,270.89			
			SUBTOTALS	$ 3,780,000.00		$ 450,742.41		$ 3,275.46	
			TOTAL COST	$ 4,234,017.87					
			CONTIGENCY 20%	$ 846,803.57					
			OVERHEAD 10%	$ 423,401.79					
			PROFIT 8%	$ 440,337.86					
			TOTAL COST						$ 5,944,561

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 4.5M spat/ac)									
option 1 (25 acre site):									
concrete	CY	40333.3333	$ 30.00	$ 1,210,000.00		$ -		$ -	
Mob/Demob	HR	39		$ -	$ 172.98	$ 6,746.22	$ 367.43	$ 14,329.77	
barge delivery	HR	551		$ -	$ 172.98	$ 95,311.98	$ 336.62	$ 185,477.62	
concrete placement	CY	40333.3333		$ -	$ 0.92	$ 37,106.67	$ 1.67	$ 67,356.67	
			MATERIAL SUBTOTAL	$ 1,210,000.00	***LABOR SUBTOTAL***	$ 139,164.87	***EQUIP SUBTOTAL***	$ 267,164.06	
			SALES TAX (MATERIALS) 5%	$ 60,500.00	***Labor Insurance 32%***	$ 44,532.76			
			SUBTOTALS	$ 1,270,500.00		$ 183,697.62		$ 267,164.06	
			TOTAL COST	$ 1,721,361.68					
			CONTIGENCY 20%	$ 344,272.34					
			OVERHEAD 10%	$ 172,136.17					
			PROFIT 8%	$ 179,021.61					
			TOTAL COST						$ 2,416,792
spat	EA	112500000	$ 0.010	$ 1,125,000.00		$ -		$ -	
Mob/Demob	HR	11			$ 172.98	$ 1,902.78	$ 118.83	$ 1,307.13	
barge delivery	HR	13		$ -	$ 172.98	$ 2,248.74	$ 151.41	$ 1,968.33	
spat planting	EA	112500000		$ -	$ 0.001	$ 105,412.50		$ -	
			MATERIAL SUBTOTAL	$ 1,125,000.00	***LABOR SUBTOTAL***	$ 109,564.02	***EQUIP SUBTOTAL***	$ 3,275.46	
			SALES TAX (MATERIALS) 5%	$ 56,250.00	***Labor Insurance 32%***	$ 35,060.49			
			SUBTOTALS	$ 1,181,250.00		$ 144,624.51		$ 3,275.46	
			TOTAL COST	$ 1,329,149.97					
			CONTIGENCY 20%	$ 265,829.99					
			OVERHEAD 10%	$ 132,915.00					
			PROFIT 8%	$ 138,231.60					
			TOTAL COST						$ 1,866,127

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
concrete	CY	80666.6667	$ 30.00	$ 2,420,000.00		$ -		$ -	
Mob/Demob	HR	39		$ -	$ 172.98	$ 6,746.22	$ 367.43	$ 14,329.77	
barge delivery	HR	1102		$ -	$ 172.98	$ 190,623.96	$ 336.62	$ 370,955.24	
concrete placement	CY	80666.6667		$ -	$ 0.92	$ 74,213.33	$ 1.67	$ 134,713.33	
			MATERIAL SUBTOTAL	$ 2,420,000.00	***LABOR SUBTOTAL***	$ 271,583.51	***EQUIP SUBTOTAL***	$ 519,998.34	
			SALES TAX (MATERIALS) 5%	$ 121,000.00	***Labor Insurance 32%***	$ 86,906.72			
			SUBTOTALS	$ 2,541,000.00		$ 358,490.24		$ 519,998.34	
			TOTAL COST	$ 3,419,488.58					
			CONTIGENCY 20%	$ 683,897.72					
			OVERHEAD 10%	$ 341,948.86					
			PROFIT 8%	$ 355,626.81					
			TOTAL COST						$ 4,800,962
spat	EA	225000000	$ 0.010	$ 2,250,000.00		$ -		$ -	
Mob/Demob	HR	11			$ 172.98	$ 1,902.78	$ 118.83	$ 1,307.13	
barge delivery	HR	13		$ -	$ 172.98	$ 2,248.74	$ 151.41	$ 1,968.33	
spat planting	EA	225000000		$ -	$ 0.001	$ 210,825.00		$ -	
			MATERIAL SUBTOTAL	$ 2,250,000.00	***LABOR SUBTOTAL***	$ 214,976.52	***EQUIP SUBTOTAL***	$ 3,275.46	
			SALES TAX (MATERIALS) 5%	$ 112,500.00	***Labor Insurance 32%***	$ 68,792.49			
			SUBTOTALS	$ 2,362,500.00		$ 283,769.01		$ 3,275.46	
			TOTAL COST	$ 2,649,544.47					
			CONTIGENCY 20%	$ 529,908.89					
			OVERHEAD 10%	$ 264,954.45					
			PROFIT 8%	$ 275,552.62					
			TOTAL COST						$ 3,719,960

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
concrete	CY	161333.333	$ 30.00	$ 4,840,000.00		$ -		$ -	
Mob/Demob	HR	39		$ -	$ 172.98	$ 6,746.22	$ 367.43	$ 14,329.77	
barge delivery	HR	2204		$ -	$ 172.98	$ 381,247.92	$ 336.62	$ 741,910.48	
concrete placement	CY	161333.333		$ -	$ 0.92	$ 148,426.67	$ 1.67	$ 269,426.67	
			MATERIAL SUBTOTAL	$ 4,840,000.00	***LABOR SUBTOTAL***	$ 536,420.81	***EQUIP SUBTOTAL***	$ 1,025,666.92	
			SALES TAX (MATERIALS) 5%	$ 242,000.00	***Labor Insurance 32%***	$ 171,654.66			
			SUBTOTALS	$ 5,082,000.00		$ 708,075.46		$ 1,025,666.92	
			TOTAL COST	$ 6,815,742.38					
			CONTIGENCY 20%	$ 1,363,148.48					
			OVERHEAD 10%	$ 681,574.24					
			PROFIT 8%	$ 708,837.21					
			TOTAL COST						$ 9,569,302
spat	EA	450000000	$ 0.010	$ 4,500,000.00		$ -		$ -	
Mob/Demob	HR	11			$ 172.98	$ 1,902.78	$ 118.83	$ 1,307.13	
barge delivery	HR	13		$ -	$ 172.98	$ 2,248.74	$ 151.41	$ 1,968.33	
spat planting	EA	450000000		$ -	$ 0.001	$ 421,650.00		$ -	
			MATERIAL SUBTOTAL	$ 4,500,000.00	***LABOR SUBTOTAL***	$ 425,801.52	***EQUIP SUBTOTAL***	$ 3,275.46	
			SALES TAX (MATERIALS) 5%	$ 225,000.00	***Labor Insurance 32%***	$ 136,256.49			
			SUBTOTALS	$ 4,725,000.00		$ 562,058.01		$ 3,275.46	
			TOTAL COST	$ 5,290,333.47					
			CONTIGENCY 20%	$ 1,058,066.69					
			OVERHEAD 10%	$ 529,033.35					
			PROFIT 8%	$ 550,194.68					
			TOTAL COST						$ 7,427,628

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 6.75M spat/ac)									
option 1 (25 acre site):									
concrete	CY	40333.3333	$ 30.00	$ 1,210,000.00		$ -		$ -	
Mob/Demob	HR	39		$ -	$ 172.98	$ 6,746.22	$ 367.43	$ 14,329.77	
barge delivery	HR	551		$ -	$ 172.98	$ 95,311.98	$ 336.62	$ 185,477.62	
concrete placement	CY	40333.3333		$ -	$ 0.92	$ 37,106.67	$ 1.67	$ 67,356.67	
			MATERIAL SUBTOTAL	$ 1,210,000.00	***LABOR SUBTOTAL***	$ 139,164.87	***EQUIP SUBTOTAL***	$ 267,164.06	
			SALES TAX (MATERIALS) 5%	$ 60,500.00	***Labor Insurance 32%***	$ 44,532.76			
			SUBTOTALS	$ 1,270,500.00		$ 183,697.62		$ 267,164.06	
			TOTAL COST	$ 1,721,361.68					
			CONTIGENCY 20%	$ 344,272.34					
			OVERHEAD 10%	$ 172,136.17					
			PROFIT 8%	$ 179,021.61					
			TOTAL COST						$ 2,416,792
spat	EA	168750000	$ 0.010	$ 1,687,500.00		$ -		$ -	
Mob/Demob	HR	11			$ 172.98	$ 1,902.78	$ 118.83	$ 1,307.13	
barge delivery	HR	13		$ -	$ 172.98	$ 2,248.74	$ 151.41	$ 1,968.33	
spat planting	EA	168750000		$ -	$ 0.001	$ 158,118.75		$ -	
			MATERIAL SUBTOTAL	$ 1,687,500.00	***LABOR SUBTOTAL***	$ 162,270.27	***EQUIP SUBTOTAL***	$ 3,275.46	
			SALES TAX (MATERIALS) 5%	$ 84,375.00	***Labor Insurance 32%***	$ 51,926.49			
			SUBTOTALS	$ 1,771,875.00		$ 214,196.76		$ 3,275.46	
			TOTAL COST	$ 1,989,347.22					
			CONTIGENCY 20%	$ 397,869.44					
			OVERHEAD 10%	$ 198,934.72					
			PROFIT 8%	$ 206,892.11					
			TOTAL COST						$ 2,793,043

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
concrete	CY	80666.6667	$ 30.00	$ 2,420,000.00		$ -		$ -	
Mob/Demob	HR	39		$ -	$ 172.98	$ 6,746.22	$ 367.43	$ 14,329.77	
barge delivery	HR	1102		$ -	$ 172.98	$ 190,623.96	$ 336.62	$ 370,955.24	
concrete placement	CY	80666.6667		$ -	$ 0.92	$ 74,213.33	$ 1.67	$ 134,713.33	
			MATERIAL SUBTOTAL	$ 2,420,000.00	***LABOR SUBTOTAL***	$ 271,583.51	***EQUIP SUBTOTAL***	$ 519,998.34	
			SALES TAX (MATERIALS) 5%	$ 121,000.00	***Labor Insurance 32%***	$ 86,906.72			
			SUBTOTALS	$ 2,541,000.00		$ 358,490.24		$ 519,998.34	
			TOTAL COST	$ 3,419,488.58					
			CONTIGENCY 20%	$ 683,897.72					
			OVERHEAD 10%	$ 341,948.86					
			PROFIT 8%	$ 355,626.81					
			TOTAL COST						$ 4,800,962
spat	EA	337500000	$ 0.010	$ 3,375,000.00		$ -		$ -	
Mob/Demob	HR	11			$ 172.98	$ 1,902.78	$ 118.83	$ 1,307.13	
barge delivery	HR	13		$ -	$ 172.98	$ 2,248.74	$ 151.41	$ 1,968.33	
spat planting	EA	337500000		$ -	$ 0.001	$ 316,237.50		$ -	
			MATERIAL SUBTOTAL	$ 3,375,000.00	***LABOR SUBTOTAL***	$ 320,389.02	***EQUIP SUBTOTAL***	$ 3,275.46	
			SALES TAX (MATERIALS) 5%	$ 168,750.00	***Labor Insurance 32%***	$ 102,524.49			
			SUBTOTALS	$ 3,543,750.00		$ 422,913.51		$ 3,275.46	
			TOTAL COST	$ 3,969,938.97					
			CONTIGENCY 20%	$ 793,987.79					
			OVERHEAD 10%	$ 396,993.90					
			PROFIT 8%	$ 412,873.65					
			TOTAL COST						$ 5,573,794

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
concrete	CY	161333.333	$ 30.00	$ 4,840,000.00		$ -		$ -	
Mob/Demob	HR	39		$ -	$ 172.98	$ 6,746.22	$ 367.43	$ 14,329.77	
barge delivery	HR	2204		$ -	$ 172.98	$ 381,247.92	$ 336.62	$ 741,910.48	
concrete placement	CY	161333.333		$ -	$ 0.92	$ 148,426.67	$ 1.67	$ 269,426.67	
			MATERIAL SUBTOTAL	$ 4,840,000.00	***LABOR SUBTOTAL***	$ 536,420.81	***EQUIP SUBTOTAL***	$ 1,025,666.92	
			SALES TAX (MATERIALS) 5%	$ 242,000.00	***Labor Insurance 32%***	$ 171,654.66			
			SUBTOTALS	$ 5,082,000.00		$ 708,075.46		$ 1,025,666.92	
			TOTAL COST	$ 6,815,742.38					
			CONTIGENCY 20%	$ 1,363,148.48					
			OVERHEAD 10%	$ 681,574.24					
			PROFIT 8%	$ 708,837.21					
			TOTAL COST						$ 9,569,302
spat	EA	675000000	$ 0.010	$ 6,750,000.00		$ -		$ -	
Mob/Demob	HR	11			$ 172.98	$ 1,902.78	$ 118.83	$ 1,307.13	
barge delivery	HR	13		$ -	$ 172.98	$ 2,248.74	$ 151.41	$ 1,968.33	
spat planting	EA	675000000		$ -	$ 0.001	$ 632,475.00		$ -	
			MATERIAL SUBTOTAL	$ 6,750,000.00	***LABOR SUBTOTAL***	$ 636,626.52	***EQUIP SUBTOTAL***	$ 3,275.46	
			SALES TAX (MATERIALS) 5%	$ 337,500.00	***Labor Insurance 32%***	$ 203,720.49			
			SUBTOTALS	$ 7,087,500.00		$ 840,347.01		$ 3,275.46	
			TOTAL COST	$ 7,931,122.47					
			CONTIGENCY 20%	$ 1,586,224.49					
			OVERHEAD 10%	$ 793,112.25					
			PROFIT 8%	$ 824,836.74					
			TOTAL COST						$ 11,135,296

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 3.6M spat/ac)									
option 1 (25 acre site):									
oyster shell dredging	CY	40333	$ 15.85	$ 639,283.33		$ -		$ -	
Mob/Demob	HR	28		$ -	$ 172.98	$ 4,843.44	$ 367.43	$ 10,288.04	
barge delivery	HR	63		$ -	$ 172.98	$ 10,897.74	$ 336.62	$ 21,207.06	
oyster placement	CY	40333		$ -	$ 6.27	$ 252,890.00		$ -	
			MATERIAL SUBTOTAL	$ 639,283.33	***LABOR SUBTOTAL***	$ 268,631.18	***EQUIP SUBTOTAL***	$ 31,495.10	
			SALES TAX (MATERIALS) 5%	$ 31,964.17	***Labor Insurance 32%***	$ 85,961.98			
			SUBTOTALS	$ 671,247.50		$ 354,593.16		$ 31,495.10	
			TOTAL COST	$ 1,057,335.76					
			CONTIGENCY 20%	$ 211,467.15					
			OVERHEAD 10%	$ 105,733.58					
			PROFIT 8%	$ 109,962.92					
			TOTAL COST						$ 1,484,499
spat	EA	90000000	$ 0.010	$ 900,000.00		$ -		$ -	
Mob/Demob	HR	11			$ 172.98	$ 1,902.78	$ 118.83	$ 1,307.13	
barge delivery	HR	13		$ -	$ 172.98	$ 2,248.74	$ 151.41	$ 1,968.33	
spat planting	EA	90000000		$ -	$ 0.001	$ 84,330.00		$ -	
Turbidity control	LF	4200	$ 0.69	$ 2,898.00	$ 0.15	$ 630.00	$ 0.39	$ 1,638.00	
			MATERIAL SUBTOTAL	$ 902,898.00	***LABOR SUBTOTAL***	$ 89,111.52	***EQUIP SUBTOTAL***	$ 4,913.46	
			SALES TAX (MATERIALS) 5%	$ 45,144.90	***Labor Insurance 32%***	$ 28,515.69			
			SUBTOTALS	$ 948,042.90		$ 117,627.21		$ 4,913.46	
			TOTAL COST	$ 1,070,583.57					
			CONTIGENCY 20%	$ 214,116.71					
			OVERHEAD 10%	$ 107,058.36					
			PROFIT 8%	$ 111,340.69					
			TOTAL COST						$ 1,503,099

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
oyster shell dredging	CY	80667	$ 15.85	$ 1,278,566.67		$ -		$ -	
Mob/Demob	HR	28		$ -	$ 172.98	$ 4,843.44	$ 367.43	$ 10,288.04	
barge delivery	HR	126		$ -	$ 172.98	$ 21,795.48	$ 336.62	$ 42,414.12	
oyster placement	CY	80667		$ -	$ 6.27	$ 505,780.00		$ -	
			MATERIAL SUBTOTAL	$ 1,278,566.67	***LABOR SUBTOTAL***	$ 532,418.92	***EQUIP SUBTOTAL***	$ 52,702.16	
			SALES TAX (MATERIALS) 5%	$ 63,928.33	***Labor Insurance 32%***	$ 170,374.05			
			SUBTOTALS	$ 1,342,495.00		$ 702,792.97		$ 52,702.16	
			TOTAL COST	$ 2,097,990.13					
			CONTIGENCY 20%	$ 419,598.03					
			OVERHEAD 10%	$ 209,799.01					
			PROFIT 8%	$ 218,190.97					
			TOTAL COST						$ 2,945,578
spat	EA	180000000	$ 0.010	$ 1,800,000.00		$ -		$ -	
Mob/Demob	HR	11			$ 172.98	$ 1,902.78	$ 118.83	$ 1,307.13	
barge delivery	HR	13		$ -	$ 172.98	$ 2,248.74	$ 151.41	$ 1,968.33	
spat planting	EA	180000000		$ -	$ 0.001	$ 168,660.00		$ -	
Turbidity control	LF	5900	$ 0.69	$ 4,071.00	$ 0.15	$ 885.00	$ 0.39	$ 2,301.00	
			MATERIAL SUBTOTAL	$ 1,804,071.00	***LABOR SUBTOTAL***	$ 173,696.52	***EQUIP SUBTOTAL***	$ 5,576.46	
			SALES TAX (MATERIALS) 5%	$ 90,203.55	***Labor Insurance 32%***	$ 55,582.89			
			SUBTOTALS	$ 1,894,274.55		$ 229,279.41		$ 5,576.46	
			TOTAL COST	$ 2,129,130.42					
			CONTIGENCY 20%	$ 425,826.08					
			OVERHEAD 10%	$ 212,913.04					
			PROFIT 8%	$ 221,429.56					
			TOTAL COST						$ 2,989,299

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
oyster shell dredging	CY	161333	$ 15.85	$ 2,557,133.33		$ -		$ -	
Mob/Demob	HR	28		$ -	$ 172.98	$ 4,843.44	$ 367.43	$ 10,288.04	
barge delivery	HR	252		$ -	$ 172.98	$ 43,590.96	$ 336.62	$ 84,828.24	
oyster placement	CY	161333		$ -	$ 6.27	$ 1,011,560.00		$ -	
			MATERIAL SUBTOTAL	$ 2,557,133.33	***LABOR SUBTOTAL***	$ 1,059,994.40	***EQUIP SUBTOTAL***	$ 95,116.28	
			SALES TAX (MATERIALS) 5%	$ 127,856.67	***Labor Insurance 32%***	$ 339,198.21			
			SUBTOTALS	$ 2,684,990.00		$ 1,399,192.61		$ 95,116.28	
			TOTAL COST	$ 4,179,298.89					
			CONTIGENCY 20%	$ 835,859.78					
			OVERHEAD 10%	$ 417,929.89					
			PROFIT 8%	$ 434,647.08					
			TOTAL COST						$ 5,867,736
spat	EA	360000000	$ 0.010	$ 3,600,000.00		$ -		$ -	
Mob/Demob	HR	11			$ 172.98	$ 1,902.78	$ 118.83	$ 1,307.13	
barge delivery	HR	13		$ -	$ 172.98	$ 2,248.74	$ 151.41	$ 1,968.33	
spat planting	EA	360000000		$ -	$ 0.001	$ 337,320.00		$ -	
Turbidity control	LF	8350	$ 0.69	$ 5,761.50	$ 0.15	$ 1,252.50	$ 0.39	$ 3,256.50	
			MATERIAL SUBTOTAL	$ 3,605,761.50	***LABOR SUBTOTAL***	$ 342,724.02	***EQUIP SUBTOTAL***	$ 6,531.96	
			SALES TAX (MATERIALS) 5%	$ 180,288.08	***Labor Insurance 32%***	$ 109,671.69			
			SUBTOTALS	$ 3,786,049.58		$ 452,395.71		$ 6,531.96	
			TOTAL COST	$ 4,244,977.24					
			CONTIGENCY 20%	$ 848,995.45					
			OVERHEAD 10%	$ 424,497.72					
			PROFIT 8%	$ 441,477.63					
			TOTAL COST						$ 5,959,948

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 4.5M spat/ac)									
option 1 (25 acre site):									
oyster shell dredging	CY	40333	$ 15.85	$ 639,283.33		$ -		$ -	
Mob/Demob	HR	28		$ -	$ 172.98	$ 4,843.44	$ 367.43	$ 10,288.04	
barge delivery	HR	63		$ -	$ 172.98	$ 10,897.74	$ 336.62	$ 21,207.06	
oyster placement	CY	40333		$ -	$ 6.27	$ 252,890.00		$ -	
			MATERIAL SUBTOTAL	$ 639,283.33	***LABOR SUBTOTAL***	$ 268,631.18	***EQUIP SUBTOTAL***	$ 31,495.10	
			SALES TAX (MATERIALS) 5%	$ 31,964.17	***Labor Insurance 32%***	$ 85,961.98			
			SUBTOTALS	$ 671,247.50		$ 354,593.16		$ 31,495.10	
			TOTAL COST	$ 1,057,335.76					
			CONTIGENCY 20%	$ 211,467.15					
			OVERHEAD 10%	$ 105,733.58					
			PROFIT 8%	$ 109,962.92					
			TOTAL COST						$ 1,484,499
spat	EA	112500000	$ 0.010	$ 1,125,000.00		$ -		$ -	
Mob/Demob	HR	11			$ 172.98	$ 1,902.78	$ 118.83	$ 1,307.13	
barge delivery	HR	13		$ -	$ 172.98	$ 2,248.74	$ 151.41	$ 1,968.33	
spat planting	EA	112500000		$ -	$ 0.001	$ 105,412.50		$ -	
Turbidity control	LF	4200	$ 0.69	$ 2,898.00	$ 0.15	$ 630.00	$ 0.39	$ 1,638.00	
			MATERIAL SUBTOTAL	$ 1,127,898.00	***LABOR SUBTOTAL***	$ 110,194.02	***EQUIP SUBTOTAL***	$ 4,913.46	
			SALES TAX (MATERIALS) 5%	$ 56,394.90	***Labor Insurance 32%***	$ 35,262.09			
			SUBTOTALS	$ 1,184,292.90		$ 145,456.11		$ 4,913.46	
			TOTAL COST	$ 1,334,662.47					
			CONTIGENCY 20%	$ 266,932.49					
			OVERHEAD 10%	$ 133,466.25					
			PROFIT 8%	$ 138,804.90					
			TOTAL COST						$ 1,873,866

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
oyster shell dredging	CY	80667	$ 15.85	$ 1,278,566.67		$ -		$ -	
Mob/Demob	HR	28		$ -	$ 172.98	$ 4,843.44	$ 367.43	$ 10,288.04	
barge delivery	HR	126		$ -	$ 172.98	$ 21,795.48	$ 336.62	$ 42,414.12	
oyster placement	CY	80667		$ -	$ 6.27	$ 505,780.00		$ -	
			MATERIAL SUBTOTAL	$ 1,278,566.67	***LABOR SUBTOTAL***	$ 532,418.92	***EQUIP SUBTOTAL***	$ 52,702.16	
			SALES TAX (MATERIALS) 5%	$ 63,928.33	***Labor Insurance 32%***	$ 170,374.05			
			SUBTOTALS	$ 1,342,495.00		$ 702,792.97		$ 52,702.16	
			TOTAL COST	$ 2,097,990.13					
			CONTIGENCY 20%	$ 419,598.03					
			OVERHEAD 10%	$ 209,799.01					
			PROFIT 8%	$ 218,190.97					
			TOTAL COST						$ 2,945,578
spat	EA	225000000	$ 0.010	$ 2,250,000.00		$ -		$ -	
Mob/Demob	HR	11			$ 172.98	$ 1,902.78	$ 118.83	$ 1,307.13	
barge delivery	HR	13		$ -	$ 172.98	$ 2,248.74	$ 151.41	$ 1,968.33	
spat planting	EA	225000000		$ -	$ 0.001	$ 210,825.00		$ -	
Turbidity control	LF	5900	$ 0.69	$ 4,071.00	$ 0.15	$ 885.00	$ 0.39	$ 2,301.00	
			MATERIAL SUBTOTAL	$ 2,254,071.00	***LABOR SUBTOTAL***	$ 215,861.52	***EQUIP SUBTOTAL***	$ 5,576.46	
			SALES TAX (MATERIALS) 5%	$ 112,703.55	***Labor Insurance 32%***	$ 69,075.69			
			SUBTOTALS	$ 2,366,774.55		$ 284,937.21		$ 5,576.46	
			TOTAL COST	$ 2,657,288.22					
			CONTIGENCY 20%	$ 531,457.64					
			OVERHEAD 10%	$ 265,728.82					
			PROFIT 8%	$ 276,357.97					
			TOTAL COST						$ 3,730,833

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
oyster shell dredging	CY	161333	$ 15.85	$ 2,557,133.33		$ -		$ -	
Mob/Demob	HR	28		$ -	$ 172.98	$ 4,843.44	$ 367.43	$ 10,288.04	
barge delivery	HR	252		$ -	$ 172.98	$ 43,590.96	$ 336.62	$ 84,828.24	
oyster placement	CY	161333		$ -	$ 6.27	$ 1,011,560.00		$ -	
			MATERIAL SUBTOTAL	$ 2,557,133.33	***LABOR SUBTOTAL***	$ 1,059,994.40	***EQUIP SUBTOTAL***	$ 95,116.28	
			SALES TAX (MATERIALS) 5%	$ 127,856.67	***Labor Insurance 32%***	$ 339,198.21			
			SUBTOTALS	$ 2,684,990.00		$ 1,399,192.61		$ 95,116.28	
			TOTAL COST	$ 4,179,298.89					
			CONTIGENCY 20%	$ 835,859.78					
			OVERHEAD 10%	$ 417,929.89					
			PROFIT 8%	$ 434,647.08					
			TOTAL COST						$ 5,867,736
spat	EA	450000000	$ 0.010	$ 4,500,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	450000000		$ -	$ 0.001	$ 421,650.00		$ -	
Turbidity control	LF	8350	$ 0.69	$ 5,761.50	$ 0.15	$ 1,252.50	$ 0.39	$ 3,256.50	
			MATERIAL SUBTOTAL	$ 4,505,761.50	***LABOR SUBTOTAL***	$ 426,016.14	***EQUIP SUBTOTAL***	$ 5,688.66	
			SALES TAX (MATERIALS) 5%	$ 225,288.08	***Labor Insurance 32%***	$ 136,325.16			
			SUBTOTALS	$ 4,731,049.58		$ 562,341.30		$ 5,688.66	
			TOTAL COST	$ 5,299,079.54					
			CONTIGENCY 20%	$ 1,059,815.91					
			OVERHEAD 10%	$ 529,907.95					
			PROFIT 8%	$ 551,104.27					
			TOTAL COST						$ 7,439,908

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
high relief reef (12 inch depth, 6.75M spat/ac)									
option 1 (25 acre site):									
oyster shell dredging	CY	40333	$ 15.85	$ 639,283.33		$ -		$ -	
Mob/Demob	HR	28		$ -	$ 172.98	$ 4,843.44	$ 367.43	$ 10,288.04	
barge delivery	HR	63		$ -	$ 172.98	$ 10,897.74	$ 336.62	$ 21,207.06	
oyster placement	CY	40333		$ -	$ 6.27	$ 252,890.00		$ -	
			MATERIAL SUBTOTAL	$ 639,283.33	***LABOR SUBTOTAL***	$ 268,631.18	***EQUIP SUBTOTAL***	$ 31,495.10	
			SALES TAX (MATERIALS) 5%	$ 31,964.17	***Labor Insurance 32%***	$ 85,961.98			
			SUBTOTALS	$ 671,247.50		$ 354,593.16		$ 31,495.10	
			TOTAL COST	$ 1,057,335.76					
			CONTIGENCY 20%	$ 211,467.15					
			OVERHEAD 10%	$ 105,733.58					
			PROFIT 8%	$ 109,962.92					
			TOTAL COST						$ 1,484,499
spat	EA	168750000	$ 0.010	$ 1,687,500.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	168750000		$ -	$ 0.001	$ 158,118.75		$ -	
Turbidity control	LF	4200	$ 0.69	$ 2,898.00	$ 0.15	$ 630.00	$ 0.39	$ 1,638.00	
			MATERIAL SUBTOTAL	$ 1,690,398.00	***LABOR SUBTOTAL***	$ 161,862.39	***EQUIP SUBTOTAL***	$ 4,070.16	
			SALES TAX (MATERIALS) 5%	$ 84,519.90	***Labor Insurance 32%***	$ 51,795.96			
			SUBTOTALS	$ 1,774,917.90		$ 213,658.35		$ 4,070.16	
			TOTAL COST	$ 1,992,646.41					
			CONTIGENCY 20%	$ 398,529.28					
			OVERHEAD 10%	$ 199,264.64					
			PROFIT 8%	$ 207,235.23					
			TOTAL COST						$ 2,797,676

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 2 (50 acre site):									
oyster shell dredging	CY	80667	$ 15.85	$ 1,278,566.67		$ -		$ -	
Mob/Demob	HR	28		$ -	$ 172.98	$ 4,843.44	$ 367.43	$ 10,288.04	
barge delivery	HR	126		$ -	$ 172.98	$ 21,795.48	$ 336.62	$ 42,414.12	
oyster placement	CY	80667		$ -	$ 6.27	$ 505,780.00		$ -	
			MATERIAL SUBTOTAL	$ 1,278,566.67	***LABOR SUBTOTAL***	$ 532,418.92	***EQUIP SUBTOTAL***	$ 52,702.16	
			SALES TAX (MATERIALS) 5%	$ 63,928.33	***Labor Insurance 32%***	$ 170,374.05			
			SUBTOTALS	$ 1,342,495.00		$ 702,792.97		$ 52,702.16	
			TOTAL COST	$ 2,097,990.13					
			CONTIGENCY 20%	$ 419,598.03					
			OVERHEAD 10%	$ 209,799.01					
			PROFIT 8%	$ 218,190.97					
			TOTAL COST						$ 2,945,578
spat	EA	337500000	$ 0.010	$ 3,375,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	337500000		$ -	$ 0.001	$ 316,237.50		$ -	
Turbidity control	LF	5900	$ 0.69	$ 4,071.00	$ 0.15	$ 885.00	$ 0.39	$ 2,301.00	
			MATERIAL SUBTOTAL	$ 3,379,071.00	***LABOR SUBTOTAL***	$ 320,236.14	***EQUIP SUBTOTAL***	$ 4,733.16	
			SALES TAX (MATERIALS) 5%	$ 168,953.55	***Labor Insurance 32%***	$ 102,475.56			
			SUBTOTALS	$ 3,548,024.55		$ 422,711.70		$ 4,733.16	
			TOTAL COST	$ 3,975,469.41					
			CONTIGENCY 20%	$ 795,093.88					
			OVERHEAD 10%	$ 397,546.94					
			PROFIT 8%	$ 413,448.82					
			TOTAL COST						$ 5,581,559

DESCRIPTION	UOM	QTY	MATERIAL UNIT COST	TOTAL MATERIAL	LABOR UNIT COST LABOR	TOTAL LABOR	EQUIP UNIT COST	TOTAL EQUIP	
option 3 (100 acre site):									
oyster shell dredging	CY	161333	$ 15.85	$ 2,557,133.33		$ -		$ -	
Mob/Demob	HR	28		$ -	$ 172.98	$ 4,843.44	$ 367.43	$ 10,288.04	
barge delivery	HR	252		$ -	$ 172.98	$ 43,590.96	$ 336.62	$ 84,828.24	
oyster placement	CY	161333		$ -	$ 6.27	$ 1,011,560.00		$ -	
			MATERIAL SUBTOTAL	$ 2,557,133.33	***LABOR SUBTOTAL***	$ 1,059,994.40	***EQUIP SUBTOTAL***	$ 95,116.28	
			SALES TAX (MATERIALS) 5%	$ 127,856.67	***Labor Insurance 32%***	$ 339,198.21			
			SUBTOTALS	$ 2,684,990.00		$ 1,399,192.61		$ 95,116.28	
			TOTAL COST	$ 4,179,298.89					
			CONTIGENCY 20%	$ 835,859.78					
			OVERHEAD 10%	$ 417,929.89					
			PROFIT 8%	$ 434,647.08					
			TOTAL COST						$ 5,867,736
spat	EA	675000000	$ 0.010	$ 6,750,000.00		$ -		$ -	
Mob/Demob	HR	9			$ 172.98	$ 1,556.82	$ 118.83	$ 1,069.47	
barge delivery	HR	9		$ -	$ 172.98	$ 1,556.82	$ 151.41	$ 1,362.69	
spat planting	EA	675000000		$ -	$ 0.001	$ 632,475.00		$ -	
Turbidity control	LF	8350	$ 0.69	$ 5,761.50	$ 0.15	$ 1,252.50	$ 0.39	$ 3,256.50	
			MATERIAL SUBTOTAL	$ 6,755,761.50	***LABOR SUBTOTAL***	$ 636,841.14	***EQUIP SUBTOTAL***	$ 5,688.66	
			SALES TAX (MATERIALS) 5%	$ 337,788.08	***Labor Insurance 32%***	$ 203,789.16			
			SUBTOTALS	$ 7,093,549.58		$ 840,630.30		$ 5,688.66	
			TOTAL COST	$ 7,939,868.54					
			CONTIGENCY 20%	$ 1,587,973.71					
			OVERHEAD 10%	$ 793,986.85					
			PROFIT 8%	$ 825,746.33					
			TOTAL COST						$ 11,147,575

APPENDIX H: Public Review

H-1: PRESS RELEASES

US Army Corps
of Engineers ®
Norfolk District
Baltimore District

News Release

Contact: Pamela Spaugy
Phone: (757) 510-6398

FOR IMMEDIATE RELEASE
February 13, 2012
01-12

Public invited!

Army Corps to host public meetings for native oyster restoration plans

In April, the Army Corps of Engineers will host three public meetings - two on the Eastern Shore in Maryland and one in Hampton, VA, to talk about a master plan to restore the population of native oysters in Maryland and Virginia tributaries.

Since the turn of the 20th century, oyster populations have declined dramatically, largely due to disease, overharvesting, loss of habitat, and degraded water quality. Oyster restoration is critical to the Chesapeake Bay ecosystem and is a high priority for Maryland and the Commonwealth of Virginia.

The Native Oyster Restoration Master Plan is the U.S. Army Corps of Engineers' plan for large-scale, science-based oyster restoration throughout the Chesapeake Bay and its tributaries. The public meetings will be an opportunity for the public to ask questions and provide feedback. Members of the Norfolk and Baltimore district's oyster teams will be present at all meetings.

USACE will also be using Social Media via Facebook (http://www.facebook.com/NAOonFB). Questions posted during the meeting(s) will be shared and discussed at the public meetings and responses will be posted on Facebook. People can also email questions and comments prior to the meetings to: NativeOysterRestMasterPlan@usace.army.mil. Public meeting dates and locations are:

Maryland
- April 10 from 3-8PM
The Philip Merrill Environmental Center (Chesapeake Bay Foundation)
6 Herndon Ave., Annapolis MD 21403

Maryland
- April 19 from 3-8PM
Chesapeake College (Route 50)
1000 College Circle, Wye Mills MD 21679

Virginia
- April 17 from 4-9PM
Thomas Nelson Community College
99 Thomas Nelson Drive, Hampton VA 23666

The master plan examines and evaluates the problems and opportunities related to oyster restoration and formulates plans for implementing large-scale Bay-wide restoration. Restoration plans recommended by USACE's master plan have been developed in coordination with the State of Maryland, the Commonwealth of Virginia, National Oceanic and Atmospheric Administration (NOAA), Environmental Protection Agency (EPA), U.S. Fish and Wildlife Service (USFWS), and Chesapeake Bay Foundation (CBF). The long-term goal is to restore an abundant, self-sustaining oyster population that performs important ecological functions such as providing reef community habitat, nutrient cycling, spatial connectivity, and water filtration, among others, and contributes to oyster fishery.

Media queries for Maryland: Please call Ashley Williams at 410-962-2809.
Media queries for Virginia: Please call Pam Spaugy at 757-510-6398.

--30--

NEWS RELEASE

U.S. ARMY CORPS OF ENGINEERS
Baltimore District
Norfolk District

BUILDING STRONG®

For Immediate Release:
Date: March 29, 2012
Release # 12-05

FOR IMMEDIATE RELEASE

Corps of Engineers releases Native Oyster Restoration Master Plan; Hosts open houses

In April, the U.S. Army Corps of Engineers will host three open houses – one on the Western Shore in Maryland, one on the Eastern Shore in Maryland, and one in Hampton, VA – to discuss the Corps' master plan to restore the population of native oysters in Maryland and Virginia tributaries.

Representatives from the Baltimore and Norfolk districts will be in attendance at each meeting to share information and receive public input. Each open house will include a formal presentation that discusses the specifics of the plan, and will also allow participants to learn about the project and share their thoughts.

Since the turn of the 20th century, oyster populations in the Chesapeake Bay have declined dramatically, largely due to disease, overharvesting, loss of habitat, and degraded water quality.

The Native Oyster Restoration Master Plan is USACE's strategy for large-scale, science-based oyster restoration throughout the Chesapeake Bay and its tributaries. Restoration plans recommended by USACE's master plan have been developed in coordination with the State of Maryland, the Commonwealth of Virginia, the National Oceanic and Atmospheric Administration, the U.S. Environmental Protection Agency, the U.S. Fish and Wildlife Service, the Potomac River Fisheries Commission, The Nature Conservancy, and the Chesapeake Bay Foundation.

The long-term goal is to restore an abundant, self-sustaining oyster population that performs important ecological functions such as providing reef community habitat, nutrient cycling, spatial connectivity, and water filtration, among others, and contributes to the oyster fishery.

To review the Native Oyster Restoration Master Plan, please visit:
http://www.nao.usace.army.mil/news/20120329_PublicMeetingsOysterRestoration.asp

Public meeting dates and locations are included below. Individuals unable to attend are encouraged to submit input at NativeOysterRestMasterPlan@usace.army.mil or the Norfolk District Facebook page www.facebook.com/NAOonFB. The public meetings will also be viewable online via Livestream. If you are unable to attend the meeting(s), please visit: http://www.livestream.com/usaceoysters/.

Media queries for Maryland:
Ashley A. Williams
Public Affairs Specialist
(410) 962-9015
ashley.a.williams@usace.army.mil

Media queries for Virginia:
Pamela K. Spaugy
Deputy Public Affairs Officer
(757) 510-6398
pam.k.spaugy@uscae.army.mil

Maryland – Western Shore
April 10 from 3-8 p.m. (Formal presentation starts at 6:30 p.m.)
The Philip Merrill Environmental Center (Chesapeake Bay Foundation)
6 Herndon Ave., Annapolis MD 21403

Maryland – Eastern Shore
April 19 from 3-8 p.m. (Formal presentation starts at 6:30 p.m.)
Chesapeake College (Route 50)
1000 College Circle, Wye Mills MD 21679

Virginia
April 17 from 5:30-9 p.m. (Formal presentation starts at 6:30 p.m.)
Thomas Nelson Community College
99 Thomas Nelson Drive, Hampton VA 23666

Media queries for Maryland:
Ashley A. Williams
Public Affairs Specialist
(410) 962-9015
ashley.a.williams@usace.army.mil

Media queries for Virginia:
Pamela K. Spaugy
Deputy Public Affairs Officer
(757) 510-6398
pam.k.spaugy@uscae.army.mil

H-2: PUBLIC COMMENTS AND USACE RESPONSES

OYSTER MASTER PLAN PUBLIC COMMENTS								
	Name	Affiliation	Method/Date	Section	Page	Topic	Comment	Response
1	G.Hansell	Public	Email Date (20 April 12)			Working reefs to avoid sedimentation	*See Attachment for full comment Does your plan include, in a closely controlled way, working some of the reefs as a way to compare health and growth to "pure sanctuaries"? If not, why not?	*See Attachment for full response. As far as working reefs to avoid sedimentation, there is no evidence that that is an effective technique.
2	G.Hansell	Public	Email Date (20 April 12)			Funding	*See Attachment for full comment No contingency plan to cope with funding cutbacks etc. is mentioned. There should be one.	*See Attachment for full response. Because of the vagaries of funding, we need to be very careful to select sites for our projects that will have the greatest chance for success and the greatest impact to surrounding areas.
3	G.Hansell	Public	Email Date (20 April 12)			Monitoring frequency	*See Attachment for full comment Interim goals, specific measurements, and milestone reports (including specific measurements and dates) should be added.	*See Attachment for full response. Any oyster spat that are deployed are usually surveyed within a year to determine survival rates We will also assess our projects after 3 years.
4	G.Hansell	Public	Email Date (20 April 12)			Survival rates	I'd be very interested to learn the definitions of survival rates and measurement methods.	*See Attachment for full response. Regarding the differences in survival rates, the 80% survival rate most likely applies to the survival of spat in the hatchery, whereas the 80% mortality may refer to the spat after they are placed on an oyster bar. Survival rates are highly variable and depend on water quality and predation. Also, high mortality for very young bivalves in the field is natural. Survival rates are determined by counting the number of live and dead oysters.
5	G.Hansell	Public	Email Date (20 April 12)			Poaching	Poaching is the major problem in sanctuaries	*See Attachment for full response. Poaching is indeed a concern, although it is difficult to quantify. We are making efforts to decrease poaching by increasing patrols by the Natural Resources Police and increasing penalties.
6	W.Flemming	Public/(VA)	Email - 20 Apr-2012			Sanctuaries (against it)	*See Attachment for full comment It is my opinion that the Army Corps of Engineers should not create sanctuary reefs that remain off limits in perpetuity to the state governments or the citizens of the respective states involved is inappropriate and unwise.	Currently, oyster populations in the Bay are a fraction of 1%. Oyster populations and habitat have been decimated by overharvesting, disease, and water quality issues. Sea level rise and ocean acidification are growing problems facing any calcifying reef building organism, such as oysters. There has yet to be demonstrated a wild oyster fishery that is truly self-sustaining, once dredges and tongs are used on oyster habitat, it is damaged and requires ongoing maintenance to keep it viable. No reef restored to date has produced enough shell to sustain itself if harvested. Nor is this likely to happen in the future. The same holds true for a restored reef being a source of shell for new reefs. If restored reefs do produce shell in excess of basic maintenance needs, this shell will, over time, increase the vertical relief and horizontal extent of the reef, increasing its areal coverage over the bottom. Oyster restoration is a difficult endeavor and one which may require some maintenance, even for sanctuaries, until oyster populations on them grow large enough to compensate for natural impacts. The US Army Corps will not "unilaterally seize" any areas of Chesapeake Bay or its tributaries. Sanctuaries remain state-owned bottom and the states would agree to maintaining the restored reefs as permanent sanctuaries prior to the reefs being built. It will be the long-term responsibility of the States to protect the sanctuary status of the reefs.

OYSTER MASTER PLAN PUBLIC COMMENTS

	Name	Affiliation	Method/Date	Section	Page	Topic	Comment	Response
7	W.Flemming	Public/(VA)	Email - 20 Apr-2012			Buy Back Oyster Shell as a Recycled Commodity:	*See Attachment for full comment. It would be valuable in the restoration of the oyster beds in the Virginia and Maryland waterways if processes were promoted to return a much larger percentage of oyster shell back to the waters where they originated. This can be promoted and encouraged by giving recycled oyster shell a monetary value in the same way that glass bottles and aluminum cans have a monetary value. I think that the U.S. Army Corps of Engineers (USACoE) could increase the recycled value of oyster shell in a variety of ways.	Shells are a valuable commodity. They are extensively used in state-run "repletion" programs and shells derived from oyster shucking are typically used to maintain harvest grounds in the wild oyster fishery. Such shells have been purchased with state taxpayer funds though in recent years, Federal funds have been used as well. Shell recycling programs have been initiated in several cities in Hampton Roads and this program is expanding over time. These programs are being run by non-profit environmental groups to date.
8	W.Flemming	Public/(VA)	Email - 20 Apr-2012			Proposal for selective harvesting vs. permanent sanctuaries	*See Attachment for full comment	While selective harvesting, if divers were used, would do less damage than tonging or dredging restored oyster habitat, the uncertainty regarding establishing self-sustaining populations makes such a management measure extremely risky and likely to push the restored oyster reefs into a negative trajectory. In fishery management throughout the world, it has been noted that it is better to have set aside sanctuaries free from fishing pressure coupled with more intensively managed fished areas when a fished population is at low levels. Such is certainly the case with native oysters in the Bay.
9	R. Midgette	Public/(VA)	Email - 13 April 12			Questions about Sedimentation	Would it be more cost and environmentally effective to remove the silt that covers the now dead and smothered oyster beds that was healthy and thriving prior to heavy development .	The Bay and its tributaries have unfortunately been permanently altered by terrestrial-derived sediment deposition due to centuries of deforestation, agriculture, and urbanization of the Bay watershed. It would likely be cost prohibitive to attempt to dredge the massive quantities of silt now deposited in the Chesapeake bay and its tributaries. It is far more cost-effective to instead locate remaining suitable bottom and construct new reefs upon them in most cases.
10	R. Midgette	Public/(VA)	Email - 13 April 12			Questions about Sedimentation	Doesn't this 2 to 4 feet of silt at the marsh line and 6 or more feet in the smaller natural channels make any attempt to reestablish healthy sustainable oyster colonies that historically existed from bank to bank in these smaller tributaries and doesn't the silt migration also greatly hinder restoration efforts down stream.	In the Lynnhaven River, most areas that once had oyster reefs now have several feet of silt on top, and it would be very costly and difficult to remove this material. There may be cases where removing thin layers of sediment from formerly productive oyster reefs might be feasible, but in these cases the sediment would likely be only a few inches thick and even then, new material would have to be put down to raise the relief of the reef to ensure it is not blanketed by sediment again.
11	R. Midgette	Public/(VA)	Email - 13 April 12			Questions about Sedimentation	Wouldn't a from the top down restoration effort that exposes the older native oyster beds, that then could be used for reestablishing new enervations without the cost of supplying other costly hard attachment substrates.	See Response to comment #10.
12	R. Midgette	Public/(VA)	Email - 13 April 12			Questions about Sedimentation	As silt levels have risen the mud flats farther out and up along the mash lines does this not expose oysters in these areas too extend out of water exposure at low tide that prohibits their ability to stabilize the erosion of the marsh line and its habitat.	Marshes can indeed by stabilized by near shore oyster reefs, and in some areas they already are in the Lynnhaven River. Any future oyster restoration efforts in the Lynnhaven should consider construction of more such reef habitat in order to reduce shoreline erosion and protect remaining wetlands.

OYSTER MASTER PLAN PUBLIC COMMENTS								
	Name	Affiliation	Method/Date	Section	Page	Topic	Comment	Response
13	R. Midgette	Public/(VA)	Email - 13 April 12			Questions about Sedimentation	Are any of the funds for restoration or other funding avenues available for cities and there property owners to stabilize soils and control there erosion problems as well as our beneficial waterway dredging projects that are now in there first steps of planning, and founded using (SSD's) Special Service tax District money. any attempt to reestablish healthy sustainable oyster colonies that historically existed from bank to bank in these smaller tributaries and doesn't the silt migration also greatly hinder restoration efforts down stream.	The funding for the 704(b) oyster restoration authority does not include providing funds for property owners to stabilize soils and control erosion on their property.
14	J. Wamsley	Public/(VA)	Email - 17 April 12			Questions about acidity	Efforts to restore proper acidity for oyster recovery are not clear in plan.	Ocean acidification is the lowering of pH due to increases in atmospheric CO2 and a growing concern due to its impact on marine life, especially shell producing organisms like oysters, which can be negatively affected by acidification. Such impacts are just now being studied and some effects on oysters have been noted. Whether this will have a strong negative impact if the water continues to acidify as CO2 increases has yet to be seen but is a concern. Oysters have the capacity to fix carbon in their shells long-term, though this very action (calcification) can lower local pH though this can be ameliorated by local phytoplankton populations which consume the byproducts of calcification via photosynthesis. Ultimately, oysters may be able to help ameliorate rising carbon levels in local waters if they can survive under more acidic conditions. Available data indicates that they can, however shells may be thinner and growth rates lower as oysters direct more energy into shell formation. Ocean acidification is a global process beyond the scope of this restoration study to address. Short term, actions that can be taken include avoiding waters most likely to experience the greatest drop in pH and maintaining the reefs as sanctuaries, such that the oysters can form hard reefs where, even if there shells are thinner, would still have significant protection from predation. Ocean acidification is a global issue and other than trying to implement large sanctuaries which could potentially exert some local influence within tributaries or the Bay itself there is little USACE can do under this program.
15		City of VA Beach	Letter- 17 May 12			Support of plan/potential partnership	* See Attachment for Entire comment Agrees with location of Lynnhaven river as a Tier 1 trib. Interested in partnering with USACE to construct reefs.	We thank the City of Virginia beach for their support of the Corps' 704(b) oyster restoration program and hope we can implement another phase of oyster reef construction with you as our partner.

OYSTER MASTER PLAN PUBLIC COMMENTS								
	Name	**Affiliation**	**Method/Date**	**Section**	**Page**	**Topic**	**Comment**	**Response**
16	M. Meritt	UMCES	Email - 24 May 12			Concern if we can really create self-sustaining populations	* See Attachment for Entire comment I believe it is unreasonable to predict that we will see a “self-sustaining” oyster population in all the tributaries as is either stated or implied in the COE document. That does not mean that tributaries unlikely to generate local recruitment events should always be avoided. There may be other important metrics that can be accomplished in those tributaries and those should be highlighted without the implication that they will eventually become self-sustaining. To mislead the public like this will only lead to further distrust and eventually adversely impact funding when these projects fail to deliver natural oyster spat to the local bars. The lack of sufficient quantities of oyster shell to use in the various oyster restoration projects is a major impediment to success. We are spending much more trying to find and deploy alternative materials in what is at best a stop-gap attempt to accomplish our goals. We need to come to grips with the fact that there must be huge deposits of buried shell scattered throughout the Bay in the footsteps of the once productive Yates bars and Baylor Grounds.	*See Attachement for full response. 1. With respect to 'self-sustainability' goal- USACE explained that we must formulate to achieve sustainability and ultimately self-sustainability. These are USACE objectives for all projects. We agree that conditions in the Chesapeake Bay today are less conducive to recruitment than in previous decades. We have screened for suitable sites based on water quality, plan to provide hard structure that is elevated off the bottom to address sedimentation and loss of habitat, and we lay out a disease strategy. Scale- habitat and broodstock- are the two factors that we can take direct action to restore, and have been deficiently addressed in previous restoration efforts. We are not predicting that we will definitively see ‘self-sustaining’ oyster populations in all the tributaries. There are no guarantees and there is a greater risk in low salinity tributaries that we may not succeed. Also, we may achieve interim goals of improved water quality, reef habitat, etc., while not reaching self-sustainability. However, ‘self-sustaining’ is the ultimate goal that plans will be formulated to achieve. The Oyster Metrics Workgroup of the Fisheries Goal Implementation Team has outlined metrics to use to determine success. It is not our intention or desire to mislead anyone. We gain nothing by doing that. We will add text to further explain the challenges that will face achieving ‘self-sustainability’ in low salinity tributaries and clarify that the risk of failure is greater in these tributaries. We will add a table that identifies the major risks/challenges in each tributary. We will also add discussion highlighting the likelihood that ecosystem servic (habitat, long-surviving oyster populations, water quality filtration, etc.) can be achieved even if we fall short of the self-sustainability goal. 2. We are aware of the potential to reclaim previously placed dredged fossil shell and support this. MDNR has had the lead on this and are undertaking efforts to further our understanding of how this might be accomplished. We have maps tha identify where plantings occurred and the quantity of shell placed. MDNR is working to develop methods to identify where the buried shell is located, how to recover it, the cost, and the recovery efficiency. Initial investigations by DNR in Harris Creek sugges that shell reclamation will not be as easy as once thought. We have wanted to incorporate shell reclamation into our plans, but the science has not developed as quickly as we would have liked. We will discuss the regulatory impediments with the Regulatory Division of USACE Baltimore as well as work with DNR on shell reclamation efforts. Additionally, we are pursuing mine deposits of marine shell in Virginia that could prove to be a suitable (and likely, more publicly preferred) substrate than currently used alternate substrates such as granite.

OYSTER MASTER PLAN PUBLIC COMMENTS								
	Name	Affiliation	Method/Date	Section	Page	Topic	Comment	Response
17	D. Olson	CEQ	Email - 26 Apr 12			Funding	How would the costs be split among stakeholders (cost-sharing)?	Cost-sharing under the current project authority (Section 704(b) of WRDA 1986) is 75% Federal and 25% non-Federal.
18	D. Olson	CEQ	Email - 26 Apr 12			Funding	How much money does the corps have now for oyster restoration in the Bay and what is the amount of new money needed, and in which budget category?	In FY12, USACE received $4.9 million which was split roughly 50-50 between the Maryland and Virginia activities. The oyster restoration program is in the president's FY13 budget for $5 million. Given the constraints on other resources (substrate, non-Federal in-kind services, spat), this amount of funding is appropriate for the project. The project comes under the ecosystem restoration business line in our Construction appropriation.
19	D. Olson	CEQ	Email - 26 Apr 12			Funding	Through the WRDA – Is there money available now? How much does it relate to how they plan for? Does the corps have a budget DOD appropriations for this plan?	Yes 4.9 million split roughly 50-50 between Maryland and Virginia activities. The funds are being used in accordance with the USACE master plan and other Chesapeake Bay initiatives (e.g., Executive Order 13508). Right now, our funding comes through the USACE Construction (3122) appropriation and the Chesapeake Bay Oyster Recovery, MD and VA line item.
20	D. Olson	CEQ	Email - 26 Apr 12			Funding	Is there state match available?	Currently, the state match is in the form of in-kind services. In Maryland, the in-kind is primarily through the provision of spat fror the state-owned hatcheries. In Virginia, the in-kind was the provision of dredged fossil shell. I can't speak to specifics in Virginia, but I do know that the dredged shell is a scarce resource with many demands on it.
21	D. Olson	CEQ	Email - 2 May 12			Typo	By the way, I noticed a typo on page 215. In the table, 2nd row, third column it reads 8,000-15,8. Is that supposed to be 15,800	Concur. Correction made.
22	A. Rasmussen	Public (MD)	Email - 8 Apr 12				We have a farm with a large cove on the Chesapeake Bay. Is this kind of location a possibility for establishing oyster beds or are they best established in mud flats on tributaries of the Bay? I am interested in attending the April 10th conference at the Chesapeake Bay Foundation but do not want to attend if our location is not an ideal setting.	USACE discussed this issue with the commenter at the April 10th meeting. Their cove is on the Bay proper. We discussed with them the challenges to establishing oyster beds in that environment. They area is not one targeted by the master plan for restoration They were going to continue to pursue additional information and opportunities that might tie oyster restoration to shoreline protection.
23		CBO- NOAA	Email - 18 May 12	Exec Summary	2	Typo	The purpose of this master plan is to provide a long-term strategy for USACE's role in restoring large-scale native oyster populations in the Chesapeake Bay to achieve ecological success. ~~It is conceivable that the~~ master plan will serve as a foundation, along with plans developed by other federal agencies, to work towards achieving the oyster restoration outcome ~~goals~~ established by the *Chesapeake Bay Protection and Restoration Executive Order* (E.O. 13508) to restore native oyster habitat and populations in 20 tributaries by 2025	Concur. Correction made.
24		CBO-NOAA	Email - 18 May 12			Clarifying goals of NORMP vs. EO	The cost estimates for native oyster restoration are extremely high and may lead to a false perception and misunderstanding as to budget estimates to achieve the EO native oyster restoration outcome. The Army Corps used 'geographically-distinct sub-segments' of rivers and the main stem in its analysis. Of those, 10 were in MD and 8 in VA. Those 'sub-segments' are much bigger than what we are now looking at per the Oyster Metrics Team. For example, the entire Potomac is one sub-segment; the Rappahannock is another; the Oyster Metrics Team report recommended starting with Harris or Lynnhaven size tributaries, which are significantly smaller than the above referenced Potomac.	Sowers discussed this comment with S. Westby of NOAA on July 5, 2012. As a result of discussions, NOAA requested that the large and medium sized tributaries that had distinct sub-segments identified be kep as DSS in the final tiered list and for cost estimating purposes. This action will expand the tributary list past the E.O. 20 tribs. E.O. implementation costs will be identified separately than 'full implementation'. Pending team approval, that change will be made to the final presentation of the tiered list and the cost estimates. Additionally, NOAA and USACE agreed to try to show the projected cost range in a figure. USACE, upon further consideration, is going to present the costs as 3 potential 'scenarios': 1. full implementation of all tributaries, 2. salinity-based implementation where low salinity tributaries require more habitat (high target) and high salinity tributaries require less (low target), and 3. E.O. implementation. A second image will present the typical implementation cost range based on tributary size (small, medium, and large). These changes will be made to section 5.7- costs, sec 9- conclusion, and the Executive Summary.

OYSTER MASTER PLAN PUBLIC COMMENTS								
	Name	**Affiliation**	**Method/Date**	**Section**	**Page**	**Topic**	**Comment**	**Response**
25		CBO-NOAA	Email - 18 May 12			Clarifying goals of NORMP vs. EO	Preliminary estimates for Harris Creek, Maryland reflect that our restoration goal of 300-600 acres would cost on the order of $20-$40 million. The Corps should consider adding a footnote or otherwise clarifying expectations with respect to native oyster restoration goals/outcomes and costs.	Agree. Discussion will be added to appropriate sections- likely 5.7, 9, and Executive Summary- to present specific cost estimates for Harris ($26 million) and Lynnhaven ($12 million).
26	K. Forget	Lynnhaven River NOW	Letter - 7 May 2012			Support Master plan	* See Attachment for Entire comment Support for alternate substrate usage. Would like to partner in design and construction with USACE.	We thank the LRN for their support of the Corps' Master Plan and of our oyster restoration program. We look forward to continuing to work with LRN as a stakeholder in coordination with the City of Virginia Beach to execute future oyster construction projects.
27	F. DiGialleonardo	Corsica River Conservancy	Letter- 12 April 12				* See Attachment for Entire comment Corsica River should be a a candidate for oyster restoration Support for alternate substrate usage. Would like to partner in design and construction with USACE.	Comment Noted. At this time datat shows that the Corsica River is a Tier 2 site so it will not be a priority for restoration.

Public Review
Consolidated comments

Chesapeake Oyster Restoration

I quickly read the posters which will be used at the Chesapeake College meeting on April 19, 2012 regarding oyster in the Chesapeake, specifically Harris Creek. They are shown at
www.dnr.state.md.us/fisheries/pdfs/Harris_Creek_open_house_031512.pdf
I will not be able to attend the open house so I'm writing some comments and questions. I may have missed or misunderstood some important points but what I understand is:

The "Native Oyster Master Plan" is (or will be available) this month. It is a 272 page document according to a newspaper article which also cited an estimated total cost of $7.85 billion. <u>I would very much like to receive a paper copy of that report!</u>

The "Clear Goal" is to restore the oyster population in 20 tributaries of the Chesapeake by 2025

The Current Focus of the Army Corps of Engineers is ecosystem restoration.

$2 million has been allocated to restore 9 sites encompassing 22 acres under Harris Creek.

"Restored reef" is stated as: Six years after restoration activity the reef should have at least 15 oysters per square meter, preferably 50, from at least two year classes. Reef structure should also persist, or preferably expand, over six years.

"Restored tributary" is stated as: 50% - 100% of currently restorable bottom is covered with restored oyster reefs.

Harris Creek is one of the first choices for restoration because it has moderate salinity which allows good reproduction yet still shows low disease levels. It also has larvae friendly flow patterns.

Comments and Questions I have are:

As an engineer and scientist (retired) I have a great appreciation for the complexities, difficulties, and long time span of "natural science" but do not accept that as a valid reason to avoid establishing short term milestones and goals. The long term goals are clearly stated and the measurements of end results are reasonably specific (assuming that the oyster density pertains only to healthy ones) but the details of milestones and measurements are missing. The restoration of Harris Creek will take several years and then it will be another 6 years before success will be determined. It does not seem reasonable to me to spend $2 million and wait nearly a decade before determining success or failure. Interim goals, specific measurements, and milestone reports (including specific measurements and dates) should be added.

Watermen with whom I've spoken recently claim that untouched sanctuaries are subject to siltation and disease while reefs which are "worked" stay healthy. Does your plan include, in a closely controlled way, working some of the reefs as a way to compare health and growth to "pure sanctuaries"? If not, why not?

I've recently attended a Christine Keiner talk at Washington College on her book "The Oyster Question in the Chesapeake Bay" where she claims the primary cause of the problems is political. I'm concerned that the restoration effort will be subject to similar issues. No contingency plan to cope with funding cutbacks etc. is mentioned. There should be one.

I've also heard from Stephanie Tobash Alexander at the Horn Point Lab and read in the newspaper that "survival rates" are very high - - 80% to 92% but I've heard from watermen that 80% of the hatchery spat die within a few weeks. I'd be very interested to learn the definitions of survival rates and measurement methods.

I've also read that poaching is the major problem in sanctuaries. But at Christine Keiner's talk Larry Simns pointed out that HPL has put out hundreds of millions of spat on shell for several years (I recollect that the demonstration piles and posters I saw at HPL recently show more than 700 million a year for at least the last four years) and that if the high survival rates are accurate and watermen were to poach most of those oysters two things would have happened: their boats would sink, and the markets would be so flooded that they couldn't sell the oysters. Any "plan" needs to address these conflicting viewpoints and develop credible measurements.

I'm sorry that I won't be at Chesapeake College Thursday to meet the presenters but hope that these questions and comments are of some use as you go forward with the very worthy goal of restoring oysters to the Chesapeake Bay. George Hansell, ghansell@verizon.net, 11 Fox Lane, Newark, DE 19711, April 17, 2012

Compton, Anna M NAB

From: Sowers, Angela NAB
Sent: Thursday, May 24, 2012 9:42 AM
To: Compton, Anna M NAB
Subject: OysterMP- Public comments-FW: Chesapeake College Oyster Restoration meeting (UNCLASSIFIED)

Classification: UNCLASSIFIED
Caveats: NONE

-----Original Message-----
From: O'Neill, Claire D NAB02
Sent: Friday, April 20, 2012 11:14 AM
To: Sowers, Angela NAB02
Subject: FW: Chesapeake College Oyster Restoration meeting (UNCLASSIFIED)

Classification: UNCLASSIFIED
Caveats: NONE

Angie -- FYI

-----Original Message-----
From: Weissberger, Eric [mailto:EWeissberger@dnr.state.md.us]
Sent: Thursday, April 19, 2012 9:04 AM
To: 'George Hansell'
Cc: 'Stephanie Westby'; O'Neill, Claire D NAB02
Subject: RE: Chesapeake College Oyster Restoration meeting

Dear Mr. Hansell:

Thank you for your recent e-mail regarding oyster restoration in Chesapeake Bay. The Army Corps master plan is available online at http://www.nao.usace.army.mil/News/20120329_PublicMeetingsOysterRestoration.asp.

Regarding the frequency of monitoring, we will indeed have interim measurements of the success of the restoration projects. Any oyster spat that are deployed are usually surveyed within a year to determine survival rates. We will also assess our projects after 3 years to determine how many more oysters must be added to achieve our goal densities.

As far as working reefs to avoid sedimentation, there is no evidence that that is an effective technique. Any sediment that is knocked off the oysters just settles back down. Natural oyster reefs have vertical structure that places the oysters up in the water column where currents are stronger and can sweep sediment away. Unfortunately a century of intensive harvesting has leveled the vertical structure of many reefs. Our restoration plan calls for increasing the height of the constructed reefs above the surrounding bottom to get the oysters up into any current.

We realize that the success of our restoration program is contingent upon funding. Because of the vagaries of funding, we need to be very careful to select sites for our projects that will have the greatest chance for success and the greatest impact to surrounding areas. We are focusing our initial efforts on areas of intermediate salinity, balancing the higher reproduction found in high salinity areas with the higher disease rates found in low salinity areas. We are also using larval transport models developed by scientists at the University of Maryland to place restoration projects in places where the oysters will not only reseed their beds, but supply larvae to surrounding reefs.

Regarding the differences in survival rates, the 80% survival rate most likely applies to the survival of spat in the hatchery, whereas the 80% mortality may refer to the spat after they are placed on an oyster bar. Survival rates are highly variable and depend on water quality and predation. Also, high mortality for very young bivalves in the field is natural. Survival rates are determined by counting the number of live and dead oysters.

Poaching is indeed a concern, although it is difficult to quantify. We are making efforts to decrease poaching by increasing patrols by the Natural Resources Police and increasing penalties.

I hope I've succeeded in answering your questions. If you have any further questions, please don't hesitate to contact me.

Regards,
Eric Weissberger

From: George Hansell [mailto:ghansell@verizon.net]
Sent: Tuesday, April 17, 2012 4:03 PM
To: Weissberger, Eric
Subject: Fw: Chesapeake College Oyster Restoration meeting

Hi Eric, I hope this reaches you now that I corrected your name. George

----- Original Message -----

From: George Hansell <mailto:ghansell@verizon.net>

To: eweissenberger@dnr.state.md.us

Sent: Tuesday, April 17, 2012 3:45 PM

Subject: Fw: Chesapeake College Oyster Restoration meeting

Hi Eric, I hope this reaches you now that I put you in the correct state. George

----- Original Message -----

From: George Hansell <mailto:ghansell@verizon.net>

To: eweissenberger@dnr.state.me.us ; claire.do'neill@usace.army.mil ; stephanie.westby@noaa.gov

Sent: Tuesday, April 17, 2012 3:24 PM

Subject: Chesapeake College Oyster Restoration meeting

Hi Eric, Claire, and Stephanie, I got your names and addresses from the note on the 'net about this meeting and hope I got them correct. I can't get there Thursday but have been very interested in oysters in the Bay for several years (being retired allows that luxury) and have visited and spoken with several folks and sites about the situation in the last few years. I'm also a three time failed "oyster farmer" from my dock on the upper Bay (above the Sasafras) but have given up due to low salinity. I'll attach a note I wrote as an attempt to summarize what I learned from your posters and the comments and questions I have. I hope you find my questions worthy of a reply. Thanks in advance. George Hansell

Classification: UNCLASSIFIED
Caveats: NONE

Classification: UNCLASSIFIED
Caveats: NONE

Public comment:
Numbers 6-8

Compton, Anna M NAB

From: William Fleming [wwfleming@hotmail.com]
Sent: Thursday, April 19, 2012 11:24 PM
To: NativeOysterRestMasterPlan
Subject: Comment regarding Native Oyster Restoration Master Plan
Attachments: Comment One regarding Native Oyster Master Plan Meeting.docx

(Note: The text is attached in Word 2010 format)

Comment One, regarding Native Oyster Master Plan Meeting

Name: William W. Fleming, PhD

Address: 1324 Five Point Road, Virginia Beach, VA 23454-1931

E-mail: wwfleming@hotmail.com <mailto:wwfleming@hotmail.com>

Phone Number: Home: (757) 481-4084; Mobile: (757) 450-4084

Expansion of Oyster Reefs: If oyster reefs are established and populated with viable native diploid oysters, the new oysters will build the oyster reef upward, but the desired outcome for oyster restoration is to expand the surface area of the reefs, not the depths. If a 1 foot thick layer of oyster shell reef is built up with 6 inches of new oysters, which may have a life span of three or four years, this shell could be used to increase the surface area of the reef. For example, if a restored reef of 100 acres were to increase in thickness by ¼ foot in 2 years, the shell of those oysters could be used to add a 1 foot thick addition of 25 acres (¼ foot x 100 acres= 25 acres), resulting in an increase in reef size from 100 acres to 125 acres. This could be done by periodically harvesting some of the mature oysters on the reef and then adding the resulting shell to the existing reef. If one were to use somewhat more conservative estimate, one could estimate that a 100 acre reef could be increased by 10% in 2 years or 5% a year by in situ harvesting of some of the oysters and recycling of the resulting shell generated by the native oysters.

To extend to multiple years the proposal for expansion of the reefs using self-generated shell, if 1000 acres of reefs were restored using fossil shell and if the self-generated shell were used to extend the reef by a conservative estimate of 5% each year, there would be about 1,700 acres of reef in 10 years! In 20 years there total surface area of restored reef could have expanded from 1,000 acres to 2,800 acres. This assumes that there is no loss of reef due to storms, currents, etc. This also assumes that all of the reefs are being continuously populated with new oyster spat during natural reproduction. This does not include any estimated new reef created by spat that sets in areas which did not originally have restoration reef. The compounding of the reef coverage is shown in the table below.

Year

Surface Area (acres)

New Reef Area (acres)

Total Surface Area (acres)

0

1,000

0

1,000

1

1,000

50

1,050

2

1,050

53

1,103

3

1,103

55

1,158

4

1,158

58

1,216

5

1,216

61

1,276

6

1,276

64

1,340

7

1,340

67

1,407

8

1,407

70

1,477

9

1,477

74

1,551

10

1,551

78

1,629

11

1,629

81

1,710

12

1,710

86

1,796

13

1,796

90

1,886

14

1,886

94

1,980

15

1,980

99

2,079

16

2,079

104

2,183

17

2,183

109

2,292

18

2,292

115

2,407

19

2,407

120

2,527

20

2,527

126

2,653

In order to harvest the shell to expand the reef, dredging or dragging should not be used because of its destructive effects to the reef. However, the use of oyster tongs or snorkel harvesting would be viable since the integrity of the reef could be maintained. A limit to the number of mature oysters that are culled per acre could be set in order to keep at a percentage of mature older oysters on the existing reefs.

Because there would be social and political resentment toward the idea of the Federal government taking state and public acreage in perpetuity, there could be socioeconomic benefits to harvesting some oysters and using the shell to expand the reefs. For example, if contracts were give out to state watermen allowing them to harvest a percentage of oysters with the guarantee that the shell would be returned to the perimeter of the reefs, there would be economic benefit for watermen, interest by the contractor in preventing poaching and destruction of these oyster beds by others, and additional local economic benefits to the economy of the states participating in the program.

Compton, Anna M NAB

From: William Fleming [wwfleming@hotmail.com]
Sent: Friday, April 20, 2012 12:05 AM
To: NativeOysterRestMasterPlan
Subject: Comment (2) regarding the Native Oyster Master Plan

Comment Two regarding Native Oyster Master Plan

Name: William W. Fleming, PhD

Address: 1324 Five Point Road, Virginia Beach, VA 23454-1931

E-mail: wwfleming@hotmail.com <mailto:wwfleming@hotmail.com>

Phone Number: Home: (757) 481-4084; Mobile: (757) 450-4084

Arguments Against Sanctuary Reefs in Perpetuity:

It is my opinion that the Army Corps of Engineers should not create sanctuary reefs that remain off limits in perpetuity to the state governments or the citizens of the respective states involved is inappropriate and unwise.

1. The idea that these areas should be taken in perpetuity suggests that the project itself will not be successful and the reefs will never be restored. If the reefs are restored, then they would not need to be kept from the people in perpetuity.

2. I question whether the U.S. Army Corps of Engineers has the right to unilaterally seize these areas of the Chesapeake Bay or the waterways feeding the Chesapeake Bay without specific authority by the U.S. Congress.

3. The areas that might be made sanctuary reefs in perpetuity, if this is even lawful, may not be appropriate as sanctuary reefs in the future as a result of changes in water flow, climate, storms, or the need to consider other changes such as the incorporation of subaqueous vegetation (SAV).

4. If science or the common good indicates that the affected areas of the Chesapeake Bay should be redesigned for other purposes such as SAV beds, aquaculture, offshore wind farms, it is inappropriate for the USACoE to obstruct these changes in plans.

5. I question the assumptions that these proposed sanctuary reefs should be left alone and never harvested. For example, the beds could be a source of income to benefit the economies of the respective states. The reefs can also be a source of new oyster shell by which additional reefs may be created. It is illogical to think that the only source of shell for future reefs in the Chesapeake Bay or state waterways is from fossil shell.

6. The U.S. Army Corps of Engineers has completed many admirable projects, but it has also caused significant harm. For example, the alterations of the Florida everglades has hurt the ecosystems of that part of the United States, the under-engineered levies around New Orleans resulted in massive damage to the City of New Orleans, and the changes to the water

flow at the mouth of the Mississippi River has harmed the Mississippi delta and adversely impacted the ecosystem of that part of the Gulf Coast. Although the goal of restoring the native oyster beds in the Chesapeake Bay is, on the surface, admirable, it has not been determined that the idea of sanctuary reefs in perpetuity is the best or the only path to this objective.

7. The improvement of the water quality and the habitat of the Chesapeake Bay is not the soul responsibility of the U.S. Army Corps of Engineers. There are other Federal entities, such as the Environmental Protection Agency, that have a say in how the Chesapeake Bay and the states' waterways are regulated. There are state agencies that have important contributions that they can make as well. Therefore, it is improper for these sanctuary reefs in perpetuity to be under the unilateral supervision of the Corps of Engineers.

Consequently, I feel that these reefs should be created in a way that provides flexibility in use and duration. These reefs should be part of a cooperative and synergistic effort of all the stakeholders involved.

Compton, Anna M NAB

From: William Fleming [wwfleming@hotmail.com]
Sent: Friday, April 20, 2012 12:29 AM
To: NativeOysterRestMasterPlan
Subject: Comment (3) Regarding Native Oyster Master Plan
Attachments: Comment Three Regarding Native Oyster Master Plan Meeting.docx

Comment Three Regarding Native Oyster Master Plan Meeting

Name: William W. Fleming, PhD

Address: 1324 Five Point Road, Virginia Beach, VA 23454-1931

E-mail: wwfleming@hotmail.com <mailto:wwfleming@hotmail.com>

Phone Number: Home: (757) 481-4084; Mobile: (757) 450-4084

Suggestion to Buy Back Oyster Shell as a Recycled Commodity: The harvesting of oysters has increased significantly over the past five or more years. Thousands of bushels of oysters are being harvested, but much of the shell is not being returned to the Chesapeake Bay. Therefore, one of the major reasons why oyster habitat was destroyed, the removal of shell from the waterways, is still a problem.

It would be valuable in the restoration of the oyster beds in the Virginia and Maryland waterways if processes were promoted to return a much larger percentage of oyster shell back to the waters where they originated. This can be promoted and encouraged by giving recycled oyster shell a monetary value in the same way that glass bottles and aluminum cans have a monetary value. I think that the U.S. Army Corps of Engineers (USACoE) could increase the recycled value of oyster shell in a variety of ways. Here is a list of a few:

1. The USACoE could establish a program of buying back oyster shell from shucking houses and restaurants so that the shell can be returned to the waterways after being cleaned and sterilized. The watermen or seafood distributors could deliver oysters to the restaurants and shucking houses and pick up the recycled shell. The shell could be delivered to one of several small businesses that would clean and sterilize the shell before selling it to the USACoE to be returned to the waters and become new oyster reef.

2. The USACoE could establish standards and procedures for civilian contractors to prepare oyster shell for use as oyster reefs and establish contracts with these companies to buy the processed shell. There would be a resulting financial incentive for restaurants and shucking houses to sell return the shell via the oyster growers or distributors. This would result in increased income on the part of the restaurants, shucking companies, oyster shell processors, and perhaps others in the supply chain.

3. In the same way that glass bottles and aluminum cans are recycled because they have value, the USACoE could help establish a viable market for oyster shell, which is without a doubt a valuable commodity.

Public comment:
Numbers 9-13

Compton, Anna M NAB

From: Rmidgette [rmidgette@aol.com]
Sent: Friday, April 13, 2012 12:56 PM
To: NativeOysterRestMasterPlan; "<NativeOysterRestMasterPlan"@usace.army.mil
Subject: Comment for Virginia

I live on Buchannan creek, a contributary of the Eastern branch of the Lynnhaven River in Va Beach.

My questions.

1. Would it be more cost and environmentally effective to (make the first step of native oyster bed
restoration in these contributaries) remove the silt that covers the now dead and smothered oyster beds that was healthy and thriving
prior to heavy development. (on the Lynnhaven this would be the past 150 or so years)

2a. Doesn't this 2 to 4 feet of silt at the marsh line and 6 or more feet in the smaller natural channels make
any attempt to reestablish healthy sustainable oyster colonies that historically existed from bank to bank in these
smaller contributaries and doesn't the silt migration also greatly hinder restoration efforts down stream.

2b.Wouldn't a from the top down restoration effort that exposes the older native oyster beds, that then could be
used for reestablishing new generations without the cost of supplying other costly hard attachment substrates.

3. As silt levels have risen the mud flats farther out and up along the mash lines does this not expose oysters
in these areas too extend out of water exposure at low tide that prohibits their ability to stabilize the erosion
of the marsh line and its habitat.

4. Are any of the funds for restoration or other funding avenues available for cities and there property owners to stabilize soils
and control there erosion problems as well as our beneficial waterway dredging projects that are now in there first steps of planing,
and founded using (SSD's) Special Service tax District money.

Public comment:
Numbers 14

Compton, Anna M NAB

From: Jim Wamsley [jwamsley5@gmail.com]
Sent: Tuesday, April 17, 2012 10:50 AM
To: NativeOysterRestMasterPlan
Subject: Comment for Virginia

Efforts to restore proper acidity for oyster recovery are not clear in this plan.

James Wamsley
7450 Spring village Drive Apt 317
Springfield VA 22150

Public comment:
Number 15

City of Virginia Beach

VBgov.com

DEPARTMENT OF PUBLIC WORKS
WATER RESOURCES
(757)-385-4131
FAX (757) 385-5668
TTY: 711

MUNICIPAL CENTER
BUILDING NUMBER 2, ROOM 345
2405 COURTHOUSE DRIVE
VIRGINIA BEACH, VA 23456-9032

Date: May 17, 2012

Ms. Susan Conner
Norfolk District Corps of Engineers
803 Front Street
Norfolk, Virginia 23510

Dear Ms. Conner:

Re: Chesapeake Bay Oyster Recovery: Native Oyster Master Plan, Draft March 2012

On April 17, 2012, I attended the Corps of Engineers (Corps) Public Meeting concerning the Draft Corps' Master Plan to restore the native oyster to the Chesapeake Bay waters of Virginia and Maryland. I have reviewed the captioned Draft Master Plan and the City of Virginia Beach conceptually supports this Master Plan subject to further communication and further City review of subsequent actions including the need for and scheduling of funding or other commitments.

The heart of this report as it affects the City of Virginia Beach is that the Corps' Congressionally authorized Master Plan specifically includes the Lynnhaven River as a prime location for restoration of the native oyster, *Crassostrea virginica*, as the keystone organism needed for recovery of these waters. This restoration effort is in line with the efforts and goals espoused by the City Council to restore the Lynnhaven Watershed and is in keeping with many of the activities undertaken by the City's Citizens and various City Departments on a daily basis. We would like to evaluate our opportunity to participate in furtherance of this worthy goal.

The City wishes to thank the Corps for correctly locating the Lynnhaven River and its Watershed outside the James River Watershed. The City wishes to have its Broad Bay/Linkhorn Bay complex in the Lynnhaven Watershed included in the formal area for inclusion in the program area.

As a Tier 1 locality with active Citizen and Government interests and commitments in increasing the native oyster stock in the City's Waters, the City is interested in exploring partnering with the Corps for the construction and stocking of *Crassostrea virginica* reefs under this program by including the option of supplying its 25% match in the form of crushed concrete to the Corps specifications as well as oyster spat on shell.

Please advise me of the next steps that would be needed to meet the goal of expanding the range of *Crassostrea virginica* reefs in the City's Waters under this program. I am the City's technical lead on this matter and can be reached at 757-385-4783 or smclaugh@vbgov.com

Sincerely,

Stephen G. McLaughlin

Stephen G. McLaughlin, PE
Stormwater Project Manager

cc: John Fowler, PE, City Engineer
Phillip Roehrs, PE, Water Resources Manager
Bill Johnston, PE, VPDES Administrator

Public comment:
Number 16

From Press Release:
“ The long-term goal is to restore an abundant, self-sustaining oyster population that performs important ecological functions such as providing reef community habitat, nutrient cycling, spatial connectivity, and water filtration, among others, and contributes to the oyster fishery.” This is repeated in the document.

From the Exective Summary:

“This master plan represents the culmination of a highly intensive, transparent, and exhaustive effort to bring together state-of-the-art science, on the ground experience, and collaborative planning focusing on native oyster restoration in the Chesapeake Bay into one comprehensive and coordinated document. This effort, which builds on USACE’s *Final Programmatic Environmental Impact Statement for Oyster Restoration Including Use of Native and/or Non-Native Oyster* in 2009 (http://www.nao.usace.army.mil/OysterEIS/FINAL_PEIS/homepage.asp), is unprecedented in that it lays out the first comprehensive Bay-wide strategy for large-scale oyster restoration. Development of the document and the approaches laid out herein were accomplished painstakingly and with a thoroughness of purpose that this complex restoration challenge deserves. The authors and collaborators sought out the most up-to-date and credible sources of information to inform decision-making and plan formulation, including peer reviewed publications, and scientific and technical work accomplished by Bay experts, state partners, Federal collaborating agencies, non-government agencies, numerous stakeholders, and others with interest or expertise in native oyster restoration. Critical and controversial topics were isolated by the project team and analyzed through a series of Technical White Papers that were vetted among USACE, the project sponsors, and collaborating agencies. Intensive agency technical review of this document was accomplished by USACE with complementary reviews by other Federal and state partners to ensure technical quality and to address the full spectrum of technical and institutional concerns. Further public review of this document will complement the sound technical and institutional foundation on which this document has been built.”

“It is conceivable that the master plan will serve as a foundation, along with plans developed by other federal agencies, to work towards achieving the oyster restoration goals established by the *Chesapeake Bay Protection and Restoration Executive Order* (E.O. 13508).”

These two sections of the Executive Summary spend way too much time attempting to convince the reader of the “highly intensive”, transparent, and exhaustive effort”….. In fact, while there were meetings and comment periods, there seems to have been a very selective use of the comments. I am about to make one important comment below and attempt to back it up with data on natural recruitment. I have personally made this comment to COE personnel involved with this project before and apparently none of my comments were deemed of sound scientific principal to have found their way into this document.

While I have not read the entire document, my comments below center on the misleading language used in several places that could ultimately do more harm than good and for no apparent reason. Passages of the document have been included to illustrate my point that one important goal for each tributary is to establish a "self-sustaining" oyster population. I have provided data at the end that hopefully illustrates the problems with this assumption.

Selected Passages from Document:

"formulates plans to restore sustainable oyster populations throughout the Chesapeake Bay;"

"USACE recognizes that self-sustainability is a lofty goal. It will require focused and dedicated funding and strong political and public support over an extended period, likely decades. It will require the use of sanctuaries and the observance of sanctuary regulations. In addition to the long-term goal, the master plan defines near-term ecological restoration and fisheries management objectives. The ecological restoration objectives cover habitat for oysters and the reef community as well as ecosystem services."

"The master plan lays out a large-scale approach to oyster restoration on a tributary basis and proposes that 20 percent to 40 percent of historic habitat (equivalent to 8 percent to 16 percent of Yates/Baylor Grounds) be restored and protected as oyster sanctuary. The concentrated restoration efforts are necessary to have an impact on depleted oyster populations within a tributary. To accomplish tributary-level restoration, the master plan includes salinity-based strategies to address disease and jumpstart reproduction."

"The evaluation was largely performed using geographic information system (GIS) analyses. The master plan identifies that 19 (Tier 1) tributaries in the Chesapeake Bay are currently suitable for large-scale oyster restoration (Table ES-1). These tributaries are distributed throughout the Bay with 11 sites in Maryland and eight sites in Virginia, as shown in Figure ES-1. Tier 1 tributaries are the highest priority tributaries that demonstrate the historical, physical, and biological attributes necessary to provide the highest potential to develop self-sustaining populations of oysters."

"The remainder of the tributaries and mainstem Bay segments are classified as Tier 2 tributaries, or those tributaries that have identified physical or biological constraints that either restrict the scale of the project required or affect its predicted long-term sustainability."

TRIB	Average Spat counts (individual bar counts) High (year)	Average	# years above 50/bu. Ave for the river
Upper Chester	274 (1947)	9.5	1/26 (4%)
Lower Chester	101 (1949)	10.4	0/35 (0%)
Severn River	186 (1963)	10.3	1/14 (7%)
South River	572(1963)	15.9	1/20 (5%)
Eastern Bay N	722 (1966)	115.6	20/34 (59%)
Eastern Bay S	476 (1966)	78.6	9/22 (41%)
Upper Choptank River	154 (1965)	18.9	3/20 (15%)
Middle Choptank River	510 (1943)	31.2	7/33 (21.2%)
Lower Choptank River	626 (1943)	54.4	10/34 (29.4%)
Harris Creek	3604 (1965)	170.4	18/30 (60%)
Little Choptank			
Broad Creek	1290 (1965)	113.3	17/30 (57%)
Upper St. Mary's River	1144 (1941)	235.6	19/29 (66%)
Lower St. Mary's River	978 (1965)	75.6	16/29 (55%)
Upper Tangier Sound	1068 (1945)	52.3	10/36 (28%)
Middle Tangier Sound	480 (1945)	43.7	7/32 (22%)
Lower Tangier Sound	567 (1945)	39.3	10/32 (31%)
Nanticoke and Wicomico Rivers	448 (1944)	27.2	13/31 (42%)
Manokin River	978 (1965)	80.5	13/31 (42%)

These numbers were generated from the data contained in the publication Oyster Spat Set on Natural Cultch in the Maryland Portion of the Chesapeake Bay (1939 – 1975) by Donald W. Meritt. University of Maryland Special Report No. 7. February 24, 1977. I have made some very arbitrary assumptions in putting this table together. Data in this publication is an average of all samples taken for a given oyster bar in a given year. Those are grouped by tributary and an average of those averages are displayed. Not all the tributaries match up exactly with the USACOE tributaries so care should be taken to better identify those oyster bars that should be included in the USACOE designations if a much more in depth comparison is required. Furthermore, it should be noted that for the tributaries with lower spatfall averages, most of those averages are inflated from one or two very high sets during the 30 + year observation period. Data in this publication covers the period from 1939 through 1975. In general, spatfall numbers from the early years is significantly higher than those seen in later years. Which was often an order of magnitude higher. Anecdotal evidence (that should be confirmed from MDNR data) indicates that the downward trend in natural recruitment has continued past 1975. Tributaries that historically served as natural seed areas for the public oyster fishery are in red and they have some significant similarities. First all but one experienced an average spatfall in excess of 50 spat/bushel of natural cultch during the entire period and all of them (plus the Manokin River) averaged over 75 spat/bushel during the entire period including the poor spatfall years. Additionally, these tributaries exhibited consistency in natural recruitment and with the exception of the southern portion of Eastern Bay (41%) all produced natural seed in excess of 50 spat/bushel in at least 55% of the years sampled.

Conversely, the Severn, South, and Chester Rivers rarely exhibited high spatfall (>50/bu.). The Chester, Severn, and South all at or below 7% of the time, and the Upper Choptank not far behind with only 15% of the years having an average spatfall at or above 50/bu. As further evidence that some of the tier 1 tributaries are not likely to respond with a local reproductive signal those rivers produced an average spat/bushel below 19. This number is much lower when those exceptional years are removed from consideration.

While it is true that we have seen a greatly reduced number of potential broodstock and an even greater reduction in viable hard substrate habitat upon which larval oysters would attach, one could argue that conditions in Chesapeake Bay today are less conducive for natural oyster recruitment than those that persisted during the years for this publication. Water quality issues, sedimentation, disease, and other important factors all play a role in natural oyster recruitment. I believe it is unreasonable to predict that we will see a "self-sustaining" oyster population in all the tributaries as is either stated or implied in the COE document.

That does not mean that tributaries unlikely to generate local recruitment events should always be avoided. There may be other important metrics that can be accomplished in those tributaries and those should be highlighted without the implication that they will eventually become self-sustaining. To mislead the public like this will only lead to further distrust and eventually adversely impact funding when these projects fail to deliver natural oyster spat to the local bars.

On another very important subject that the COE is aware of but does not seem willing to assist. The lack of sufficient quantities of oyster shell to use in the various oyster restoration projects is a major impediment to success. We are spending much more trying to find and deploy alternative materials in what is at best a stop-gap attempt to accomplish our goals. We need to come to grips with the fact that there must be huge deposits of buried shell scattered throughout the Bay in the footsteps of the once productive Yates bars and Baylor Grounds. We need to all work in concert to identify the location of these resources and then work with the scientific community to find a beneficial and environmentally friendly way to mine them and use them in our restoration projects. If sites could be found in close proximity to the restoration sites this would lower the cost and make this a win win situation. We might actually learn how to take advantage of the natural contours of the Bay bottom to use as a base for high relief reefs. Someone needs to tackle the politics of this and get it moving forward. If permits have been issued for shell mining in some sites, why not others? This makes no sense to me and we need to remember this is a net benefit to the health of the Bay.

"A second critical factor is the availability of hard substrate for reef construction. Oyster reef is the principal hard habitat in the Bay and significant amounts of reef habitat will need to be restored to meet restoration goals. However, a sufficient supply of oyster shell is currently not available for oyster restoration. Alternate substrates will need to be a part of large-scale habitat restoration. Alternate substrates such as concrete and stone are significantly more expensive and may not be publicly acceptable on such a large-scale; however, these materials greatly eliminate the risk of poaching because the materials can damage traditional harvest equipment."

Comment 1: These two sections of the Executive Summary spend way too much time attempting to convince the reader of the "highly intensive", transparent, and exhaustive effort"….. In fact, while there were meetings and comment periods, there seems to have been a very selective use of the comments. I am about to make one important comment below and attempt to back it up with data on natural recruitment. I have personally made this comment to COE personnel involved with this project before and apparently none of my comments were deemed of sound scientific principal to have found their way into this document.

RESPONSE: The statements below will be toned down and revised as stated.

From Press Release:
" The long-term goal is to restore an abundant, self-sustaining oyster population that performs important ecological functions such as providing reef community habitat, nutrient cycling, spatial connectivity, and water filtration, among others, and contributes to the oyster fishery." This is repeated in the document.
This is our overarching goal. We do not think it will be easy, but this is the long-term goal that we are working towards with our efforts. This statement will not change. We must formulate to achieve sustainability and ultimately self-sustainability. These are USACE objectives for all projects. We understand your argument and recognize in the master plan that the lower salinity tributaries (i.e. Severn, South, Chester) historically had low spatsets that do not necessarily set the stage to achieve this goal in those tributaries. Those tributaries did, however, have healthy, functioning oyster populations that did not rely on humans to keep in existence. Restoration of significant levels of oysters in these lower salinity populations will provide a broad spectrum of ecosystem services as well as develop an oyster population that is conditioned to the low salinity environment. These low salinity areas have the potential to support long-lived oyster populations. Healthy, low salinity populations will add diversity and resiliency to the Bay's oyster population. These low salinity tributaries will not be the first selected from the Tier 1 list. Due to the challenges of low reproduction expected, they would follow, at some point in the future, efforts in other tributaries. We expect that restoration in the low salinity tributaries will require an increased effort compared to high salinity tributaries, i.e. because there is reduced reproduction, more habitat and broodstock will be needed. This is tied to the restoration target. Low salinity tributaries will likely need to be restored to the higher end of the restoration target, while high salinity tributaries may only need to reach the low end of the restoration target. Increased habitat will require higher amounts of investment. We expect to use lessons learned from working in the other tributaries to help guide restoration in these very challenging, low salinity tributaries. Additionally, we will need to investigate larval transport more in depth. By the time that we start detailed restoration planning in these tributaries, there may be additional developments in larval transport modeling that would benefit our understanding of reproduction in low salinity tributaries. USACE is also working with the U.S. Naval Academy to study reproduction from 13 acres of reefs constructed in the Severn on 2009. Additionally, larval transport connections to higher salinity tributaries may be identified that show input of larvae from other tributaries.

From the Executive Summary:
"This master plan represents the culmination of a ~~highly intensive, transparent, and exhaustive~~

effort to bring together state-of-the-art science, on the ground experience, and collaborative, science-based planning effort focusinged on native oyster restoration in the Chesapeake Bay into one comprehensive and coordinated document. This effort, which builds on USACE's *Final Programmatic Environmental Impact Statement for Oyster Restoration Including Use of Native and/or Non-Native Oyster* in 2009 (http://www.nao.usace.army.mil/OysterEIS/FINAL_PEIS/homepage.asp), is unprecedented in that it lays out the first detailed, comprehensive Bay-wide strategy for large-scale oyster restoration. Development of the document and the approaches laid out herein incorporatedwere accomplished painstakingly and with a thoroughness of purpose that this complex restoration challenge deserves. The authors and collaborators sought out the most up-to-date and credible sources of information to inform decision-making and plan formulation, including peer reviewed publications, and scientific and technical work accomplished by Bay experts, state partners, Federal collaborating agencies, nongovernment agencies, numerous stakeholders, and others with interest or expertise in native oyster restoration. Critical and controversial topics were isolated by the project team and analyzed through a series of Technical White Papers that were vetted among USACE, the project sponsors, and collaborating agencies. Intensive Agency technical review of this document was accomplished by USACE with complementary reviews by Federal and state partners to ensure technical quality and to address the full spectrum of technical and institutional concerns. Once internal and agency reviews were complete, public review of the master plan was conducted. Further public review of this document will complement the sound technical and institutional foundation on which this document has been built."

"It is conceivable that The master plan will serve as a foundation, along with plans developed by other federal agencies, to work towards achieving the oyster restoration outcomes goals established by the *Chesapeake Bay Protection and Restoration Executive Order* (E.O. 13508) to restore native oyster habitat and populations in 20 tributaries by 2025."

Comment [AAS1]: This statement was coordinated with NOAA.

Comment 2: While I have not read the entire document, my comments below center on the misleading language used in several places that could ultimately do more harm than good and for no apparent reason.

Passages of the document have been included to illustrate my point that one important goal for each tributary is to establish a "self-sustaining" oyster population. We must formulate to achieve sustainability and ultimately self-sustainability. These are USACE objectives for all projects. I have provided data at the end that hopefully illustrates the problems with this assumption.

Selected Passages from Document:
"formulates plans to restore sustainable oyster populations throughout the Chesapeake Bay;"

"USACE recognizes that self-sustainability is a lofty goal. It will require focused and dedicated funding and strong political and public support over an extended period, likely decades. It will require the use of sanctuaries and the observance of sanctuary regulations. In addition to the longterm goal, the master plan defines near-term ecological restoration and fisheries management objectives. The ecological restoration objectives cover habitat for oysters and the reef community as well as ecosystem services." This language is included in an effort to explain that we do not think the efforts needed to achieve our goals will be trivial or without challenge.

"The master plan lays out a large-scale approach to oyster restoration on a tributary basis and proposes that 20 percent to 40 percent of historic habitat (equivalent to 8 percent to 16 percent of Yates/Baylor Grounds) be restored and protected as oyster sanctuary. The concentrated restoration efforts are necessary to have an impact on depleted oyster populations within a tributary. To accomplish tributary-level restoration, the master plan includes salinity-based strategies to address disease and jumpstart reproduction."

"The evaluation was largely performed using geographic information system (GIS) analyses. The master plan identifies that 19 (Tier 1) tributaries in the Chesapeake Bay are currently suitable for large-scale oyster restoration (Table ES-1). These tributaries are distributed throughout the Bay with 11 sites in Maryland and eight sites in Virginia, as shown in Figure ES-1. Tier 1 tributaries are the highest priority tributaries that demonstrate the historical, physical, and biological attributes necessary to provide the highest potential to develop self-sustaining populations of oysters."

"The remainder of the tributaries and mainstem Bay segments are classified as Tier 2 tributaries, or those tributaries that have identified physical or biological constraints that either restrict the scale of the project required or affect its predicted long-term sustainability."

These numbers were generated from the data contained in the publication Oyster Spat Set on Natural Cultch in the Maryland Portion of the Chesapeake Bay (1939 – 1975) by Donald W. Meritt. University of Maryland Special Report No. 7. February 24, 1977. I have made some very arbitrary assumptions in putting this table together. Data in this publication is an average of all samples taken for a given oyster bar in a given year. Those are grouped by tributary and an average of those averages are displayed. Not all the tributaries match up exactly with the USACOE tributaries so care should be taken to better identify those oyster bars that should be included in the USACOE designations if a much more in depth comparison is required. Furthermore, it should be noted that for the tributaries with lower spatfall averages, most of those averages are inflated from one or two very high sets during the 30 + year observation period. Data in this publication covers the period from 1939 through 1975. In general, spatfall numbers from the early years is significantly higher than those seen in later years. Which was often an order of magnitude higher. Anecdotal evidence (that should be confirmed from MDNR data) indicates that the downward trend in natural recruitment has continued past 1975. Tributaries that historically served as natural seed areas for the public oyster fishery are in red and they have some significant similarities. First all but one experienced an average spatfall in excess of 50 spat/bushel of natural cultch during the entire period and all of them (plus the Manokin River) averaged over 75 spat/bushel during the entire period including the poor spatfall years. Additionally, these tributaries exhibited consistency in natural recruitment and with the exception of the southern portion of Eastern Bay (41%) all produced natural seed in excess of 50 spat/bushel in at least 55% of the years sampled. Conversely, the Severn, South, and Chester Rivers rarely exhibited high spatfall (>50/bu.). The

Chester, Severn, and South all at or below 7% of the time, and the Upper Choptank not far behind with only 15% of the years having an average spatfall at or above 50/bu. As further evidence that some of the tier 1 tributaries are not likely to respond with a local reproductive signal those rivers produced an average spat/bushel below 19. This number is much lower when those exceptional years are removed from consideration.

While it is true that we have seen a greatly reduced number of potential broodstock and an even greater reduction in viable hard substrate habitat upon which larval oysters would attach, one could argue that conditions in Chesapeake Bay today are less conducive for natural oyster recruitment than those that persisted during the years for this publication. Water quality issues, sedimentation, disease, and other important factors all play a role in natural oyster recruitment. I believe it is unreasonable to predict that we will see a "self-sustaining" oyster population in all the tributaries as is either stated or implied in the COE document.

We agree that conditions in the Chesapeake Bay today are less conducive to recruitment than in previous decades. We have screened for suitable sites based on water quality, plan to provide hard structure that is elevated off the bottom to address sedimentation and loss of habitat, and we lay out a disease strategy. Scale- habitat and broodstock- are the two factors that we can take direct action to restore, and have been deficiently addressed in previous restoration efforts. We are not predicting that we will definitively see 'self-sustaining' oyster populations in all the tributaries. There are no guarantees and there is a greater risk in low salinity tributaries that we may not succeed. Also, we may achieve interim goals of improved water quality, reef habitat, etc., while not reaching self-sustainability. However, 'self-sustaining' is the ultimate goal that plans will be formulated to achieve. The Oyster Metrics Workgroup of the Fisheries Goal Implementation Team has outlined metrics to use to determine success.

That does not mean that tributaries unlikely to generate local recruitment events should always be avoided. There may be other important metrics that can be accomplished in those tributaries and those should be highlighted without the implication that they will eventually become selfsustaining. To mislead the public like this will only lead to further distrust and eventually adversely impact funding when these projects fail to deliver natural oyster spat to the local bars. It is not our intention or desire to mislead anyone. We gain nothing by doing that. **We will add text to further explain the challenges that will face achieving 'self-sustainability' in low salinity tributaries and clarify that the risk of failure is greater in these tributaries. We will add a table that identifies the major risks/challenges in each tributary. We will also add discussion highlighting the likelihood that ecosystem services (habitat, long-surviving oyster populations, water quality filtration, etc.) can be achieved even if we fall short of the self-sustainability goal.**

On another very important subject that the COE is aware of but does not seem willing to assist. The lack of sufficient quantities of oyster shell to use in the various oyster restoration projects is a major impediment to success. We are spending much more trying to find and deploy alternative materials in what is at best a stop-gap attempt to accomplish our goals. We need to come to grips with the fact that there must be huge deposits of buried shell scattered throughout the Bay in the footsteps of the once productive Yates bars and Baylor Grounds. We need to all work in concert to identify the location of these resources and then work with the scientific community to find a beneficial and environmentally friendly way to mine them and use them in our restoration projects. If sites could be found in close proximity to the restoration sites this would lower the cost and make this a win win situation. We might actually learn how to take advantage of the natural contours of the Bay bottom to use as a base for high relief reefs. Someone needs to tackle the politics of this and get it moving forward. If permits have been issued for shell mining in some sites, why not others? This makes no sense to me and we need to remember this is a net benefit to the health of the Bay.

"A second critical factor is the availability of hard substrate for reef construction. Oyster reef is the principal hard habitat in the Bay and significant amounts of reef habitat will need to be restored to meet restoration goals. However, a sufficient supply of oyster shell is currently not available for oyster restoration. Alternate substrates will need to be a part of large-scale habitat restoration. Alternate substrates such as concrete and stone are significantly more expensive and may not be publicly acceptable on such a large-scale; however, these materials greatly eliminate the risk of poaching because the materials can damage traditional harvest equipment."

We are aware of the potential to reclaim previously placed dredged fossil shell and support this. MDNR has had the lead on this and are undertaking efforts to further our understanding of how this might be accomplished. We have maps that identify where plantings occurred and the quantity of shell placed. MDNR is working to develop methods to identify where the buried shell is located, how to recover it, the cost, and the recovery efficiency. Initial investigations by DNR in Harris Creek suggest that shell reclamation will not be as easy as once thought. We have wanted to incorporate shell reclamation into our plans, but the science has not developed as quickly as we would have liked. **We will discuss the regulatory impediments with the Regulatory Division of USACE Baltimore as well as work with DNR on shell reclamation efforts.** Additionally, we are pursuing mine deposits of marine shell in Virginia that could prove to be a suitable (and likely, more publicly preferred) substrate than currently used alternate substrates such as granite.

Public comment:
Numbers 17-21

Compton, Anna M NAB

From: Olson, Derik (Intern) [Derik_J_Olson@ceq.eop.gov]
Sent: Thursday, April 26, 2012 2:36 PM
To: NativeOysterRestMasterPlan
Subject: RE: copy of oyster plan (UNCLASSIFIED)

By the way, I noticed a typo on page 215. In the table, 2nd row, third column it reads 8,000-15,8. Is that supposed to be 15,800?
-Derik

-----Original Message-----
From: NativeOysterRestMasterPlan [mailto:NativeOysterRestMasterPlan@usace.army.mil]
Sent: Thursday, April 26, 2012 1:49 PM
To: Olson, Derik (Intern)
Subject: RE: copy of oyster plan (UNCLASSIFIED)

Classification: UNCLASSIFIED
Caveats: NONE

Hi Derik,
At your request, I put a hard copy in the mail last week addressed to Jeff Peterson. Did you receive it? Or, are you requesting another copy?

Thanks,
Angie

-----Original Message-----
From: Olson, Derik (Intern) [mailto:Derik_J_Olson@ceq.eop.gov]
Sent: Tuesday, April 24, 2012 9:28 AM
To: NativeOysterRestMasterPlan
Subject: copy of oyster plan

Hello,

I am wondering if there are bound hard copies available of the Native Oyster Restoration Plan? If so, please send one to the following address:

Derik Olson

730 Jackson Place

Washington D.C. 20503

Thank you,

Derik Olson

Land & Water Team Intern | Council on Environmental Quality (202-395-2011 | *
Derik J Olson@ceq.eop.gov <mailto:Mark H Foster@ceq.eop.gov> | www.whitehouse.gov/ceq
<http://www.whitehouse.gov/ceq>

Classification: UNCLASSIFIED
Caveats: NONE

Compton, Anna M NAB

From: Sowers, Angela NAB
Sent: Thursday, May 24, 2012 9:26 AM
To: Compton, Anna M NAB
Subject: Oyster MP- Public Comments- FW: Questions Regarding Draft Chesapeake Bay Oyster Recovery Plan (UNCLASSIFIED)

Classification: UNCLASSIFIED
Caveats: NONE

-----Original Message-----
From: O'Neill, Claire D NAB02
Sent: Wednesday, May 02, 2012 4:54 PM
To: Derik_J_Olson@ceq.eop.gov
Cc: Henn, Roselle E NAD; Guise, Amy M NAB; Sowers, Angela NAB02; Conner, Susan L. NAO; Armstrong, Jennifer R. NAO
Subject: RE: Questions Regarding Draft Chesapeake Bay Oyster Recovery Plan (UNCLASSIFIED)

Classification: UNCLASSIFIED
Caveats: NONE

Derik,
Hi. I'm Claire O'Neill the program manager for the Chesapeake Bay Oyster Restoration Program; I am also the project manager for the native oyster restoration master plan and the construction activities in Maryland. Let me see if I can answer your questions.

(1) How would the costs be split? Cost-sharing under the current project authority (Section 704(b) of WRDA 1986) is 75% Federal and 25% non-Federal.
(2) How much money do we have now? In FY12, USACE received $4.9 million which was split roughly 50-50 between the Maryland and Virginia activities.
(3) What amount of new money is needed? The oyster restoration program is in the president's FY13 budget for $5 million. Given the constraints on other resources (substrate, non-Federal in-kind services, spat), this amount of funding is appropriate for the project.
(4) What budget category? I'm not sure what you mean by that; the project comes under the ecosystem restoration business line in our Construction appropriation.
(5) Through WRDA, is there money available now? Yes, please see answer to #2 about our FY12 funding.
(6) How much does it relate to how they plan for? Not sure what you mean by this, but the funds are being used in accordance with the USACE master plan and other Chesapeake Bay initiatives (e.g., Executive Order 13508).
(7) Does USACE have a budget DOD appropriations for this plan? Right now, our funding comes through the USACE Construction (3122) appropriation and the Chesapeake Bay Oyster Recovery, MD and VA line item.
(8) Is there state match available? Currently, the state match is in the form of in-kind services. In Maryland, the in-kind is primarily through the provision of spat from the state-owned hatcheries. In Virginia, the in-kind was the provision of dredged fossil shell. I can't speak to specifics in Virginia, but I do know that the dredged shell is a scarce resource with many demands on it.
(9) Where/how would the army start? Not sure what you mean by this. The USACE oyster restoration program has been funded fairly continuously since 1995. I am unaware of other U.S. Army activities related to oysters, but others may know more.

This may be a lot to digest. If you want to call me at 410-962-0876, I will try to answer any follow-up questions.

Claire D. O'Neill, P.E.
Project Manager
USACE-Baltimore District

From: Olson, Derik (Intern) [mailto:Derik_J_Olson@ceq.eop.gov]
Sent: Wednesday, May 02, 2012 12:10 PM
To: Sowers, Angela NAB02
Subject: RE: Questions Regarding Draft Chesapeake Bay Oyster Recovery Plan

Angie,

Questions:

How would the costs be split among stakeholders (cost-sharing)?

How much money does the corps have now for oyster restoration in the Bay and what is the amount of new money needed, and in which budget category?

Through the WRDA – Is there money available now? How much does it relate to how they plan for? Does the corps have a budget DOD appropriations for this plan?

Is there state match available? Where/how would the army start?

Thank you,

Derik Olson

Land & Water Team Intern | Council on Environmental Quality
(202-395-2011 | * Derik_J_Olson@ceq.eop.gov <mailto:Mark_H_Foster@ceq.eop.gov> |
www.whitehouse.gov/ceq <http://www.whitehouse.gov/ceq>

From: Sowers, Angela NAB02 [mailto:Angela.Sowers@usace.army.mil]
Sent: Wednesday, May 02, 2012 10:09 AM
To: Olson, Derik (Intern)
Subject: Re: Questions Regarding Draft Chesapeake Bay Oyster Recovery Plan

Hi Derik,
I will see if our Project Manager is in the office to talk with you. In the meantime, could you email me the questions?

Thanks,
Angie

Angie Sowers, Ph.D.
U.S. Army Corps of Engineers
Planning Division, Baltimore
Integrated Water Resource Management Specialist
443.676.4679
Message sent via my BlackBerry Wireless Device

From: Olson, Derik (Intern) [mailto:Derik_J_Olson@ceq.eop.gov]
Sent: Wednesday, May 02, 2012 06:32 AM
To: Sowers, Angela NAB02
Subject: RE: Questions Regarding Draft Chesapeake Bay Oyster Recovery Plan

Angie,

Jeff was asking me to writeup something by COB today. Is there another staffer working on the master plan, whom I may speak with? Or I could just email you the questions. No pressure.

-Derik

From: Sowers, Angela NAB02 [mailto:Angela.Sowers@usace.army.mil]
Sent: Tuesday, May 01, 2012 5:16 PM
To: Olson, Derik (Intern)
Subject: Re: Questions Regarding Draft Chesapeake Bay Oyster Recovery Plan

Hi Derik,
Glad you received the master plan and would be hay to answer any questions you have. I am out of the office until Thursday but do have time Thursday morning for a call.

Angie

Angie Sowers, Ph.D.
U.S. Army Corps of Engineers
Planning Division, Baltimore
Integrated Water Resource Management Specialist
443.676.4679
Message sent via my BlackBerry Wireless Device

From: Olson, Derik (Intern) [mailto:Derik_J_Olson@ceq.eop.gov]
Sent: Tuesday, May 01, 2012 01:40 PM
To: Sowers, Angela NAB02
Subject: Questions Regarding Draft Chesapeake Bay Oyster Recovery Plan

Hello Angie,

Jeff received the copy of the document you sent. Thanks for sending it so quickly. I sat down with him to discuss, and he had several questions. Are you available to talk on the phone tomorrow? Let me know what time, and I'll give you a call. Or you can call me as well.

Look forward to talking with you,

Derik Olson

Land & Water Team Intern | Council on Environmental Quality
(202-395-2011 | * Derik_J_Olson@ceq.eop.gov <mailto:Mark_H_Foster@ceq.eop.gov> |
www.whitehouse.gov/ceq <http://www.whitehouse.gov/ceq>

Classification: UNCLASSIFIED
Caveats: NONE

Classification: UNCLASSIFIED
Caveats: NONE

Public comment:
Number 22

Compton, Anna M NAB

From: Ann Rasmussen [arasmus1@yahoo.com]
Sent: Thursday, April 12, 2012 12:51 PM
To: NativeOysterRestMasterPlan
Subject: RE: oyster restoration conference (UNCLASSIFIED)

Hi Angie,
Thanks for your response, we enjoyed the conference and learned so much. We appreciate all the time you spent answering our many questions. We were able to connect with Eric Weissberger in the parking lot on our way out of the conference, and he emailed some information to us that may be useful in networking. It seems that aquaculture is our best option, and we will look into that as a possible option. Good luck with your oyster restoration project. It seems like a very important aspect of restoration of the Chesapeake Bay ecosystem.
Best wishes,
Ann Rasmussen & Mark Rankin

--- On Thu, 4/12/12, NativeOysterRestMasterPlan <NativeOysterRestMasterPlan@usace.army.mil> wrote:

From: NativeOysterRestMasterPlan <NativeOysterRestMasterPlan@usace.army.mil>
Subject: RE: oyster restoration conference (UNCLASSIFIED)
To: "Ann Rasmussen" <arasmus1@yahoo.com>
Date: Thursday, April 12, 2012, 6:52 AM

Classification: UNCLASSIFIED
Caveats: NONE

Hi Ann,
It was great to talk with you on Tuesday evening. Please let me know if I can help in any other ways. Thanks again for taking the time to come to our meeting.

Angie Sowers

-----Original Message-----
From: Ann Rasmussen [mailto:arasmus1@yahoo.com <http://us.mc1261.mail.yahoo.com/mc/compose?to=arasmus1@yahoo.com>]
Sent: Sunday, April 08, 2012 10:09 AM
To: NativeOysterRestMasterPlan
Subject: oyster restoration conference

We have a farm with a large cove on the Chesapeake Bay. Is this kind of location a possibility for establishing oyster beds or are they best established in mud flats on tributaries of the Bay? I am interested in attending the April 10th conference at the Chesapeake Bay Foundation but do not want to attend if our location is not an ideal setting.
Ann Rasmussen

Classification: UNCLASSIFIED
Caveats: NONE

Public comment:
Numbers 23-25

NOAA Chesapeake Bay Office – Comments on Native Oyster Restoration Master Plan
Friday, May 18, 2012

Comment #1: Suggested edit to Page 2 of the Executive Summary:

The purpose of this master plan is to provide a long-term strategy for USACE's role in restoring large-scale native oyster populations in the Chesapeake Bay to achieve ecological success. ~~It is conceivable that the~~ The master plan will serve as a foundation, along with plans developed by other federal agencies, to work towards achieving the oyster restoration outcome~~goals~~ established by the *Chesapeake Bay Protection and Restoration Executive Order* (E.O. 13508) to restore native oyster habitat and populations in 20 tributaries by 2025.

Comment #2:

The cost estimates for native oyster restoration are extremely high and may lead to a false perception and misunderstanding as to budget estimates to achieve the EO native oyster restoration outcome. The Army Corps used 'geographically-distinct sub-segments' of rivers and the main stem in its analysis. Of those, 10 were in MD and 8 in VA. Those 'sub-segments' are much bigger than what we are now looking at per the Oyster Metrics Team. For example, the entire Potomac is one sub-segment; the Rappahannock is another; the Oyster Metrics Team report recommended starting with Harris or Lynnhaven size tributaries, which are significantly smaller than the above referenced Potomac. Preliminary estimates for Harris Creek, Maryland reflect that our restoration goal of 300-600 acres would cost on the order of $20-$40 million. The Corps should consider adding a footnote or otherwise clarifying expectations with respect to native oyster restoration goals/outcomes and costs.

Public comment:
Number 26

May 7, 2012

Department of the Army
Norfolk District, Corps of Engineers
Attn: Ms. Susan Conner
803 Front Street
Norfolk, VA 23510-1096

Dear Ms. Conner,

Thank you for the opportunity to provide a letter of support for the USCAE Chesapeake Bay Oyster Recovery Native Oyster Restoration Plan for Maryland and Virginia, which was presented at your public meeting in Newport News on April 17, 2012. Lynnhaven River NOW is a small non-profit organization dedicated to substantially improving water quality and habitat in the Lynnhaven River.

Restoration of the native *Crassostrea virginica* oyster in the Lynnhaven is one of Lynnhaven River NOW's highest priorities. Over the last 15 years, thousands of students and citizens have worked together with non-profits and governmental organizations to build oyster reefs in the Lynnhaven and to stock millions of reproductive native oysters to the reefs. After only 15 years of restoration activities, we have seen that the effort is clearly working! Fifteen years ago, the Lynnhaven's oyster population was estimated to be at 1% of historic abundance, and recent calculations estimate that we may have already increased the Lynnhaven's population to as much as 15% of historic abundance.

The Lynnhaven's remarkable oyster rebound is to the credit of a great community synergy between the federal government, the state, the City of Virginia Beach, scientists, managers, industry, non-profits and thousands of committed, engaged citizens who are working to see the legendary Lynnhaven oyster restored. The native oyster recovery is a source of great pride in this region, and our progress is a model for other sub-estuaries around the Chesapeake to demonstrate the potential for native oyster restoration. **Lynnhaven River NOW wants to see the scale of native oyster restoration increased in the Chesapeake Bay** for the benefit of the burgeoning oyster population in the Lynnhaven, and for the benefit of other rivers and other regions who aim to replicate the Lynnhaven's oyster restoration progress.

We are particularly excited to see that the Master Plan will seek to work increasingly with alternative substrate rather than mined shell. Alternative substrate negates the need for the costly and destructive mining of limited shell reserves, plus if offers the benefits of both preventing poaching potential and recycling old buildings into new environmentally-beneficial initiatives. Our organization is

FSC Recycled Supporting responsible use of forest resources www.fsc.org Cert no. SCS-COC-001935 © 1996 Forest Stewardship Council
100%

currently working to identify and secure clean concrete for used as non-federal match for your project in the Lynnhaven and we genuinely embrace that role in the restoration effort.

We are also pleased to see that your master plan aims to conduct oyster restoration using a tributary by tributary approach, and we embrace the strategy of working in high salinity areas, where oyster disease is most virulent, in order to expedite the natural selection process.

Lynnhaven River NOW looks forward to working with your team during the design and construction phases of the project and we will continue to assist the Army Corps with securing subaqueous acreage for reef construction in the Lynnhaven. In addition, the construction of the planned Spat on Shell facility on the Lynnhaven River will aid oyster restoration and provide additional non-federal match.

Thank you for inviting and welcoming our comments. We can be reached at (757)-962-5398 for additional comment if necessary.

Sincerely,

Karen W. Forget
Executive Director

Recycled
Supporting responsible use of forest resources
FSC www.fsc.org Cert no. SCS-COC-001935
© 1996 Forest Stewardship Council
100%

Public comment:
Number 27

Corsica River Conservancy

A Proposal for Oyster Habitat Restoration in the Corsica River
DRAFT

Project Name: Community-based Oyster Habitat Restoration in the Corsica River

Project Abstract:

The Corsica River Watershed has been undergoing intensive ecosystem-wide restoration since 2006 having been targeted by Maryland as a watershed of the highest priority. A particularly strong community-based program of municipal, county, state, NGO conservation organizations and the public has developed. The Corsica restoration is at a key tipping point an incremental increase in clarity will have a multiplier effect in reviving benthic habitat throughout the River. CRC, along with its public and private partners, seeks funds to help it establish small scale oyster reefs to complement living shorelines that have been established at key locations along the River. These oyster reefs will more fully leverage the habitat potential of these living shorelines and the overall watershed restoration, while helping to protect them from erosive forces. Moreover, these locally concentrated oyster populations will improve clarity thereby helping to revive underwater grasses and other benthic habitat.

Project Description:

The Corsica River Watershed is located on Maryland's Eastern Shore (39°2′46″N 76°3′52″W). It comprises 25,299 acres with 1395 acres of that being open water. The Town of Centreville is located at the head of tide at the confluence of three sub watersheds feeding the main stem. The Corsica is an "8 digit" watershed within Maryland's watershed classification and is designated 02130507. Land use is primarily agriculture (62%) with 28% forested.

The Corsica River Watershed has been under intensive restoration since 2005 as a targeted watershed, following a land mark Watershed Restoration Action Plan (WRAS) that was completed in 2004. An ecosystem approach has been taken encompassing specific, measurable restoration initiatives addressing all major sources of pollution. These efforts have been implemented by an award-winning project team of state, county, municipal, civic and federal entities representing all land use sectors which has met and reported on a monthly basis for over the past six years. This community-based effort has become a model restoration project management approach. A specific restoration strategy and work plan has been continuously implemented, monitored and managed as a project As a result, very substantial progress has been made in reducing sources of pollution and limiting population growth effects. Some of these efforts are cited further below.

As the primary public representative on this team, the Corsica River Conservancy (CRC) has carried out both public outreach and on the ground restoration projects on its own and in concert with other team members. CRC's efforts have included installing over 300 residential rain

P. O. Box 235 • Centreville, MD • 21617

http://corsicariverconservancy.org/

Phone: 410-758-8756

Corsica River Conservancy

gardens most of which were funded under a large National Fish and Wildlife Service grant which it managed over several years.

One of the key initiatives of the program has been to restore oyster habitat in the Corsica. The Maryland Department of Natural Resources (DNR) has documented that at one time the Corsica had numerous and extensive oyster bars. Restoration efforts thus far have focused on two historic bars, Possum Point and Emory Wharf. Spat were deposited on these bars by the Oyster Recovery Partnership (ORP) in 2005, 2006 and 2008. The Corsica River Conservancy (CRC) has been growing oysters under the state's Maryland Grows Oysters (MGO) program since 2009. These have been deposited annually on the Possum Point bar. There are also extensive oyster bars that have existed as sanctuaries at the mouth of the Corsica in the Middle Chester for many years. By all known accounts, oysters have grown successfully throughout these locations. For example, data obtained from Ken Paynter (UMD) show oyster density greater than 5 oysters per square meter on 62% of the Possum Point bar with 70% shell coverage in 2010.

The thrust of this particular project will be to create new oyster habitat that will leverage the investment that has been made in several living shorelines recently installed in the Corsica. As a complement to the periodic large oyster spat deposit on the larger historic bars in the River and the small MGO deposits at those same bars, this project would construct smaller artificial oyster reefs on the outer fringes of the new living shorelines. These small reefs will both help protect and preserve the living shorelines and supplement the habitat that is already growing there. The resulting enhanced habitats will help provide islands of refuge as well as localized benthic communities which are expected to show water quality improvements in advance of those expected for the Corsica River at large.

Improvements in the Corsica Watershed have been significant and continuing, including: record setting cover crop usage (4425 acres in 2011), four extensive shoreline restorations with a fifth in the works, BNR waste treatment from the Centreville WWTP with spray irrigation at least 9 months each year, 308 residential rain gardens, 88 acres of added wetlands, 100 acres of agricultural buffers, another 100 acres of non-agricultural buffers, 10 municipal and county storm water control installations treating 112 acres, 7 years of continuing water quality monitoring and renowned community outreach programs. Water Quality Report Card grades for the Corsica sub-watersheds have been among the highest Bay wide.

In October 2009, Walter Boynton and others from the University of Maryland Center for Environmental Science (UMCES), reported on their "Ecological Assessment of the Corsica River Estuary and Watershed". A major purpose of this report was to synthesize the data collected in the Corsica watershed and to forecast likely responses of the ecosystem to further nutrient load reductions. This study concluded that restoration of the Corsica could reach a tipping point with increased clarity. Specifically, because of the Corsica's depth and physical characteristics, a 75% improvement in water clarity would lead to a 95% increase in the area of river sediments that could support benthic algae and a 60% increase in SAV habitat. The number of hypoxic hours could decrease by an astounding 80%.

P. O. Box 235 • Centreville, MD • 21617

http://corsicariverconservancy.org/

Phone: 410-758-8756

A more anecdotal corroboration of this prediction is provided by the sudden emergence and effect of dark false mussels in the Corsica and Magothy Rivers in 2004. As reported by Peter Bergstrom (NOAA,CBO), these filter feeders had an immediate effect of increasing water clarity to as much as 1.8 meters (Bergstrom et al 2009). The effect on underwater grasses was immediate and extensive as it reemerged in volume throughout these estuaries.

Unfortunately, this event was short lived with previous conditions returning in 2005 and the large number of mussels disappearing. But this event does provide a strong, tangible indication of how dramatically filter feeders can clarify the Corsica and how immediate an effect that clarification can have on reestablishing benthic habitat as well as the overall health of the River and its water quality.

CRC and the Implementation Project Team believe that coupling a more extensive oyster restoration targeted to several living shoreline restorations that have been installed in the Corsica, can restore healthy benthic habitat while helping to preserve those restorations.

Because of its size and the ecosystem wide improvements and investments, the Corsica, may represent the best watershed to demonstrate the beneficial effects of oyster sanctuaries in the context of a watershed restoration that is ecosystem-wide. Moreover, the world class monitoring system that has been implemented in the watershed through EPA funding of the restoration project can further leveraged to provide a comprehensive data set of reference points to empirically assess the extent of improvements that are achieved.

The Corsica, taken together with the oyster sanctuaries at its mouth in the middle Chester, forms an excellent candidate tributary for the concentrated oyster restoration and a living laboratory in which to assess its effects on a continuing basis. This could be just the kind of full oyster habitat restoration in a tributary that is called for under Executive Order 13508. It would be unfortunate to waste this unique opportunity and the extensive investment that Maryland, EPA, NOAA and the local community have made and continue to make in the Corsica. The Corsica has the physical characteristics, the existing investments, the monitoring system and the inter-government and community commitment to make such a restoration a success.

References:

Water quality & SAV improved in mesohaline Chesapeake Bay in 2004: Was this due to abundant dark false mussels? Authors: Peter Bergstrom, Richard Carey, Sally Hornor, and Chris Judy. Poster at Long Island Sound Study Bioextraction Workshop, Stamford, CT, December 2009. Poster presentation available at: http://longislandsoundstudy.net/wp-content/uploads/2010/02/Bergstrom_DFMPOSTER120309FINAL.pdf

An Ecological Assessment of the Corsica River Estuary and Watershed - Authors: Walter R. Boynton, Jeremy Mr. Teta, and W. Michael Kemp; University of Maryland Center for Environmental Services, October, 2009.

P. O. Box 235 • Centreville, MD • 21617

http://corsicariverconservancy.org/

Phone: 410-758-8756

Corsica River Conservancy

Contact Person: Frank DiGialleonardo for The Corsica River Conservancy (CRC)
309 Quail Run Drive
Centreville, MD 21617
410 758 4806
franardo@gmail.com

Drafted by Frank DiGialleonardo on behalf of the Corsica River Conservancy
April 18m 2012
Phone: 410-758-4806

P. O. Box 235 • Centreville, MD • 21617
http://corsicariverconservancy.org/
Phone: 410-758-8756

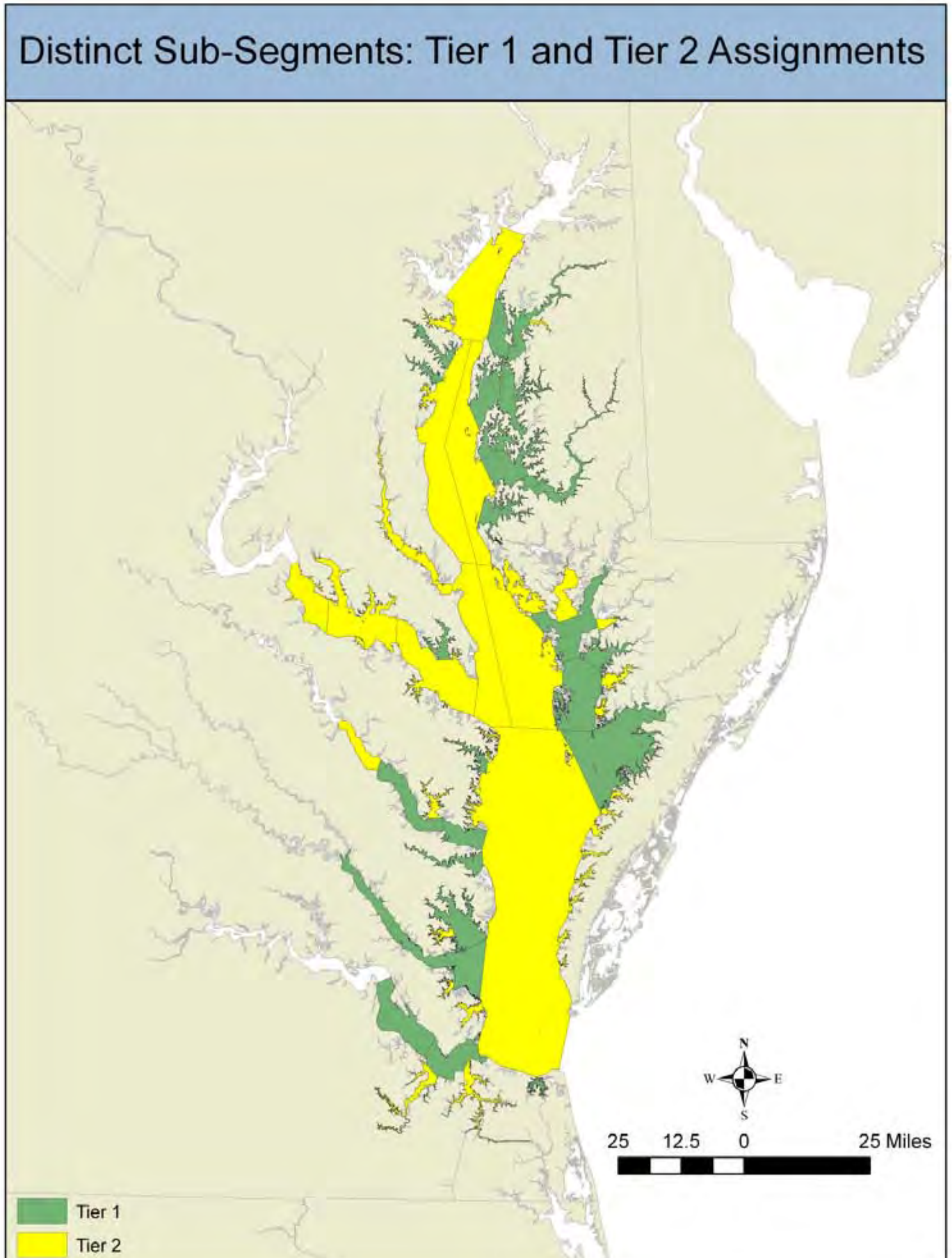
H-3: PUBLIC MEETING HANDOUTS

Master Plan Results:

Prioritization of Bay Tributaries

Tier 1 = Tributaries Suitable for Large-Scale Restoration Now

Tier 2 = Tributaries That Currently Have Physical or Biological Constraints to Large-Scale or Long-Term Sustainable Restoration



Tier 1 Tributaries/Areas	*Restoration Target (Acres)*
Maryland	
Severn River	190-290
South River	90-200
Chester River	1,100-2,200
Eastern Bay	1,500-3,000
Choptank River	1,800-3,600
Harris Creek	300-600
Little Choptank	400-700
Broad Creek	200-400
St. Mary's River	200-400
Tangier Sound (includes Nanticoke River)	1,800-3,600
Manokin River	400-800
Virginia	
Great Wicomico River	100-400
Rappahannock River (lower and middle segments)	3,800-7,500
Piankatank River	700-1,300
Tangier/Pocomoke	3,000-5,900
Mobjack Bay	800-1,700
York River	1,100-2,300
James River	2,900-5,700
Lynnhaven River	40-150

How To Submit Comments

U.S. Army Corps of Engineers will be accepting public comments during the public meetings. In addition, written comments on the proposal will be accepted through May 19, 2012, to supplement the meeting records. Faxed comments will not be accepted. To submit written comments, please send them to:

Ms. Angela Sowers
U.S. Army Corps of Engineers
P.O. Box 1715
Baltimore, MD 21203-1715

Or Email: NativeOysterRestMasterPlan@usace.army.mil

H-4: PUBLIC MEETING POSTERS

Native Oyster Restoration Master Plan

US Army Corps of Engineers®

Open House

Native Oyster Restoration Master Plan

US Army Corps of Engineers®

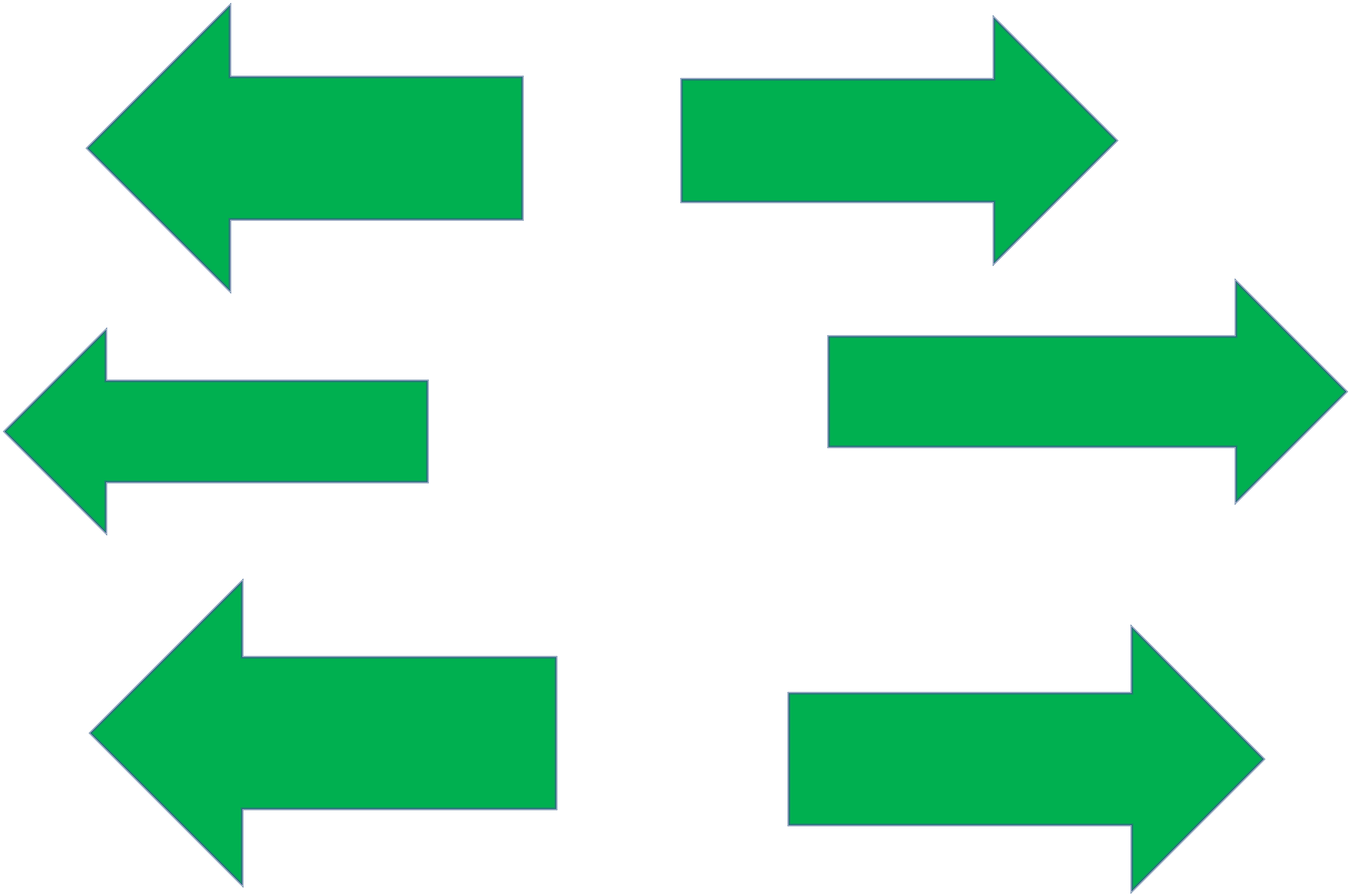
Open House

Native Oyster Restoration Master Plan

US Army Corps of Engineers®

Open House

Arrows to add to locator posters



Welcome!

We would like to hear your suggestions and comments on the Corps of Engineers' Chesapeake Bay-wide native oyster restoration master plan.

Please look at the posters and feel free to ask questions and leave comments.

US Army Corps of Engineers®

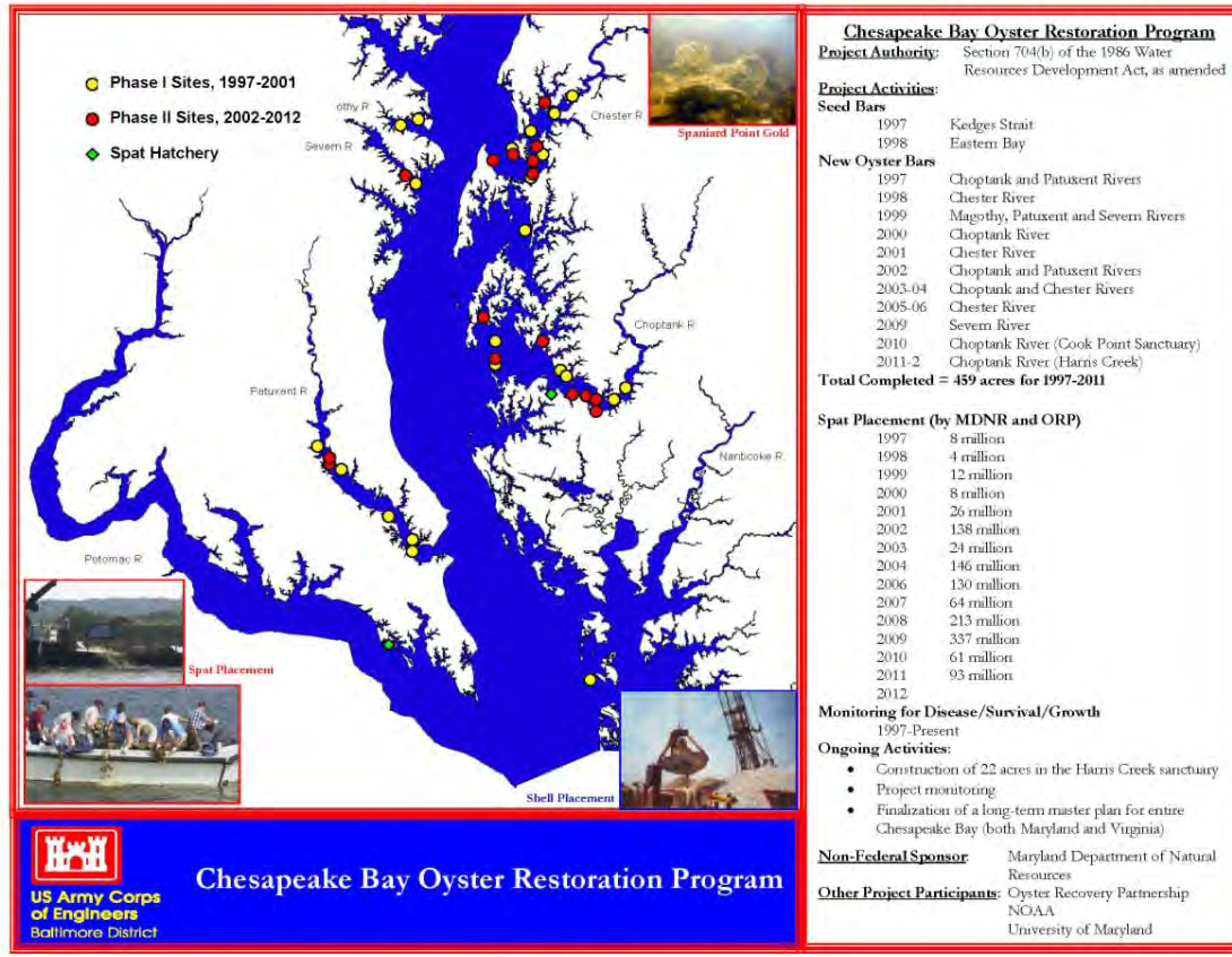
Corps of Engineers and Oysters

Congress authorized the Corps of Engineers to do oyster restoration in the Chesapeake Bay in Section 704(b) of the Water Resources Development Act of 1986.

The initial funding for the oyster restoration came in fiscal year 1995; since then, over the past 17 years, more than $16 million has been received for the Maryland effort [there is a similar effort ongoing in Virginia waters] .

The Corps has been partnering with Maryland DNR since 1997 to construct oyster bars in the Chesapeake Bay.

In the past 15 years, the Corps has placed substrate (both shell and alternative substrate) in the Severn, Magothy, Patuxent, Chester, and Choptank Rivers, as well as Eastern Bay and Kedges Strait.

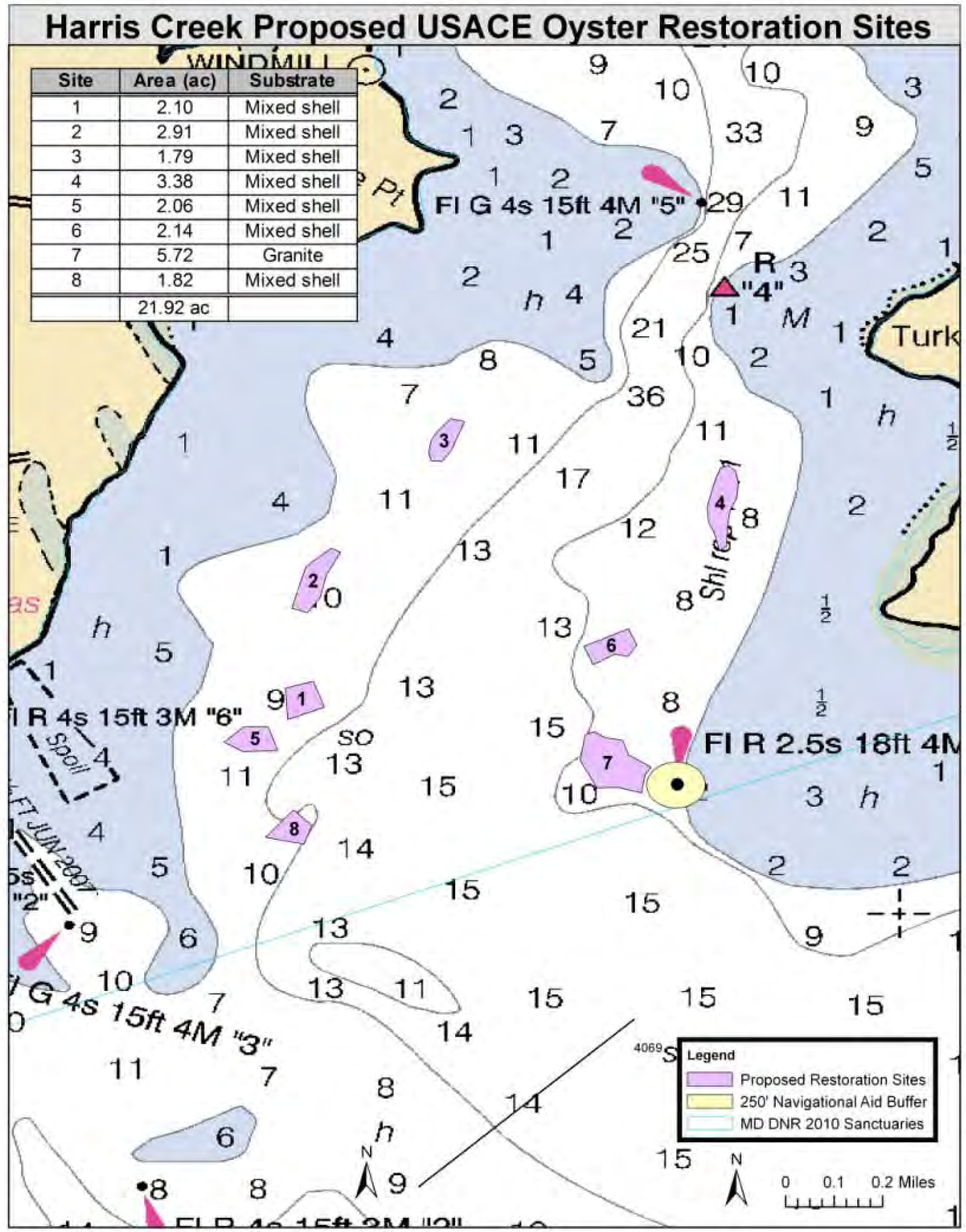


Currently, the Corps' mission is focused on ecosystem restoration to maximize aquatic habitat benefits.

Corps of Engineers and Oysters

Current Harris Creek Work

- In 2011, Congress gave the Corps of Engineers a little over $2 million for its efforts in Maryland waters.
- With those funds, we will be placing substrate on 22 acres in Harris Creek at 9 sites.
- Substrate will be mixed shell (primarily clam) and granite
- Construction planned for May-June 2012
- Bars will be seeded in July 2012 with hatchery spat-on-shell



Site	Area (ac)	Substrate
1	2.10	Mixed shell
2	2.91	Mixed shell
3	1.79	Mixed shell
4	3.38	Mixed shell
5	2.06	Mixed shell
6	2.14	Mixed shell
7	5.72	Granite
8	1.82	Mixed shell
	21.92 ac	

Future Harris Creek Work

- We received more $$ in 2012, so we are working with NOAA and MDNR to do more substrate work in Harris Creek.
- Preliminary sites were coordinated with the public in March
- Final site selection expected in April
- Construction expected in winter 2012-13.

Why a Bay-Wide Master Plan?

- Previous state and Federal efforts have been focused on smaller, dispersed areas.
- These efforts make it clear that we need to think larger scale.
- But resources ($$$, substrate, spat, monitoring) are limited so we need to prioritize to maximize results.
- Executive Order 13508 calls for 20 tributaries to be restored by 2025

Long-Term Restoration Goal of Master Plan:
Throughout the Chesapeake Bay, restore an abundant, self-sustaining oyster population that performs important ecological functions such as providing reef community habitat, nutrient cycling, spatial connectivity, and water filtration, among others, and contributes to an oyster fishery.

Operational Goal of Master Plan:
Identify tributaries/regions most likely to develop sustainable populations of oysters with the implementation of reef construction, seeding, and other oyster restoration activities.

Implementation: Master plan will ensure that USACE-implemented restoration is logical, science-based, and cost-effective with the greatest potential for success in achieving the restoration goal.

Strategic Plan: Master plan will present a strategic plan for pursuing long-term, large-scale restoration throughout the Bay that complements ongoing efforts by state and Federal agencies, and future uses of the Bay.

Oyster Locations: Master plan will not define specific projects for specific locations; specific locations will be determined in future tributary plans.

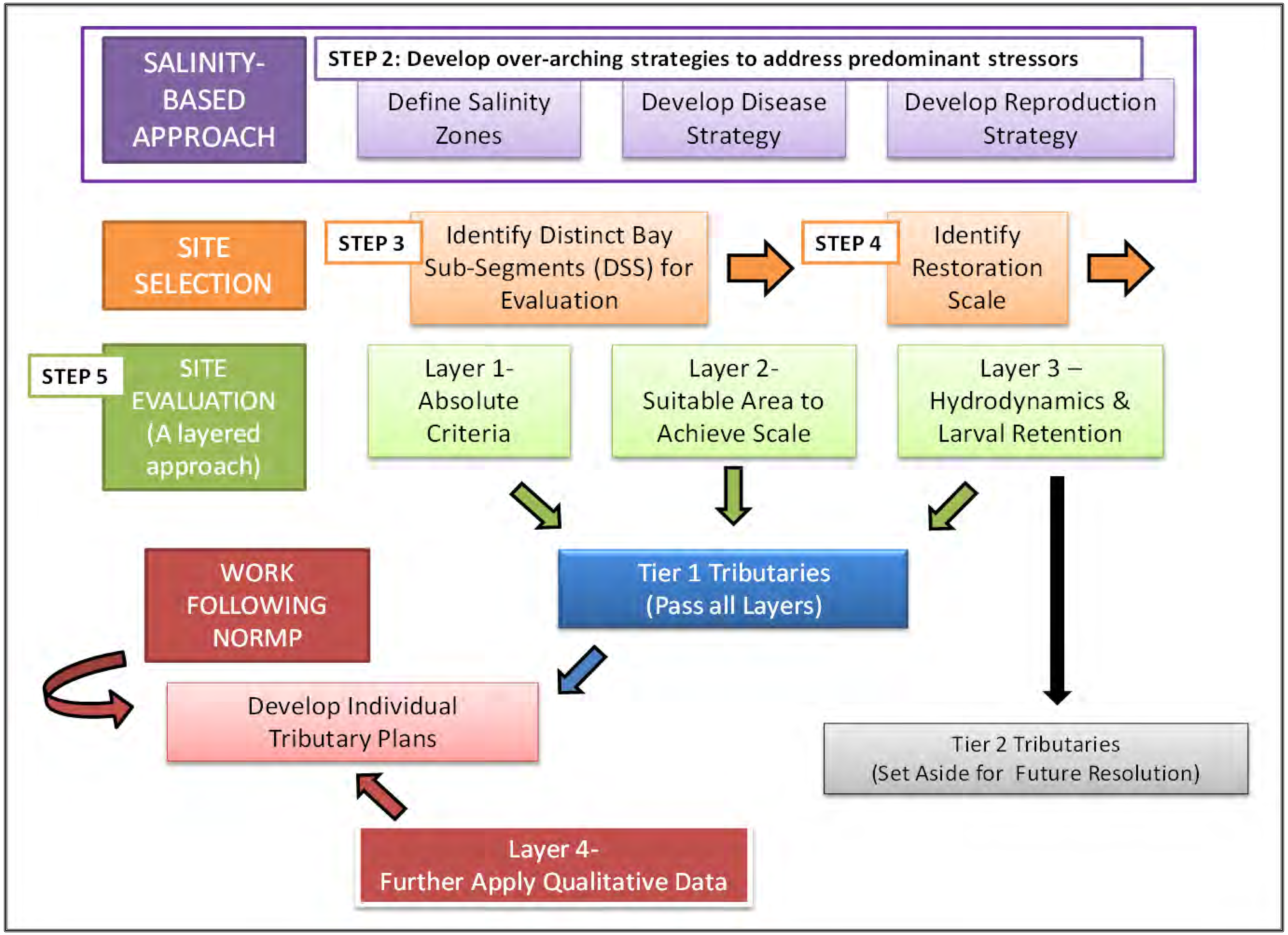
Summary of Master Plan Inputs

Problem		
Degraded oyster populations in Chesapeake Bay due to loss of habitat, disease, water quality, and overharvesting.		
Objectives		
Long-Range	Restore self-sustaining oyster sanctuary populations.	
Near-Term: Habitat for Oysters	Restore oyster abundances. Focus on restoring and maintaining habitat; and in low salinity regions, also focus on broodstock.	
Near-Term: Habitat for Reef Community	Restore bar/reef characteristics similar to non-degraded oyster habitat.	
Near-Term: Ecological Services	Restore native oyster populations that provide ecological services typical of non-degraded oyster habitat.	
Fisheries Management	Restore oyster spawning/habitat sanctuaries in multiple tributaries that export larvae outside the sanctuary boundaries and provide a larval source to harvest grounds.	
Constraint	**Master Plan Considerations**	**Restoration Action Taken to Address Consideration**
Water Quality – Salinity	Freshets, salinity	Site selection (in tributary plans)*
Water Quality – Dissolved Oxygen	Dissolved oxygen (DO), water depth	Site selection for good dissolved oxygen (DO), limit water depth, construct reefs with elevation off bottom
Disease	Salinity	Sanctuaries, selection of strains for seeding, construct in trap estuaries, site selection for suitable salinity
Reproduction	Historic and recent spatsets, salinity, connectivity and available information about larval transport, existing oyster populations in region	Trap estuaries, broodstock and seed planting, sanctuaries, site selection for suitable salinity
Harvest	Harvest records	Sanctuaries
Substrate/Habitat	Bottom condition, water quality, predation pressure, existing oyster populations	Construct hard base, reseed or add substrate, site projects where bottom can support oysters
Scale	Historic oyster habitat, past restoration efforts	Target tributaries for large, system-wide restoration
Water Quality – Sedimentation	Bottom condition	Construct reefs with elevation off bottom; consider orientation to flow and currents in tributary plans; site selection to avoid high sedimentation levels
Predation	Salinity	Site selection for suitable salinity, seed with spat-on-shell, predator exclusion devices if cost-effective
General Water Quality	Watershed land use	Consider land use and proximity of site to potential sources of toxicity, harmful algal blooms
Funding	Cost estimates based on region	Accomplish restoration by leveraging resources of all organizations involved, adaptive management, start in small tributaries

* “Site selection" under "Restoration Action" refers to site selection within follow-on tributary plans

The Plan Formulation Process

1. Develop formulation white papers
2. Adopt salinity-zone, disease, and reproduction strategies
3. Identify distinct sub-segments of the Chesapeake Bay for evaluation and prioritization
4. Determine the appropriate scale at which restoration should be undertaken
5. Tributary evaluation and prioritization
   - A layered formulation evaluation
   - Identify Tier I and II Bay segments



Step 1. Develop formulation white papers.

- Purpose of white papers was to organize the team's thoughts on various subjects and reach agency consensus on these topics.
- Topics were selected based on significance to oyster restoration and the master plan.
- White paper content drew on current science and knowledge.
- White papers were reviewed and coordinated with federal and state resource agencies

<u>White Paper Topics:</u>

- Project scale
- Disease
- Populations – Bayscape setting
- Populations – individual reefs
- Physio-chemical factors
- Hydrodynamics
- Reproduction

Potomac River Fisheries Commission

Step 2. Adopt salinity-zone, disease, and reproduction strategies.

WHY?? We need overarching strategies to address predominant stressors

SUMMARY OF SALINITY-ZONE STRATEGY

1. Define salinity zones
2. Plans will take into consideration that >8 parts per thousand (ppt) is needed for reproduction, but >5 ppt supports growth.

	Low Salinity (Zone 1)	High Salinity (Zone 2)
Salinity	5-12 ppt	>12 ppt
Disease Pressure	Low	Moderate-High
Survival	Good	Moderate-Poor
Recruitment	Poor	Moderate-Good

SUMMARY OF REPRODUCTION STRATEGY

Low to moderate salinity zones (<12 ppt) – low and intermittent recruitment events, often separated by many years

1. Provide substrate as needed.
2. Substrate should be stocked immediately following planting to avoid degradation.
3. Use adult wild stock from endemic disease areas to produce the spat-on-shell in hatcheries, to take advantage of any naturally developed disease resistance, that could be passed on to progeny.
4. Monitor (pre- and post-construction) to assess natural recruitment, population, mortality, and condition, to determine the need for additional stocking.
5. Monitor and, as needed, restock at initial stocking rate, 2 to 3 years following initial planting to provide a multi-age population.

High salinity zones (> 12 ppt) - higher, more consistent spatsets

1. Provide substrate as needed.
2. Plant substrate immediately prior to spawning season. Where natural recruitment is sufficient, may not need seeding. Where reefs were not planted and either natural recruitment is not occurring and/or substrate degradation is occurring, consider adding new material and/or restocking.
3. Use either adult wild spat-on-shell from areas where broodstock is showing signs of disease resistance or use stock from endemic disease areas to produce the spat-on-shell in hatcheries.
4. Stock and aggregate large natural oysters harvested from areas with demonstrated disease resistance to enhance fertilization success.
5. Monitor (pre- and post-construction) to assess natural recruitment, population, mortality, and condition, to determine the need for additional stocking.
6. Reseed if sufficient natural spatset is not occurring as predicted based on spatfall survey data.

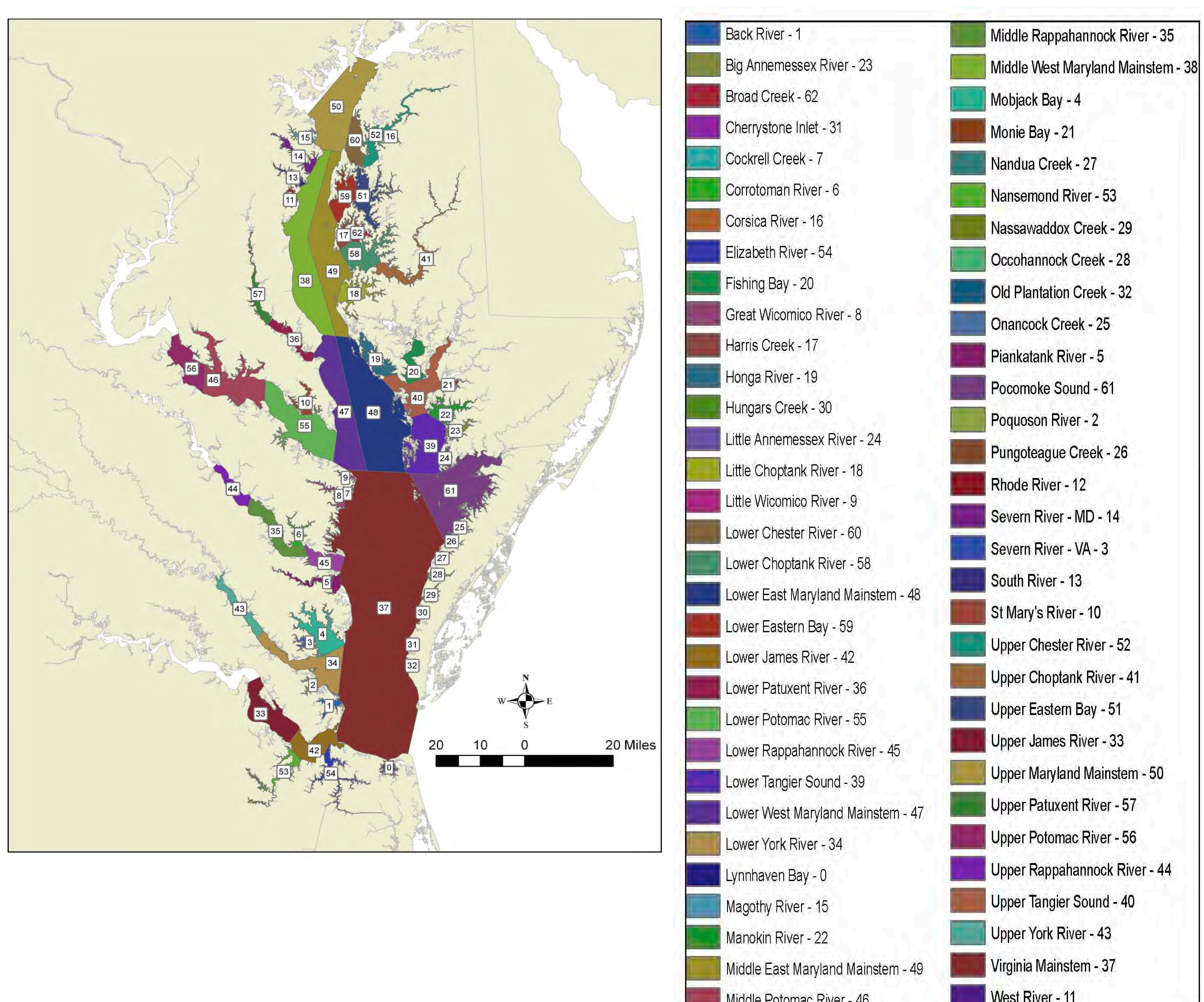
SUMMARY OF DISEASE STRATEGY

1. Establish a network of permanent sanctuaries spanning salinity zones to develop population level disease resistance.
2. Focus initial efforts in retentive systems (trap estuaries where possible) to concentrate and magnify larval production.
3. Do not use domesticated oyster strains such as DEBY and CROSSBred for stock enhancement.
4. Use a rotating brood stock approach for hatchery production.
5. In low salinity zones, and where appropriate in high salinity, plant sites with spat from disease-resistant parent stock either from hatcheries or obtained from wild populations growing in similar conditions to the restoration site.
6. Seed restoration sites with sufficient numbers of large adult wild oyster broodstock that have survived disease.
7. Restrict the movement of wild broodstock and spat-on-shell to areas with a similar or higher salinity regime.
8. Use “incubator reefs” to provide a seed source for restoration work.
9. Transplant spat-on-shell produced on incubator reefs to restoration sites within the same or greater salinity zone.

Step 3. Identify distinct sub-segments for evaluation and prioritization.

- First, tributaries and sub-regions were identified based on the extent of historic oyster habitat
- Next, large and medium-sized tributaries and sub-regions were broken into smaller areas based on groupings of simulated oyster bars, channel morphology, and oyster bar spacing
- Smaller tributaries were not broken down
- Result = 63 segments for the final analysis
  - 34 Maryland segments
  - 29 Virginia segments

Tributaries Identified



Step 4. Determine the appropriate scale at which restoration should be undertaken.

Scale = the approximate number of acres of functioning habitat in a given tributary or sub-region required to develop a self-sustaining oyster population.
No "one size fits all."

What do we know???

- Past restoration efforts have been too small to impact system
- Need to concentrate resources

Define historic habitat baseline

Identify the percent of historic habitat that needs to be restored to achieve goals.

Restoration goal = **20-40%** of historic (corrected) habitat

Step 5. Tributary evaluation and prioritization.

Layer 1 → Absolute Criteria →

Identify absolute criteria. Determine the number of suitable acres for restoration available.

Layer 2 → Scale →

Determine if there is enough suitable acreage available to meet the scale targeted for sustainable restoration.

Layer 3 →Qualitative Hydrodynamic Rating →

Indicates whether a tributary has high, medium or low indicators of the hydrodynamic properties preferred for restoration.

Layer 4 → Qualitative Data →

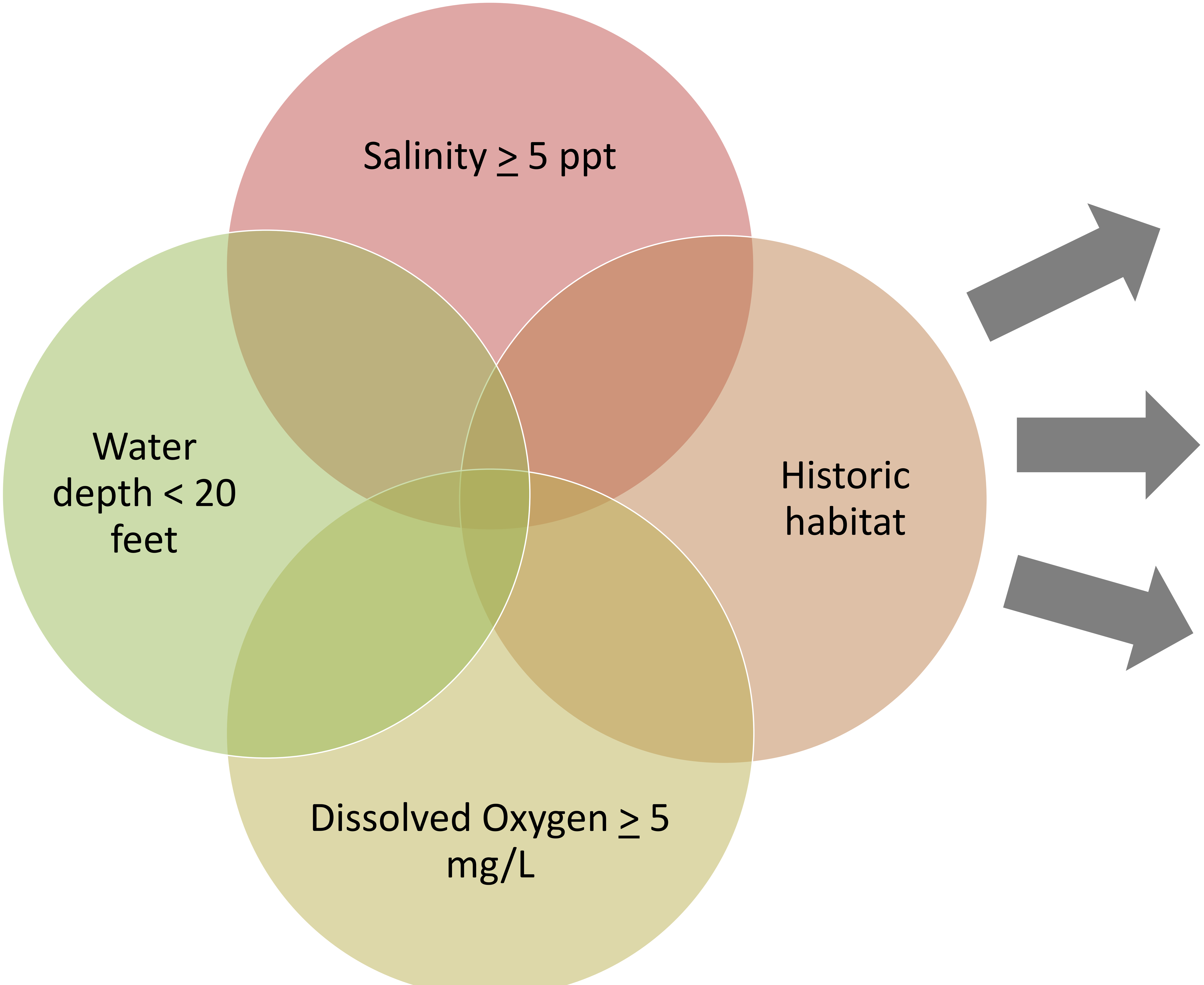
Additional considerations that are important for restoration, but are not as well documented or quantified.

→

List of Tier 1 and Tier 2 Tributaries

Step 5. Tributary evaluation and prioritization.

Absolute Criteria were used to determine suitability.

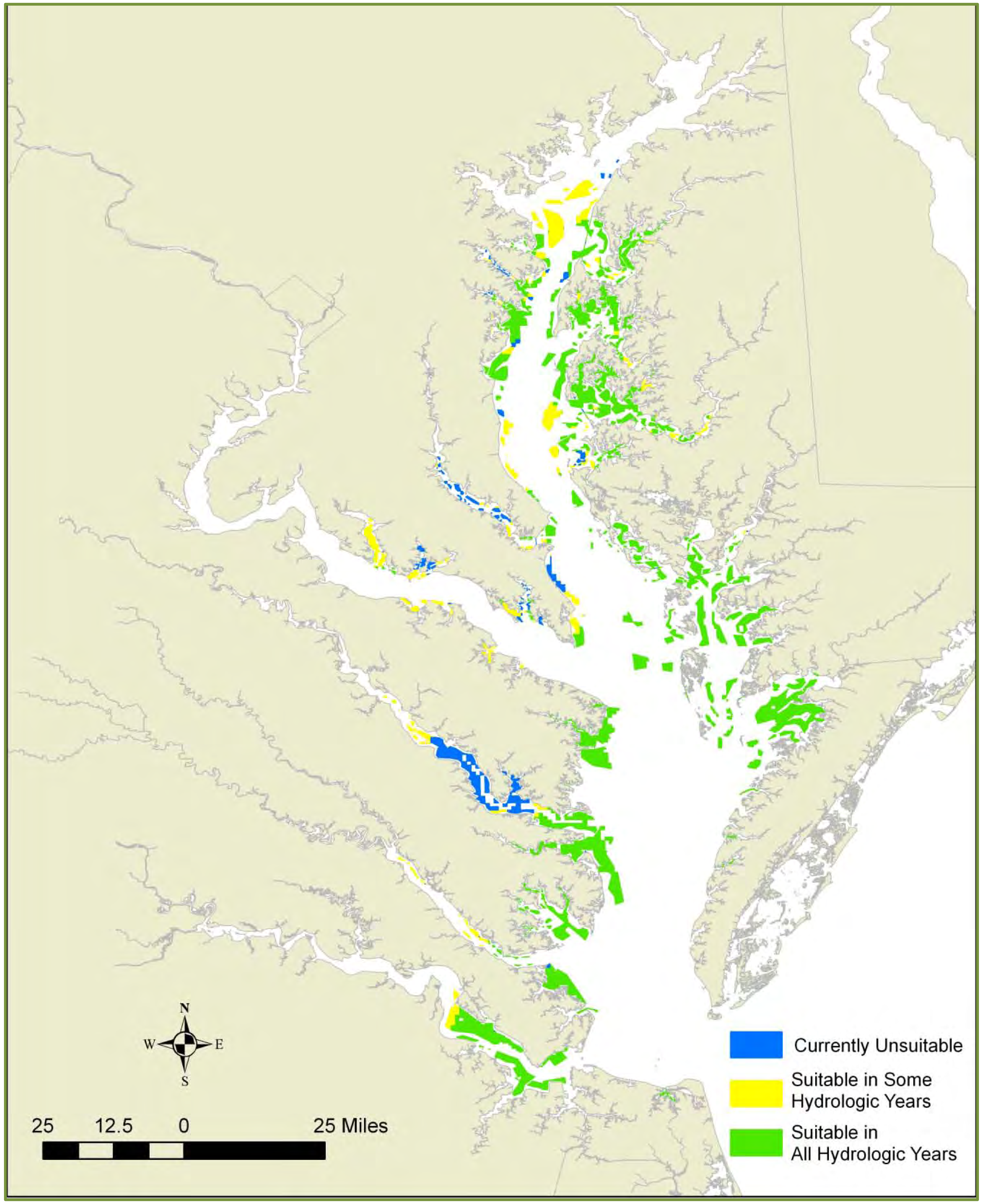


Currently unsuitable
denotes areas that do not meet the absolute criteria under current conditions under any hydrologic regime (wet, dry, average rainfall).

Suitable in some hydrologic years
denotes areas that meet the absolute criteria in some, but not all hydrologic regimes.

Suitable in all hydrologic years
denotes areas that meet the absolute criteria regardless of hydrologic regime.

Step 5. Tributary evaluation and prioritization – suitability analysis results.



Criteria considered

- Salinity
  - Surface
  - Bottom
- Bottom DO
- Water Depth
- Yates and Baylor Grounds

Total Suitable Area

MD= 132,000 acres

VA= 121,000 acres

Step 5. Tributary evaluation and prioritization – summary by state.

Maryland Data

A	B	C	D	E	F				G	H	I	J	K	L	M	N	O	P
	Salinity Type		Scale							Sanctuaries			Suitability Analysis- Absolute Criteria and Yates/Baylor				Hydrodynamics	Tier
Distinct Sub-Segment (DSS)	Salinity	Salinity > or < 12 ppt	Yates or Baylor Grounds (Historic Oyster habitat) (acres)	Oyster Habitat within Yates/Baylor Grounds (43% Yates; 47% Baylor)	Raw Restoration Target-minimum (20%)	Raw Restoration Target-maximum (40%)	Rounded Restoration Target(min) (acres)	Rounded Restoration Target (max) (acres)	Rounded Restoration Target Range (acres)	Existing Designated Oyster Sanctuaries (acres)	Existing Restored Habitat	Revised Target	Suitable All Conditions	Suitable Some Conditions	Not Currently Suitable Under All Conditions	Is suitable Habitat Greater Than Restoration Target?	Qualitative Trap Estuary Retention Rating	Restoration Teir (I, II)
MARYLAND				(43%)	(20%)	(40%)												
Magothy River	Low Mesohaline	<	228	98	20	39	20	40	20-40	5,603			193	0	0	yes	M	II
Severn River	High Mesohaline	<	1,980	851	170	341	200	300	200-300	7,664	10	190-290	1,411	147	220	yes	H	I
South River	High Mesohaline	<	1,057	455	91	182	90	200	90-200	2,238			872	48	61	yes	H	I
Rhode River	High Mesohaline	<	84	36	7	14	10	10	10-10				26	17	0	yes	L	II
West River	High Mesohaline	<	136	58	12	23	10	20	10-20				33	23	0	yes	L	II
Chester River	Low and High Mesohaline	<	12,747	5,481	1,096	2,192	1,100	2,200	1100-2200				10,577	809	4	yes	H	I
lower Chester		<	6,344	2,728	546	1,091	500	1,100	500-1100	24,310			5,179	562	4	yes		
upper Chester		<	6,404	2,754	551	1,101	600	1,100	600-1100	13,814			5,398	247	0	yes		
Corsica River	Low Mesohaline	<	190	82	16	33	20	30	20-30				67	114	0	yes	L	II
Eastern Bay	High Mesohaline	<	17,358	7,464	1,493	2,986	1,500	3,000	1500-3000				14,472	919	0	yes	H	I
upper Eastern Bay		<	9,070	3,900	780	1,560	800	1,600	800-1600	8,825			7,328	705	0	yes		
lower Eastern Bay		<	8,288	3,564	713	1,426	700	1,400	700-1400	6,543			7,145	213	0	yes		
Choptank River	Oligohaline, Low and High Mesohaline	~	20,995	9,028	1,806	3,611	1,800	3,600	1800-3600				17,232	1,372	21	yes	H	I
upper Choptank		~	4,938	2,123	425	849	400	800	400-800	13,978			3,185	874	0	yes		
lower Choptank		>	16,057	6,905	1,381	2,762	1,400	2,800	1400-2800	11,903			14,047	498	21	yes		
Harris Creek	High Mesohaline	~	3,479	1,496	299	598	300	600	300-600	4,519			3,245	0	1	yes	H	I
Broad Creek	High Mesohaline	~	2,569	1,105	221	442	200	400	200-400				2,353	0	0	yes	H	I
Little Choptank	High Mesohaline	>	4,092	1,760	352	704	400	700	400-700	9,221			1,851	910	841	yes	H	I
Honga River	High Mesohaline	>	5,163	2,220	444	888	400	900	400-900				4,798	0	12	yes	M	II
Potomac River	Tidal Fresh, Oligohaline, Low and High Mesohaline	~	10,808	4,647	929	1,859	900	1,900	900-1900				253	7,207	1,595	no	M	II
upper Potomac		<	0	0	-	-	-	-	-				-	-	-	yes		
middle Potomac		~	9,817	4,221	844	1,689	800	1,700	800-1700	3,626			253	6,724	1,337	no		
lower Potomac		>	991	426	85	170	90	200	90-200				0	483	258	no		
St. Mary's River	High Mesohaline	>	2,461	1,058	212	423	200	400	200-400	1,302			341	1,092	610	yes	H	I
Tangier Sound	Polyhaline, High Mesohaline	~	21,049	9,051	1,810	3,620	1,800	3,600	1800-3600				18,163	69	23	yes	H	I
upper Tangier		~	11,086	4,767	953	1,907	1,000	1,900	1000-1900	17,018			9,812	69	21	yes		
lower Tangier		>	9,963	4,284	857	1,714	900	1,700	900-1700	102			8,351	0	2	yes		
Fishing Bay	Low Mesohaline	~	4,434	1,907	381	763	400	800	400-800				4,404	0	0	yes	M	II
Monie Bay	Low Mesohaline	<	392	169	34	67	30	70	30-70	541			392	0	0	yes	L	II
Manokin R.	High Mesohaline	>	4,869	2,094	419	837	400	800	400-800	15,935			4,599	0	0	yes	M	II
Big Annemessex R.	High Mesohaline	>	1,220	525	105	210	100	200	100-200	722			1,220	0	0	yes	M	II
Little Annemessex R.	Polyhaline	>	0	0	-	-	-	-	-				-	-	-	yes	L	II
Patuxent River	Oligohaline, Low and High Mesohaline	~	5,662	2,435	487	974	500	1,000	500-1000				153	986	2,817	no	M	II
upper Patuxent		<	1,474	634	127	254	100	300	100-300	10,090			0	63	1,188	no		
lower Patuxent		>	4,188	1,801	360	720	400	700	400-700	1,165			153	924	1,630	no		
Upper MD Mainstem		<	21,461	9,228	1,846	3,691	1,800	3,700	1800-3700	4,747			4,623	15,833	354	yes	L	II
Middle West Mainstem		~	25,178	10,827	2,165	4,331	2,200	4,300	2200-4300	25,144			15,100	3,733	1,156	yes	M	II
Middle East Mainstem		~	21,385	9,196	1,839	3,678	1,800	3,700	1800-3700	2,476			13,299	5,856	596	yes	M	II
Lower West Mainstem		>	16,841	7,242	1,448	2,897	1,400	2,900	1400-2900	3,467			4,008	2,652	2,092	yes	M	II
Lower East Mainstem		>	8,664	3,726	745	1,490	700	1,500	700-1500	38,797			7,848	0	0	yes	M	II

Virginia Data

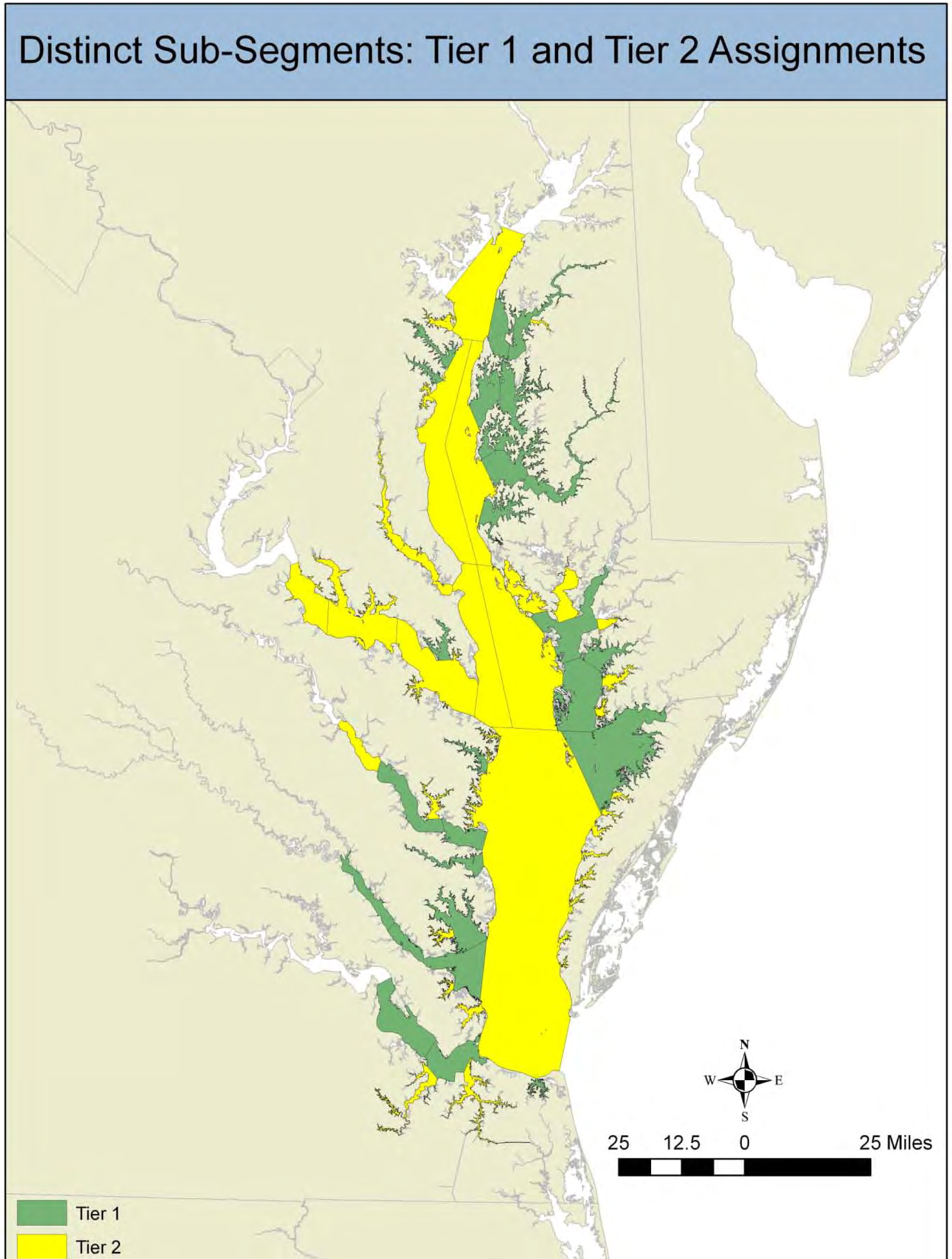
A	B	C	D	E	F				G	H	I	J	K	L	M	N	O	P
	Salinity Type		Scale							Sanctuaries			Suitability Analysis- Absolute Criteria and Yates/Baylor				Hydrodynamics	Tier
Distinct Sub-Segment (DSS)	Salinity	Salinity > or < 12 ppt	Yates or Baylor Grounds (Historic Oyster habitat) (acres)	Oyster Habitat within Yates/Baylor Grounds (43% Yates; 47% Baylor)	Raw Restoration Target-minimum (20%)	Raw Restoration Target-maximum (40%)	Rounded Restoration Target(min) (acres)	Rounded Restoration Target (max) (acres)	Rounded Restoration Target Range (acres)	Existing Designated Oyster Sanctuaries (acres)	Existing Restored Habitat	Revised Target	Suitable All Conditions	Suitable Some Conditions	Not Currently Suitable Under All Conditions	Is suitable Habitat Greater Than Restoration Target?	Qualitative Trap Estuary Retention Rating	Restoration Teir (I, II)
VIRGINIA				(47%)	(20%)	(40%)												
Virginia Mainstem		>	36,136	16,984	3,397	6,794	3,400	6,800	3400-6800	-			29,108	0	0	yes	L	II
Little Wicomico R.	Polyhaline	>	206	97	19	39	20	40	20-40	-			198	0	0	yes	L	II
Cockrell Creek	High Mesohaline	>	23	11	2	4	2	4	2-4	-			11	0	0	yes	L	II
Great Wicomico R.	High Mesohaline	>	2,479	1,165	233	466	200	500	200-500	80	100	100-400	2,086	0	0	yes	H	I
Rappahannock River	Tidal Fresh, Oligohaline, Low and High Mesohaline	>	40,127	18,860	3,772	7,544	3,800	7,500	3800-7500				7,443	3,225	16,874	yes	H	I
upper Rappahannock		~	2,520	1,184	237	474	200	500	200-500				0	1,977	543	no		
middle Rappahannocl		>	23,904	11,235	2,247	4,494	2,200	4,500	2200-4500				0	579	15,962	no		
lower Rappahannock		>	13,703	6,440	1,288	2,576	1,300	2,600	1300-2600	48			7,443	669	369	yes		
Corrotoman River	High Mesohaline	>	2,757	1,296	259	518	300	500	300-500	2			0	0	2,171	no	M	II
Piankatank River	Polyhaline	>	7,097	3,336	667	1,334	700	1,300	700-1300	7			6,210	0	0	yes	H	I
Mobjack Bay	Polyhaline	>	8,866	4,167	833	1,667	800	1,700	800-1700	-			8,589	0	0	yes	H	I
Severn River	Polyhaline	>	193	91	18	36	20	40	20-40	-			165	0	0	yes	L	II
York River	Tidal Fresh, Oligohaline, Polyhaline, High Mesohaline	~	11,986	5,633	1,127	2,253	1,100	2,300	1100-2300	60			8,750	1,619	117	yes	H	I
upper York		~	760	357	71	143	70	100	70-100				0	508	3	no		
lower York		>	11,226	5,276	1,055	2,110	1,100	2,100	1100-2100				8,750	1,112	115	yes		
Poquoson River	Polyhaline	>	180	85	17	34	20	30	20-30	-			180	0	0	yes	L	II
Back River	Polyhaline	>	182	86	17	34	20	30	20-30	-			182	0	0	yes	L	II
Pocomoke/Tangier	Polyhaline, High	>	31,576	14,841	2,968	5,936	3,000	5,900	3000-5900	8			29,879	0	2	yes	H	I
Onancock Creek	Polyhaline	>	0	0	-	-	-	-	-	-			-	-	-	yes	L	II
Pungoteague Creek	Polyhaline	>	91	43	9	40	10	40	10	-			88	0	0	yes	L	II
Nandua Creek	Polyhaline	>	0	0	-	-	-	-	-	-			-	-	-	yes	L	II
Occohannock Creek	High Mesohaline	>	130	61	12	60	10	60	10	-			130	0	0	yes	L	II
Nassawaddox Creek	Polyhaline	>	166	78	16	80	20	80	20	-			100	0	0	yes	L	II
Hungars Creek	Polyhaline	>	0	0	-	-	-	-	-	-			-	-	-	yes	L	II
Cherrystone Inlet	Polyhaline	>	0	0	-	-	-	-	-	-			-	-	-	yes	L	II
Old Plantation Creek	Polyhaline	>	0	0	-	-	-	-	-	-			-	-	-	yes	L	II
James River	Tidal Fresh, Oligohaline, Polyhaline, Low and High Mesohaline	~	30,393	14,285	2,857	5,714	2,900	5,700	2900-5700				25,902	2,988	3	yes	H	I
upper James		~	20,815	9,783	1,957	3,913	2,000	3,900	2000-3900				16,521	2,988	3	yes	H	
lower James		>	9,578	4,502	900	1,801	900	1,800	900-1800				9,381	0	0	yes	H	
Elizabeth River	Polyhaline	>	2,620	1,231	246	493	200	500	200-500	14 sites			177	0	0	no	L	II
Nansemond River	Polyhaline	>	1,173	551	110	221	100	200	100-200	-			1,151	0	0	yes	L	II
Lynnhaven Bay	Polyhaline	>	986	463	93	185	90	200	90-200	52	50	40-150	251	0	0	yes	H	I

Master Plan Results:

Prioritization of Bay Tributaries

Tier 1 = Tributaries Suitable for Large-Scale Restoration Now

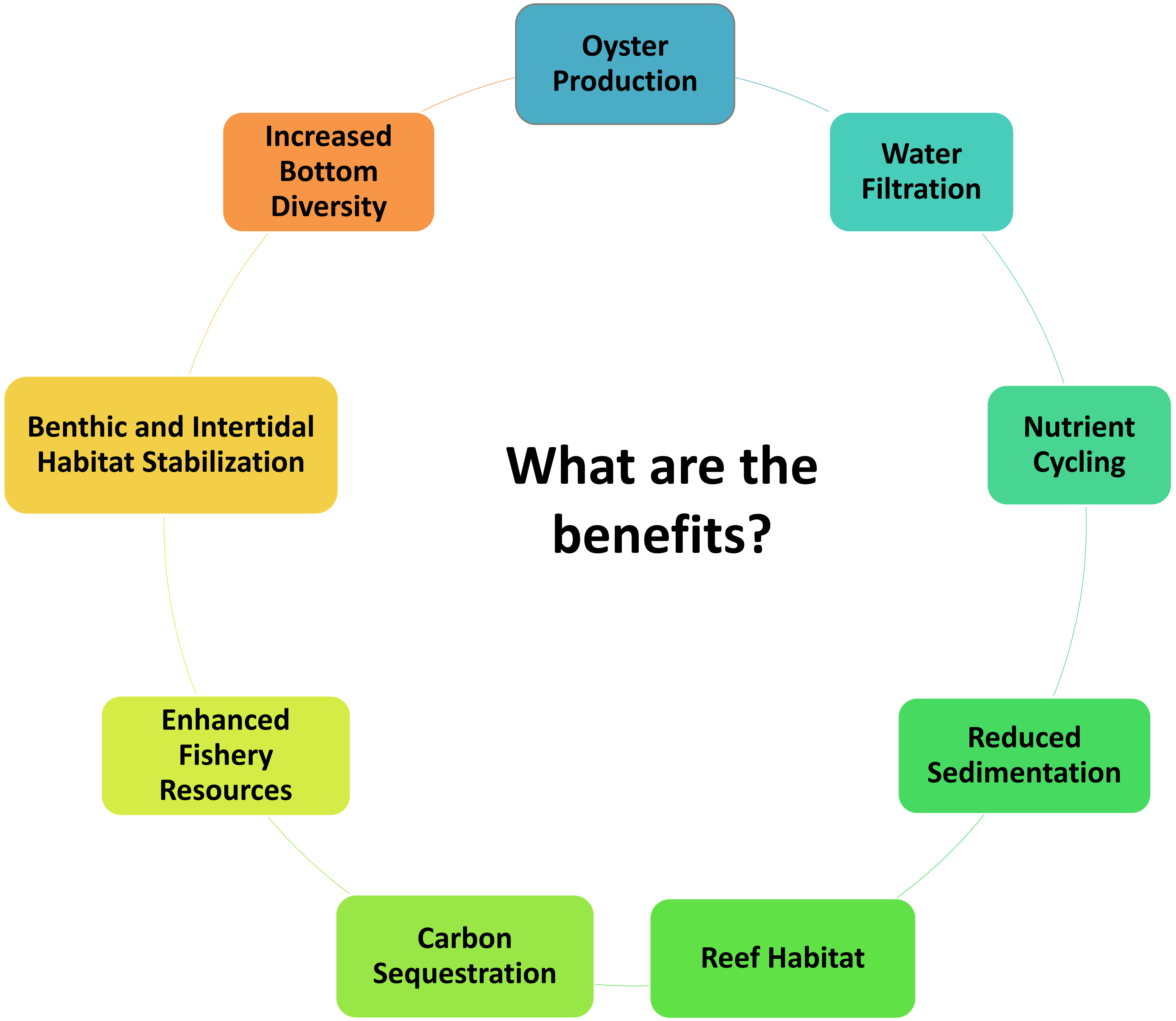
Tier 2 = Tributaries That Currently Have Physical or Biological Constraints to Large-Scale or Long-Term Sustainable Restoration



Tier 1 Tributaries/Areas	*Restoration Target (Acres)*
Maryland	
Severn River	190-290
South River	90-200
Chester River	1,100-2,200
Eastern Bay	1,500-3,000
Choptank River	1,800-3,600
Harris Creek	300-600
Little Choptank	400-700
Broad Creek	200-400
St. Mary's River	200-400
Tangier Sound (includes Nanticoke River)	1,800-3,600
Manokin River	400-800
Virginia	
Great Wicomico River	100-400
Rappahannock River (lower and middle segments)	3,800-7,500
Piankatank River	700-1,300
Tangier/Pocomoke	3,000-5,900
Mobjack Bay	800-1,700
York River	1,100-2,300
James River	2,900-5,700
Lynnhaven River	40-150

Costs and Benefits of Large-Scale Restoration

- Large-scale restoration is still in the learning mode
- Cost estimates for restoration need to include habitat construction, seeding, and monitoring
- Costs expected to be spread over multiple years for a given tributary
- Cost range for a tributary reflects the low and high acreage target and the lowest and highest priced alternate substrates.
- Example of a tributary cost estimate to achieve the restoration target:
  - Smallest Tier 1 MD tributary = South River, 90 to 200 acres, $16 million to $48 million
  - Largest Tier 1 MD tributary= Tangier Sound, 1,800 to 3,600 acres, $154 million to $652 million
- Estimates are conservatively high – existing habitat is not included in most estimates; some areas may need only seed (no substrate)
  - Once quantified in a tributary plan, these considerations would reduce the effort needed to reach restoration targets



Master Plan Recommendations

Specific Tributary Plan
- Develop with restoration partners
- Parameters to consider identified in master plan
- Additional surveys = population, bottom condition, hydrodynamic, larval transport, and recruitment

Construction
- Construct a portion of target (25, 50, or 100 acres) per year
- Funding dependent
- Continue until success metrics reached

Target Higher Salinities for Development of Disease Resistance
- Initial efforts in mesohaline-polyhaline salinities
- Special attention given to mid-river reefs

Reef Design Recommendations
- Bar morphology, reef fragmentation, reef height, reef topography, orientation to flow, water depth, distance between reefs, etc.

Research Needs
- Quantification of benefits, larval transport, development of disease resistance and transmission, site selection with respect to water currents and bottom topography, etc.

Use Adaptive Management
- Such as additional stocking of disease resistant oysters, moving of disease resistant spat-on-shell, addition of fresh substrate, measures to reduce predation, etc.

Monitoring Protocols
- Monitoring element, type of data recorded, method of monitoring, monitoring objective

Concentrate Resources and Funding
- Necessary to establish self-sustaining populations

Follow Success Metrics Defined by Oyster Metric Workgroup
- Biomass, density, and shell accretion

Comparison of Selected Tributaries to Other Restoration Plans

Tributary	*MD Oyster Advisory Commission*	*MD Oyster Restoration and Aquaculture Development Plan*	*VA Blue Ribbon Panel*	*USACE Native Oyster Restoration Master Plan*
MARYLAND				
Magothy River	X	X		
Chester River		X (upper and lower)		X
Little Choptank River		X		X
Patuxent River		X (upper and small area in lower)		
Choptank River	X	X (middle and lower)		X
Broad Creek				X
Harris Creek		X		X
Tred Avon River		X (upper)		X (within lower Choptank)
Severn River	X	current sanctuary		X
South River	X	current sanctuary (upper)		X
Honga River	X			X
Eastern Bay		X (parts)		X
Manokin River				X
Miles River		X (upper)		X (within Eastern Bay)
Wye River		X		X (within Eastern Bay)
St. Mary's River	X	X (upper)		X
Mainstem		X (Point Lookout)		
Breton Bay		X		
Tangier Sound				X
Nanticoke River		X		X (included in Tangier Sound)
Manokin River		X		
VIRGINIA				
Eastern Shore seaside coastal bays			X	
Lynnhaven River			X	X
Great Wicomico River			X	X
Piankatank River			X	X
Rappahannock River				middle and lower segments
Mobjack Bay				X
York River				X
Pocomoke/Tangier Sound				X
James River				X
Lynnhaven River				X

Future Tributary Plans

First up in Maryland = Harris Creek in the Choptank River.

Tributary plan is underway.

Base mapping and bathymetry has been completed.

22 acres being constructed in May-June 2012.

More acres to be constructed in winter 2012-13.

Design Considerations

Design Factor	Recommendation
Reef morphology and size	Determine in tributary plans, will depend on historic size, currently suitable bottom, and quantity of hard substrate needed to provide suitable bottom habitat.
Reef fragmentation	Include fragmentation in designs during tributary plans, likely at intermediate levels (<50%).
Reef height	Elevate reefs off bottom, expect minimum needed is 1 foot. Determine specific height in tributary plans. Include heterogeneity.
Reef topography	Include heterogeneity. Provide for intersticial space within reef complex.
Orientation to flow	Determine in tributary plans based on historic position and current water flows and bathymetric gradients.
Water depth	Less than 20 feet MLLW.
Distance between reefs	Determine in tributary plans based on historic placement. Consider larval transport modeling findings.
Predator exclusion devices	Determine in tributary plans based on location in Bay, need and effectiveness of devices, costs, and available resources.
Poaching deterrents	Incorporate into future restoration plans.
Substrate	Determine in tributary plans, will depend on available resources and other users/activities in selected tributary.
Sea level rise and climate change	Evaluate proposed restoration plans for future sea level rise and climate change impacts in tributary plans.

NOAA
MARYLAND DEPARTMENT OF NATURAL RESOURCES

Oyster Recovery Partnership
ORP

Partners in Restoration

Activity (3)

Step 1	Step 2	Step 3	Step 4	Step 5	Step 6
Site Selection	Bottom Survey	Reef Construction	Ground Truth	Produce & Plant Oysters	Post Planting Monitoring

Partners / Roles

Project Coordination - ORP

Step 1	Step 2	Step 3	Step 4	Step 5	Step 6
All	NOAA, MGS ($) DNR, NOAA	Watermen, Corporation ($) NOAA, USACE, DNR	UMD, ORP ($) NOAA	UMCES, ORP (1)(2) ($) DNR, UMCES, NOAA	UMD, DNR, Morgan, USNA ($) NOAA, DNR, USACE

Enforcement & Management Agency – NRP / DNR

Permits / Regulations – USACE Regulatory / DNR / MDE

Data Collection & Management – DNR / ORP / NOAA

Notes: (1) In 2009, DNR (Piney Point), Morgan State, ORP & watermen conducting remote setting pilot projects; (2) Based on salinity regimes, oyster reefs may only receive shell rehabilitation (no spat) in higher salinity waters where a natural spat set could occur; (3) For aquaculture projects, watermen to be trained on all steps with guidance and technical support by partners; the steps may be modified to minimize watermen costs.

State Agency, Non-Profit, Federal Agency, University, Corporation

H-5: PUBLIC MEETING SIGN-IN SHEETS AND WRITTEN COMMENTS

Native Oyster Restoration Master Plan

Maryland-Western Shore Open House Sign-In Sheet

Name	Affiliated group	E-mail Address	Telephone Number
Stephanie Westby	NOAA	Stephanie.Westby@NOAA.gov	410 991 3564
Ken Hastings	self	kensandyh@verizon.net	(301)884-4872
Eric Weissberger	DNR	eweissberger@dnr.state.md.us	(410) 260-8344
Robert Wieland		Robert.Wieland@gmail.com	410 822 5998
Bob Whitcomb	SRA	bwhitcomb2@comcast.net	410-849-3072
Frank Marenghi	DNR	fmarenghi@dnr.state.md.us	410-260-8302
Doug Legum		Douglegum@AOL.COM	
Anne Thomas		~~alfdt75~~ ALFDT75@gmail.com	#(410)349-4997

Native Oyster Restoration Master Plan

Maryland-Western Shore Open House Sign-In Sheet

April 10, 2012 – Chesapeake Bay Foundation

Name	Affiliated group	E-mail Address	Telephone Number
ANN RASMUSSEN		arasmus1@yahoo.com	410-221-6262
MARK W. RANKIN		MARKRANKIN95511@YAHOO.COM	410-221-6262
Alex Dominguez		adominguez@ap.org	410 837 8315 443 831 2862 [illegible]
Karl Willey	CBF	KWilley@CBF.ORG	410.353.0564
Dan Johannes	CBF	DJOHANNES@CBF.ORG	703-585-3066 (c)
Carmera Thomas	CBF	CThomas@cbf.org	443-481-2156
Evan Thalenberg	CHESAPEAKE BAYSAVERS	EKTLAW@gmail.com	410-625-9100
Chris Judy	DNR	cjudy@dnr.state.md.us	410 260 8259
Lindsay Sheppard		LSheppard@aacps.org	443-223-5201

Comment Sheet

Native Oyster Restoration Master Plan Open House (Maryland)

You may give your written comments to any Corps staff member during the meeting. You may also mail your comments to:

Ms. Angie Sowers
Baltimore District Corps of Engineers
P.O. Box 1715
Baltimore, MD 21203-171

Or by e-mail to NativeOysterRestMasterPlan@usace.army.mil.

Name Chris Judy

Address Md DNR
580 Taylor Ave B-2 Annapolis MD 21401

Email cjudy@dnr.state.md.us

Phone Number 410 260 8259

Comments

It would help to have these posters on-line and/or the power pt presentation on-line.

Thanks for the clear, well designed posters. Well done.

Native Oyster Restoration Master Plan

Maryland-Eastern Shore Open House Sign-In Sheet

April 19, 2012 – Chesapeake College, Wye Mills, MD

Name	Affiliated group	E-mail Address	Telephone Number
Steve Schneider	MD-DNR	sschneider@dnr.state.md.us	410-260-8329
Fredrick Bolem [illegible]	CBCFA		410 548 2773
Bunky Chance	CBCFA-MWA	TlbtCo.Wtrmns Assoc. Com	443-496-1359
Bill Wolinski	Talbot Co DPW	wwolinski@talbotcountymd.gov	410-770-8169
W^m^. N. Kirby	—	wkirby3@goeaston.net	410-822-4421
Daniel Webster	Somerset Cty	1seafoodx1@netzero.com	443-366-2010
Greg Reinbold	Record Observer Star Democrat	newsroom@recordobserver.com	410 758 1400
JR Thomas	Harris Oyster Co	Raythom@yahoo.com	410-725-0007
Don Meritt	UMCES		

Native Oyster Restoration Master Plan
Maryland-Eastern Shore Open House Sign-In Sheet

April 19, 2012 – Chesapeake College, Wye Mills, MD

Name	Affiliated group	E-mail Address	Telephone Number
John Osborn	ARGO System, LLC	josborn@argo-sys.com	(410) 768-2444
Jeff Johnson	" "	jjohnson@argo-sys.com	" "
Jeff Harrison	Talbot Co. Waterm Asc	harrison2413@verizon.net	410 829 6892
Frank DiGialleonardo	Corsica River Conservancy	franardo@gmail.com	410 758 4806
Phil Jewell	Queen Annes County Watermans Assoc.		410-490-8897
Tony Young	QA Co. Waterman		410 827 6295
Moochie Gilmer	QA Co Watermen	baitmanmooch@verizon.net	

Native Oyster Restoration Master Plan

Maryland-Eastern Shore Open House Sign-In Sheet

April 19, 2012 – Chesapeake College, Wye Mills, MD

Name	Affiliated group	E-mail Address	Telephone Number
Chrissy Aull	Wye River Upper School	chrissyaull@wyeriverupperschool.org	410-827-5822
Dick Sossi	Cong. Andy Harris, MD	Richard.Sossi G Mail.House.Gov	4106435425
PATRICK LEE		PATRICKMLEEJR@GMAIL.COM	443-496-0022
Will Nuckols	WH Nuckols Consulting	Will@whnuckolsconsulting.com	443 994 1493
Linda Prochaska	Office of US Senator Barbara Mikulski	linda_prochaska@mikulski.senate.gov	410546-7711
Jamie Taylor		TaylorPileDriving@Gmail.com	443-880-7722
LAURA PLOSILA			
Elaine Tama			410 200 2194
PHIL HESSER		philliphesser@gmail.com	

Comment Sheet

Native Oyster Restoration Master Plan Open House (Maryland)

You may give your written comments to any Corps staff member during the meeting. You may also mail your comments to:

Ms. Angie Sowers
Baltimore District Corps of Engineers
P.O. Box 1715
Baltimore, MD 21203-171

Or by e-mail to NativeOysterRestMasterPlan@usace.army.mil.

Name Herman Harrison

Address

Email harrison2413@verizon.net

Phone Number 410-829-6892

Comments

In the first chart it said that granite and mixed shell had been used in the past 15 yrs. How did those planting perform as far as spat fall?

Comment Sheet

Native Oyster Master Planning Meeting (Virginia)

You may give your written comments to any Corps staff member during the meeting. You may also mail your comments to Susan Conner, Norfolk District Corps of Engineers, 803 Front Street, Norfolk Virginia 23510, or by e-mail to NativeOysterRestMasterPlan@usace.army.mil.

Name Jeff Harrison

Address

Email harrison2413@verizon.net

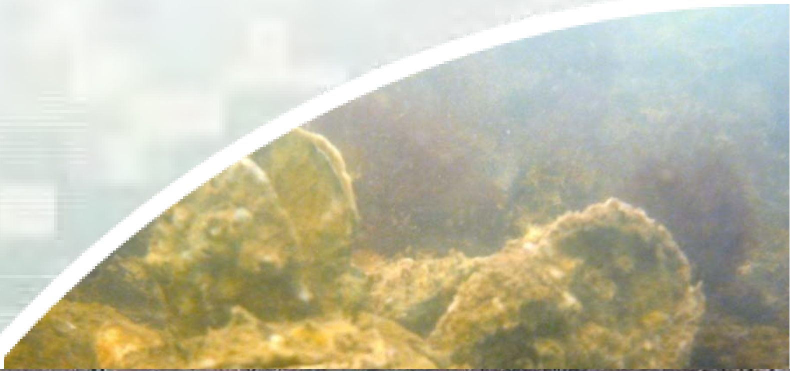
Phone Number 410-829-6892

Comments

Broad Creek in Choptank River is a Public Shellfish area that is harvestable. Are there any plans ~~to~~ in the Master plan to make oyster rehabilitation?

H-6: PUBLIC MEETING POWERPOINT PRESENTATIONS

USACE Native Oyster Restoration Master Plan



Public Meeting

April 2012

US Army Corps of Engineers
BUILDING STRONG®

Presentation Outline

- USACE Oyster Restoration Program
- Native Oyster Restoration Master Plan
  - Goals and Purpose
  - Plan Formulation
  - Results
  - Recommendations
- Path Forward
- Questions

USACE Oyster Restoration Program

Established in Section 704(b) of the Water Resources Development Act of 1986

- 75% Federal, 25% non-Federal funding
- First year of funding = FY1995
- Initially focused on Maryland; first report was in 1996, with cooperation agreement signed in 1997
- Maryland project sponsor is Maryland Department of Natural Resources
- Project has received up to $1-5 million Federal per year for MD+VA

Amended in 1996, 2000, 2002, 2006, and 2007

- Added Virginia to project location
- Increased authorization limit to $50 million
- Identifies specific type of construction activities
- Purpose : To establish sanctuaries and harvest management areas
- USACE activities to be consistent with other plans and strategies

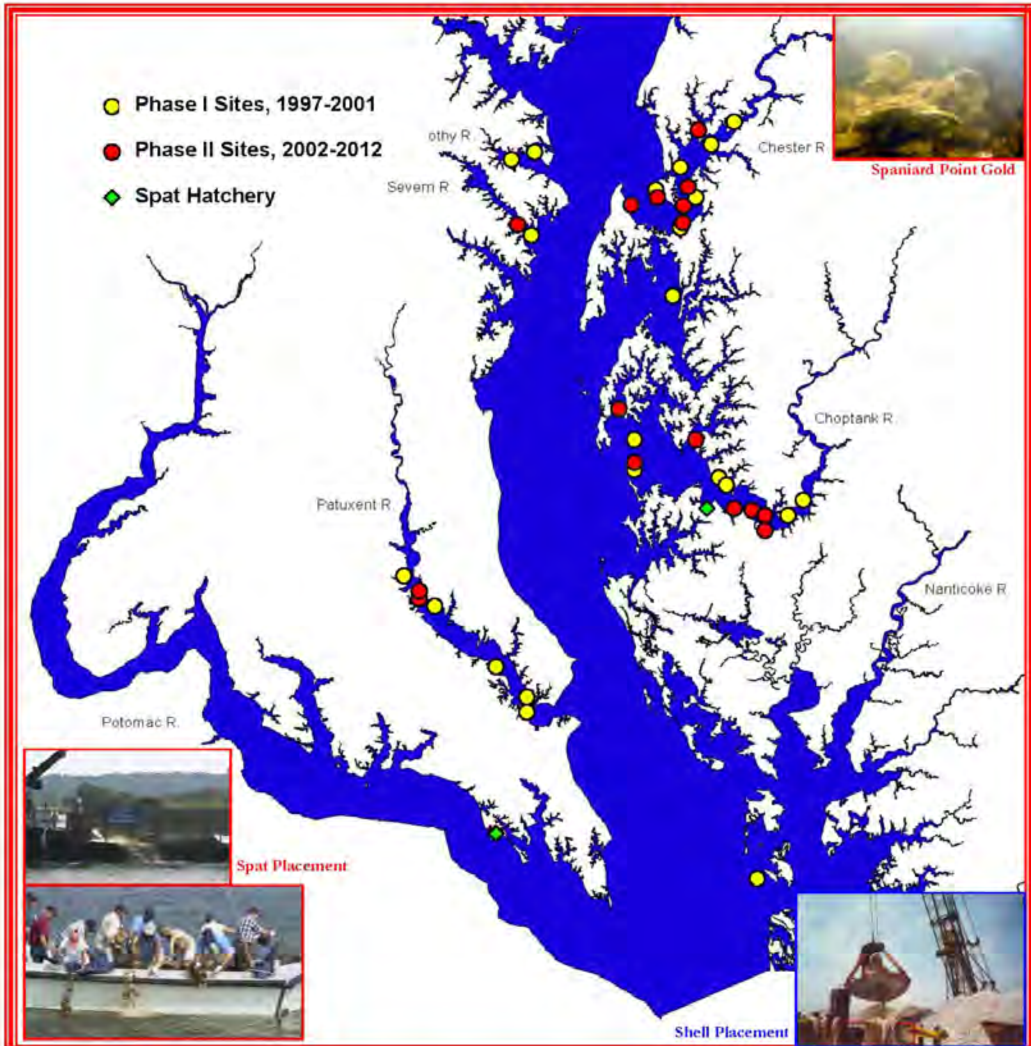
Construction Summary
Maryland
1997-2011

- 459 acres of substrate placed
- 22 additional acres at Harris Creek to be constructed May-June 2012
- Locations:
  - Magothy, Severn, and Patuxent Rivers
  - Chester and Choptank Rivers (includes Harris Creek), Eastern Bay
  - Kedges Strait
- Material Used:
  - Dredged fossil shell (1997-2006)
  - Alternative substrate (2009-2011)
- Periodic project monitoring

Construction Summary
Virginia
2001-2011

- 389 acres of substrate placed
- Locations:
  - Rappahannock (Section 510 authority)
  - Tangier/ Pocomoke Sounds
  - Great Wicomico and Lynnhaven Rivers
- Material Used:
  - Dredged fossil shell (2001-2011)
- Periodic project monitoring

USACE Oyster Restoration Program - Maryland



US Army Corps of Engineers
Baltimore District

Chesapeake Bay Oyster Restoration Program

Chesapeake Bay Oyster Restoration Program

Project Authority: Section 704(b) of the 1986 Water Resources Development Act, as amended

Project Activities:

Seed Bars

1997	Kedges Strait
1998	Eastern Bay

New Oyster Bars

1997	Choptank and Patuxent Rivers
1998	Chester River
1999	Magothy, Patuxent and Severn Rivers
2000	Choptank River
2001	Chester River
2002	Choptank and Patuxent Rivers
2003-04	Choptank and Chester Rivers
2005-06	Chester River
2009	Severn River
2010	Choptank River (Cook Point Sanctuary)
2011-2	Choptank River (Harris Creek)

Total Completed = 459 acres for 1997-2011

Spat Placement (by MDNR and ORP)

1997	8 million
1998	4 million
1999	12 million
2000	8 million
2001	26 million
2002	138 million
2003	24 million
2004	146 million
2006	130 million
2007	64 million
2008	213 million
2009	337 million
2010	61 million
2011	93 million
2012	

Monitoring for Disease/Survival/Growth

1997-Present

Ongoing Activities:

- Construction of 22 acres in the Harris Creek sanctuary
- Project monitoring
- Finalization of a long-term master plan for entire Chesapeake Bay (both Maryland and Virginia)

Non-Federal Sponsor: Maryland Department of Natural Resources

Other Project Participants: Oyster Recovery Partnership
NOAA
University of Maryland

Native Oyster Restoration Master Plan

Long-Term Restoration Goal:
Throughout the Chesapeake Bay, restore an abundant, self-sustaining oyster population that performs important ecological functions such as providing reef community habitat, nutrient cycling, spatial connectivity, and water filtration, among others, and contributes to an oyster fishery.

Operational Goal:
Identify tributaries/regions most likely to develop sustainable populations of oysters with the implementation of reef construction, seeding, and other oyster restoration activities.

Purpose

Implementation

- The master plan ensures that USACE-implemented oyster restoration is conducted in a logical, science-based, and cost-effective manner with the greatest potential for success in achieving the restoration goal.

Strategic Plan

- The master plan will present a strategic plan for pursuing long-term, wide-scale restoration throughout the Bay that complements the States' oyster restoration programs as well as other Bay-wide restoration efforts and future uses of the Chesapeake Bay.

Oyster Locations

- It will not define specific projects for specific locations; locations will be determined in future tributary plans.

Plan Formulation Process

1. Develop formulation white papers

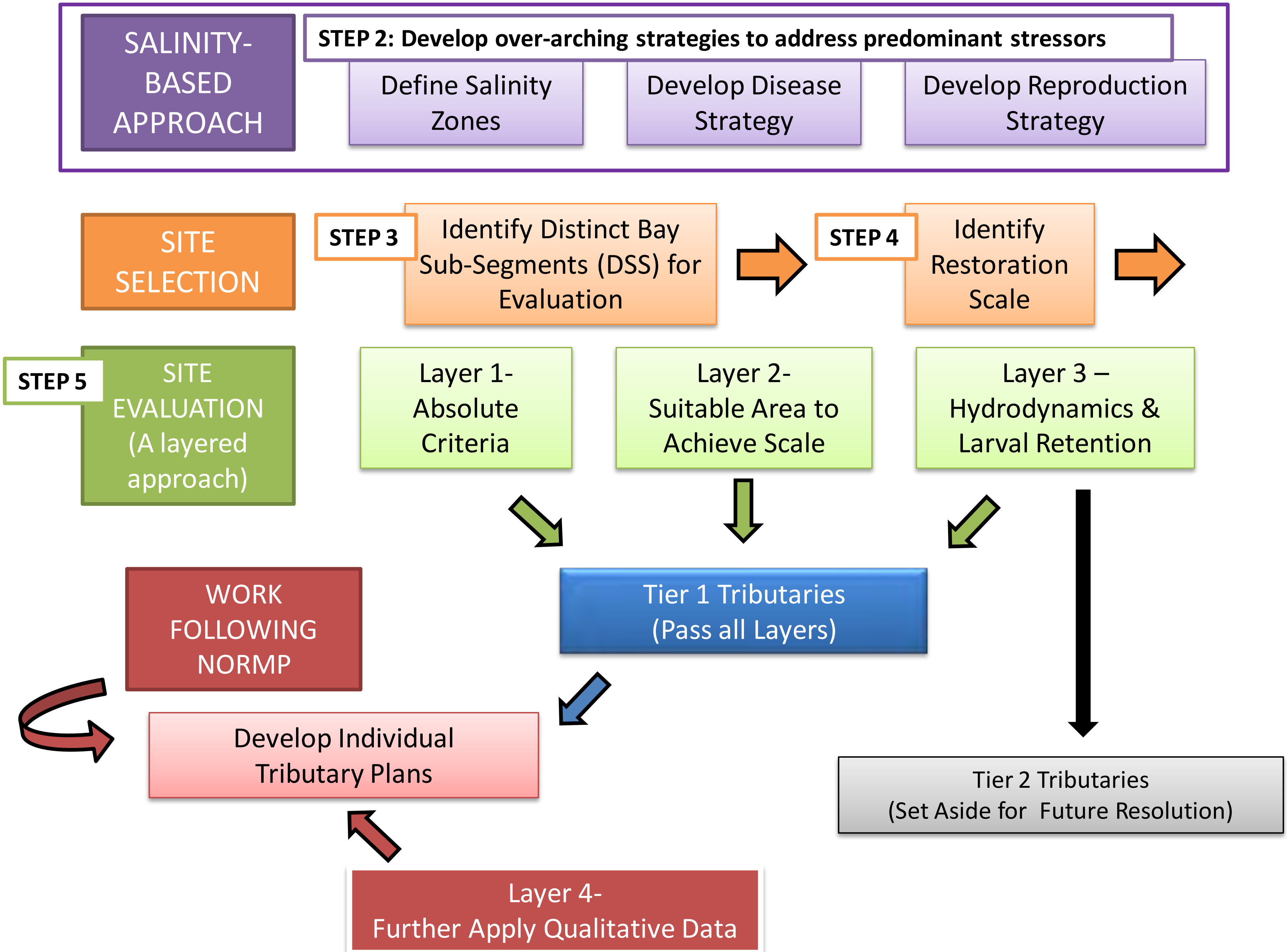
2. Adopt salinity-zone, disease, and reproduction strategies

3. Identify distinct sub-segments of the Chesapeake Bay for evaluation and prioritization

4. Determine the appropriate scale at which restoration should be undertaken

5. Tributary evaluation and prioritization:

A layered formulation evaluation	Identify Tier I and II Bay segments


SALINITY-BASED APPROACH
STEP 2: Develop over-arching strategies to address predominant stressors
Define Salinity Zones
Develop Disease Strategy
Develop Reproduction Strategy
SITE SELECTION
STEP 3
Identify Distinct Bay Sub-Segments (DSS) for Evaluation
STEP 4
Identify Restoration Scale
STEP 5
SITE EVALUATION (A layered approach)
Layer 1- Absolute Criteria
Layer 2- Suitable Area to Achieve Scale
Layer 3 – Hydrodynamics & Larval Retention
WORK FOLLOWING NORMP
Tier 1 Tributaries (Pass all Layers)
Develop Individual Tributary Plans
Tier 2 Tributaries (Set Aside for Future Resolution)
Layer 4- Further Apply Qualitative Data

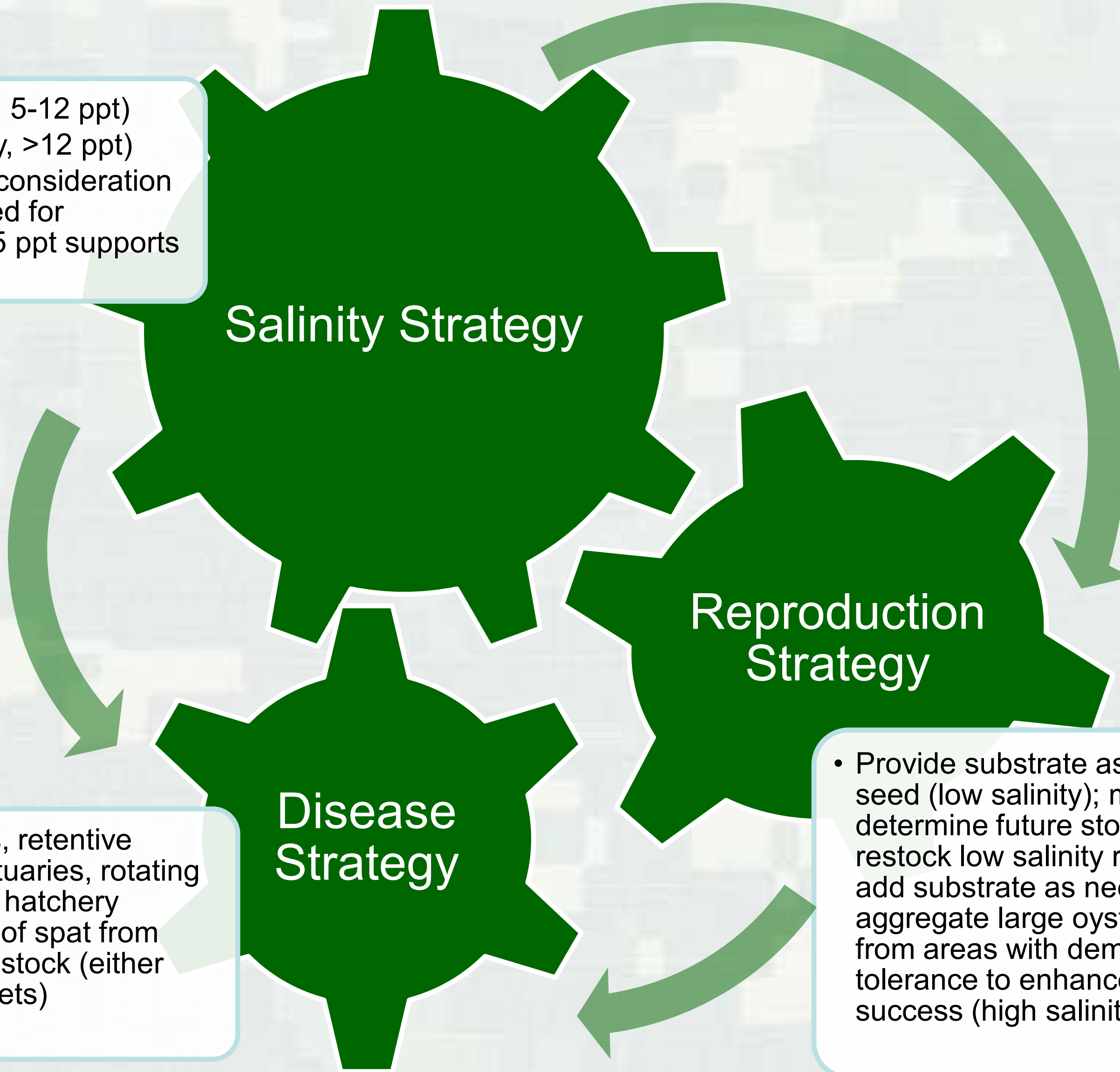
Step 1- Develop White Papers

- Scale
- Disease
- Populations – bayscape setting
- Populations - individual reefs
- Physio-chemical factors
- Hydrodynamics
- Reproduction

- ➢ Significance to oyster restoration and master plan
- ➢ Scientific basis and state of knowledge
- ➢ Application to the master plan
- ➢ Reviewed and coordinated with resource agencies

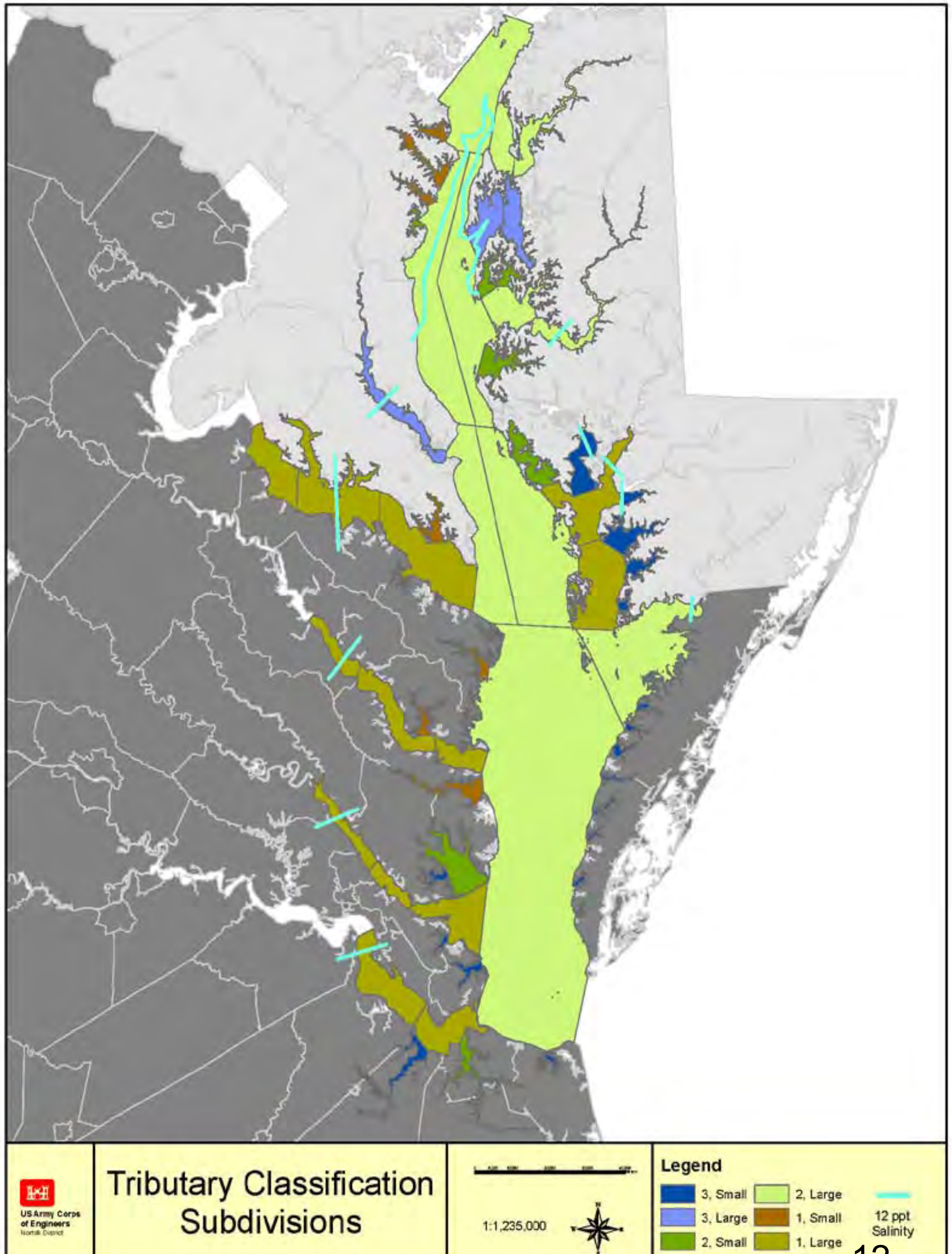
Step 2: Salinity-Based Approach

- Zone 1 (low salinity, 5-12 ppt)
- Zone 2 (high salinity, >12 ppt)
- Plans will take into consideration that >8 ppt is needed for reproduction, but >5 ppt supports growth



- Incorporates sanctuaries, retentive systems such as trap estuaries, rotating broodstock approach for hatchery production, and planting of spat from disease-resistant parent stock (either from hatcheries or wild sets)

- Provide substrate as needed and seed (low salinity); monitor to determine future stocking needs; restock low salinity reefs at 2-3 years; add substrate as needed; Stock and aggregate large oysters harvested from areas with demonstrated disease tolerance to enhance fertilization success (high salinity)



Step 3: Distinct Sub-Segment Delineations

34 Maryland segments
29 Virginia segments

Step 4: Scale

Scale = the approximate number of acres of functioning habitat in a given tributary or sub-region required to develop a self-sustaining oyster population. No "one size fits all."

What do we know???

- Past restoration efforts have been too small to impact system
- Need to concentrate resources

Define historic habitat baseline

Identify the percent of historic habitat that needs to be restored to achieve goals.

Restoration goal = **20-40%** of historic (corrected) habitat

Step 5: Tributary Evaluation and Prioritization

Layer 1 → Absolute Criteria →

Identify absolute criteria. Determine the number of suitable acres for restoration available.

Layer 2 → Scale →

Determine if there is enough suitable acreage available to meet the scale targeted for sustainable restoration.

Layer 3 →Qualitative Hydrodynamic Rating →

Indicates whether a tributary has high, medium or low indicators of the hydrodynamic properties preferred for restoration.

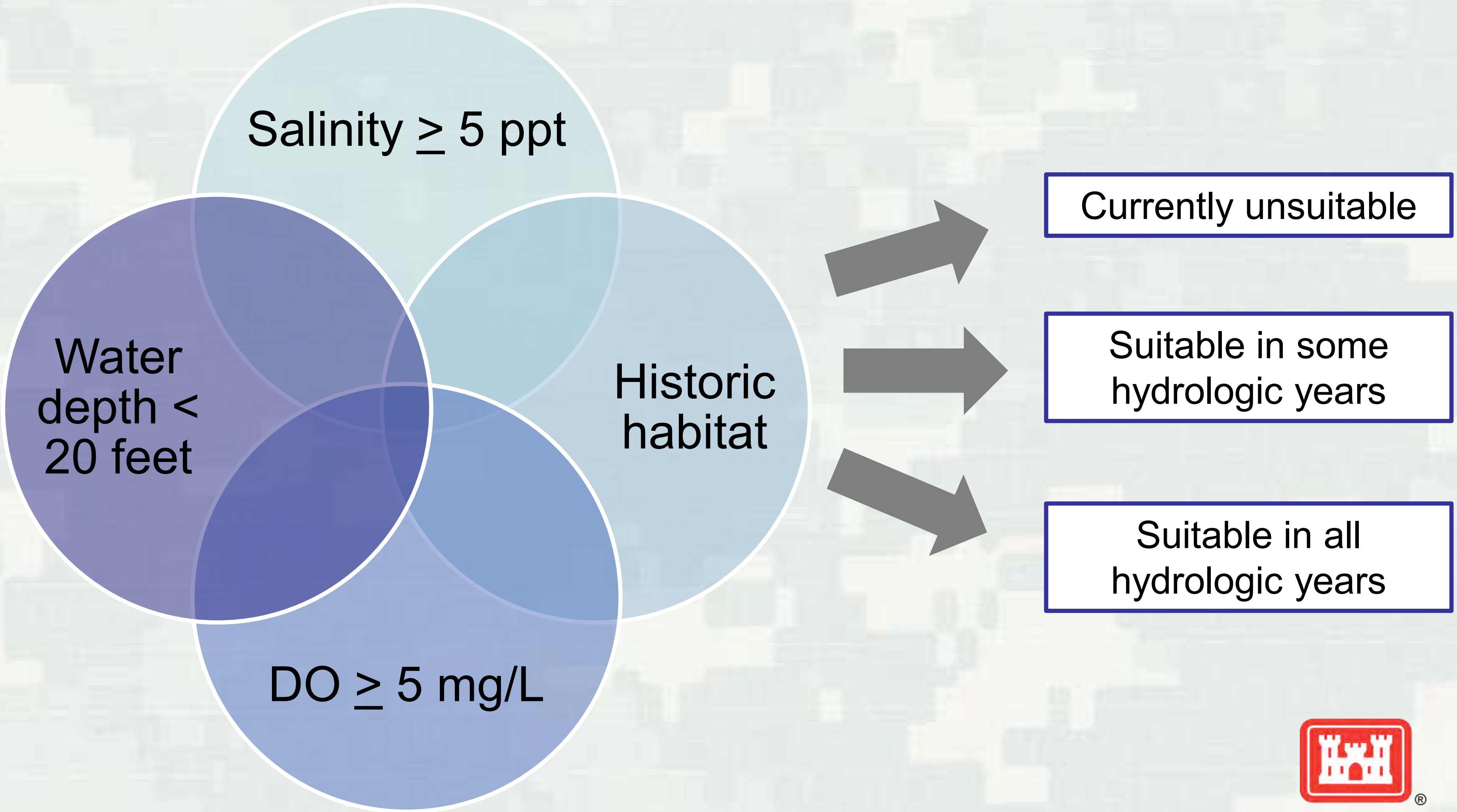
Layer 4 → Qualitative Data →

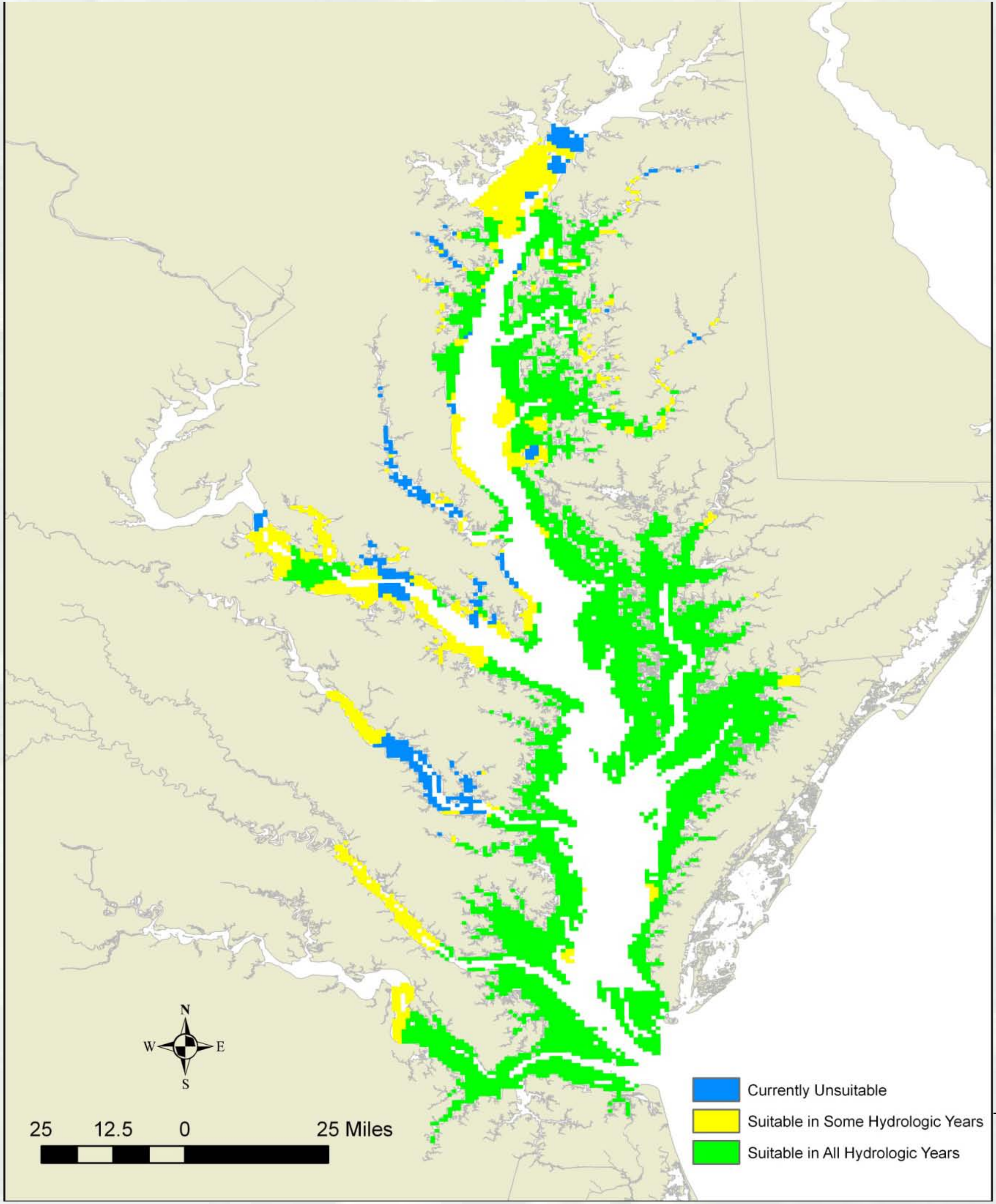
Additional considerations that are important for restoration, but are not as well documented or quantified.

List of Tier 1 and Tier 2 Tributaries

Step 5: Tributary Evaluation and Prioritization

Absolute Criteria





Suitability Analysis Results

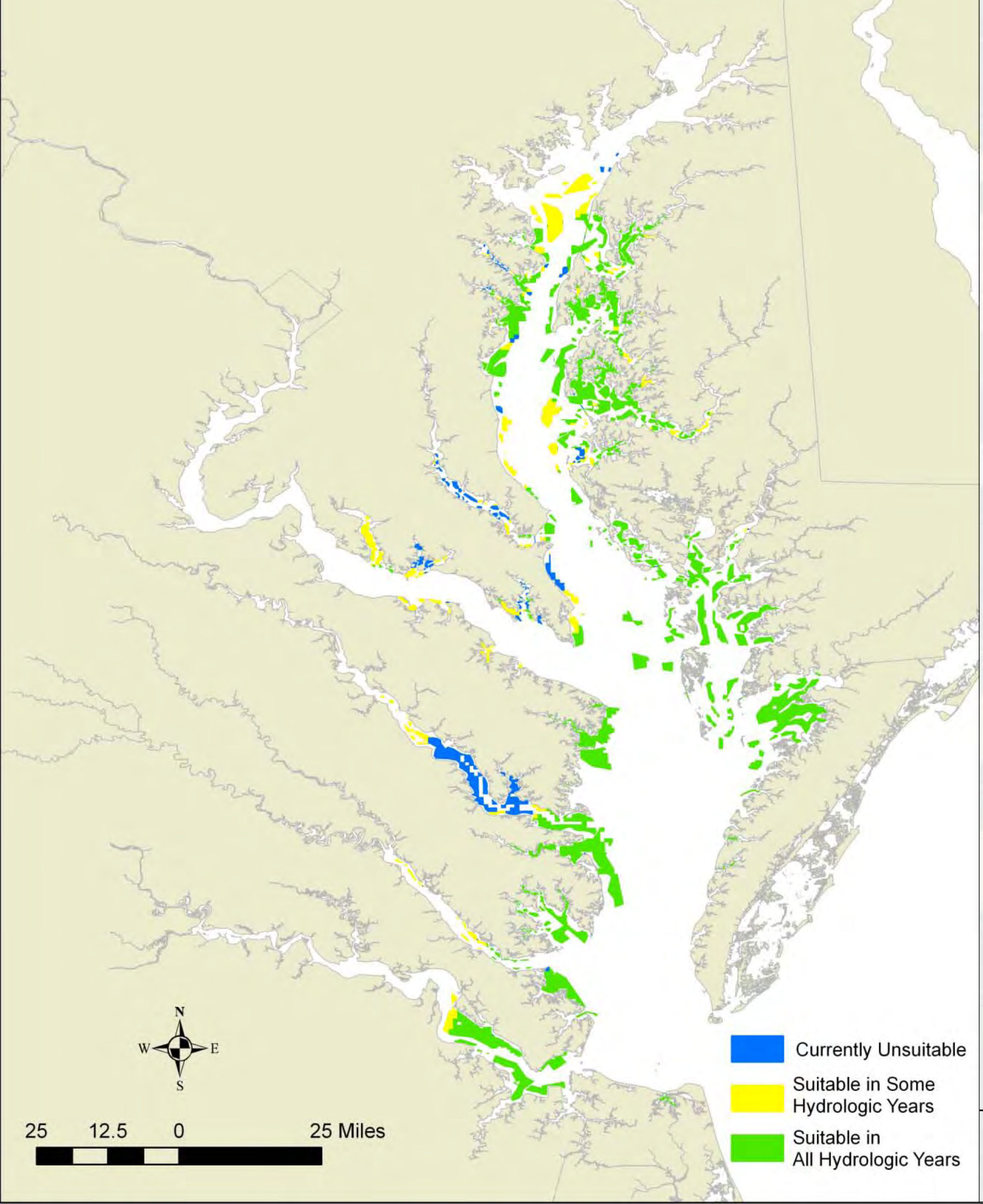
- Salinity
  - Surface
  - Bottom
- Bottom DO
- Water Depth

<u>Total Suitable Area</u>

MD= 513,000 acres

VA= 580,000 acres

BUILDING STRONG®



Suitability Analysis Results within Yates/Baylor Boundaries

- Salinity
  - Surface
  - Bottom
- Bottom DO
- Water Depth
- Yates and Baylor Grounds

<u>Total Suitable Area</u>

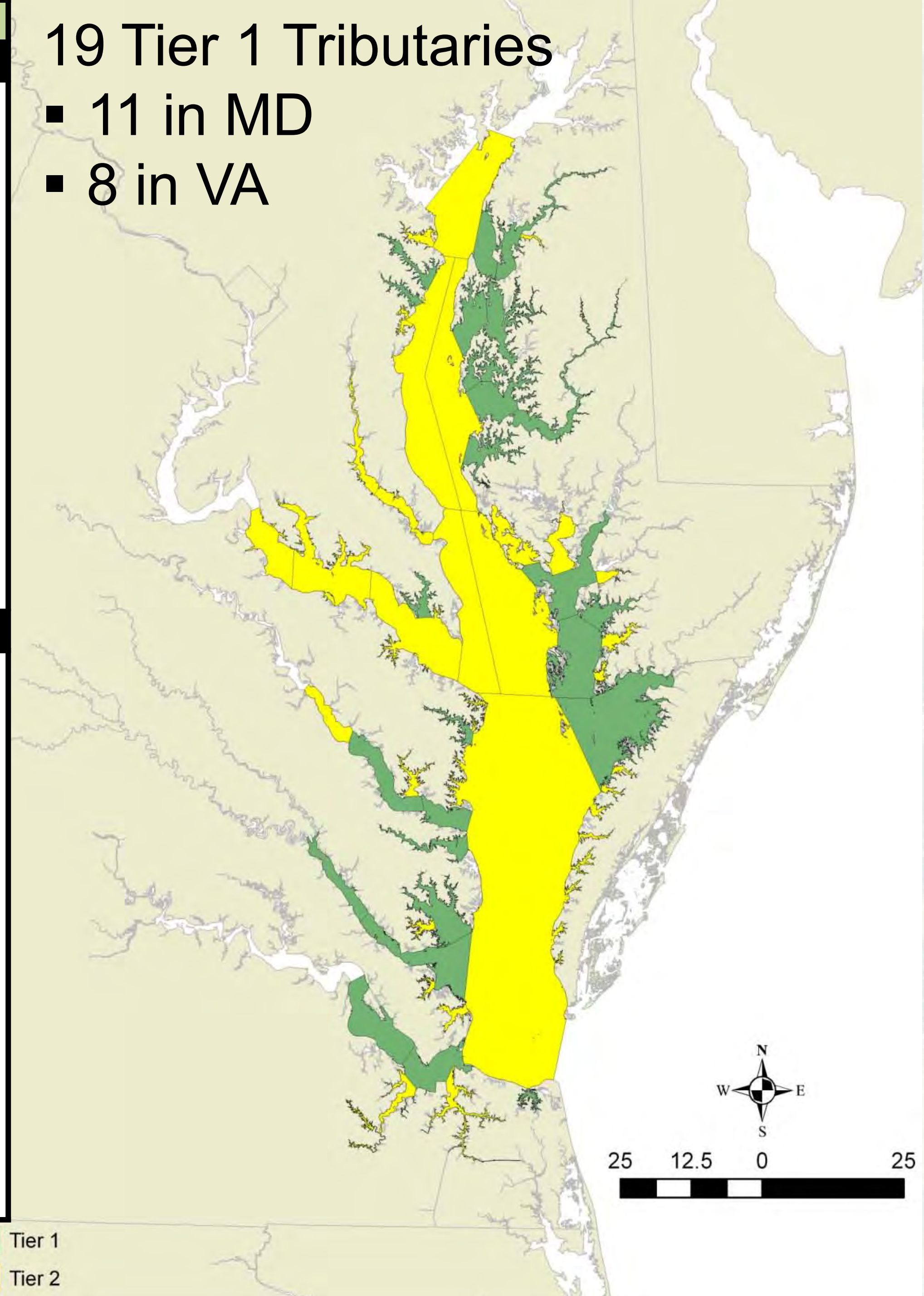
MD= 132,000 acres

VA= 121,000 acres

Tier 1	Tier 2
Maryland	
Severn R (S)	Magothy R (S)
South (S)	Rhode R
Chester R (S)	West R
Eastern Bay (S)	Corsica R (S)
Choptank R (S)	Honga R
Harris Creek (S)	Potomac R
Broad Creek	Fishing Bay
Little Choptank (S)	Monie Bay
St. Mary's R (S)	Big Annemessex R
Tangier Sound (includes Nanticoke R (S))	Little Annemessex R
Manokin R (S)	Patuxent R (S)
	All MD Mainstem Segments (S)
Virginia	
Rappahannock R (lower, middle)	VA Mainstem
Great Wicomico R (S)	Little Wicomico R
Piankatank R	Cockrell Creek
Mobjack Bay	Corrotoman R
York R	Severn R
Pocomoke/Tangier Sound	Poquoson R
James R	Back R
Lynnhaven R	Onancock Creek
	Nassawaddox Creek
	Hungars Creek
	Cherrystone Inlet
	Old Plantation Creek
	Elizabeth R
	Nansemond R

19 Tier 1 Tributaries

- 11 in MD
- 8 in VA



What Will Large-Scale Restoration Cost???

- Large-scale restoration is still in the learning mode
- Cost estimates for restoration need to include habitat construction, seeding, and monitoring
- Costs expected to be spread over multiple years for a given tributary
- Cost range for a tributary reflects the low and high acreage target and the lowest and highest priced alternate substrates.
- Example of a tributary cost estimate to achieve the restoration target:
  - Smallest Tier 1 MD tributary = South River, 90 to 200 acres, $16 million to $48 million
  - Largest Tier 1 MD tributary= Tangier Sound, 1,800 to 3,600 acres, $154 million to $652 million
- Estimates are conservatively high – existing habitat is not included in most estimates; some areas may need only seed (no substrate)
  - Once quantified in a tributary plan, these considerations would reduce the effort needed to reach restoration targets

What are the benefits ?

- Oyster Production
- Water Filtration
- Nutrient Cycling
- Reduced Sedimentation
- Reef Habitat
- Carbon Sequestration
- Enhanced Fishery Resources
- Benthic and Intertidal Habitat Stabilization
- Increased Bottom Diversity

Master Plan Recommendations

Specific Tributary Plan

- Develop with restoration partners
- Parameters to consider identified in master plan
- Additional surveys = population, bottom condition, hydrodynamic, larval transport, and recruitment

Construction

- Construct a portion of target (25, 50, or 100 acres) per year
- Funding dependent
- Continue until success metrics reached

Target Higher Salinities for Development of Disease Resistance

- Initial efforts in mesohaline-polyhaline salinities
- Special attention given to mid-river reefs

Reef Design Recommendations

- Bar morphology, reef fragmentation, reef height, reef topography, orientation to flow, water depth, distance between reefs, etc.

Master Plan Recommendations (Continued)

Research Needs	• Quantification of benefits, larval transport, development of disease resistance and transmission, site selection with respect to water currents and bottom topography, etc.
Use Adaptive Management	• Such as additional stocking of disease resistant oysters, moving of disease resistant spat-on-shell, addition of fresh substrate, measures to reduce predation, etc.
Monitoring Protocols	• Monitoring element, type of data recorded, method of monitoring, monitoring objective
Concentrate Resources and Funding	• Necessary to establish self-sustaining populations
Follow Success Metrics Defined by Oyster Metric Workgroup	• Biomass, density, and shell accretion

What is the Future of USACE Program?

Master plan will open up USACE's MD restoration program to additional tributaries (currently only eight areas covered by NEPA)

Work with NOAA and other agencies toward achieving E.O. 13508 goal of restoring 20 tributaries by 2025

Focus will be on restoring one tributary at a time

Large-scale oyster restoration will only succeed with the cooperation of all agencies and organizations involved. Resources and skills must be leveraged to achieve the most from restoration dollars.

Oyster Recovery Partnership
ORP

Partners in Restoration

Activity (3)	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6
	Site Selection	Bottom Survey	Reef Construction	Ground Truth	Produce & Plant Oysters	Post Planting Monitoring

Partners / Roles

Project Coordination - ORP

Step 1	Step 2	Step 3	Step 4	Step 5	Step 6
All	NOAA, MGS ($) DNR, NOAA	Watermen, Corporation ($) NOAA, USACE, DNR	UMD, ORP ($) NOAA	UMCES, ORP (1)(2) ($) DNR, UMCES, NOAA	UMD, DNR, Morgan, USNA ($) NOAA, DNR, USACE

Enforcement & Management Agency – NRP / DNR

Permits / Regulations – USACE Regulatory / DNR / MDE

Data Collection & Management – DNR / ORP / NOAA

Notes: (1) In 2009, DNR (Piney Point), Morgan State, ORP & watermen conducting remote setting pilot projects; (2) Based on salinity regimes, oyster reefs may only receive shell rehabilitation (no spat) in higher salinity waters where a natural spat set could occur; (3) For aquaculture projects, watermen to be trained on all steps with guidance and technical support by partners; the steps may be modified to minimize watermen costs.

State Agency, Non-Profit, Federal Agency, University, Corporation

Thank you for your time.

Questions?

Extra Slides

NORMP Plan Formulation – Stocking

- Stocking rate by salinity zone
  - Salinity influences fecundity and recruitment
    - Some high salinity reefs may not require stocking
    - Low salinity reefs projected to require multiple stocking events to establish multi-age population with male and females
    - For reefs that require stocking, recommend stocking of 4 to 5 million spat per acre on both high and low salinity reefs
  - Climatic events (freshets and droughts) may affect the frequency of restocking, which would affect cost
  - Recommend stocking all low salinity reefs and 80% of high salinity reefs

NORMP Plan Formulation

- 34 Maryland distinct sub-segments were evaluated:

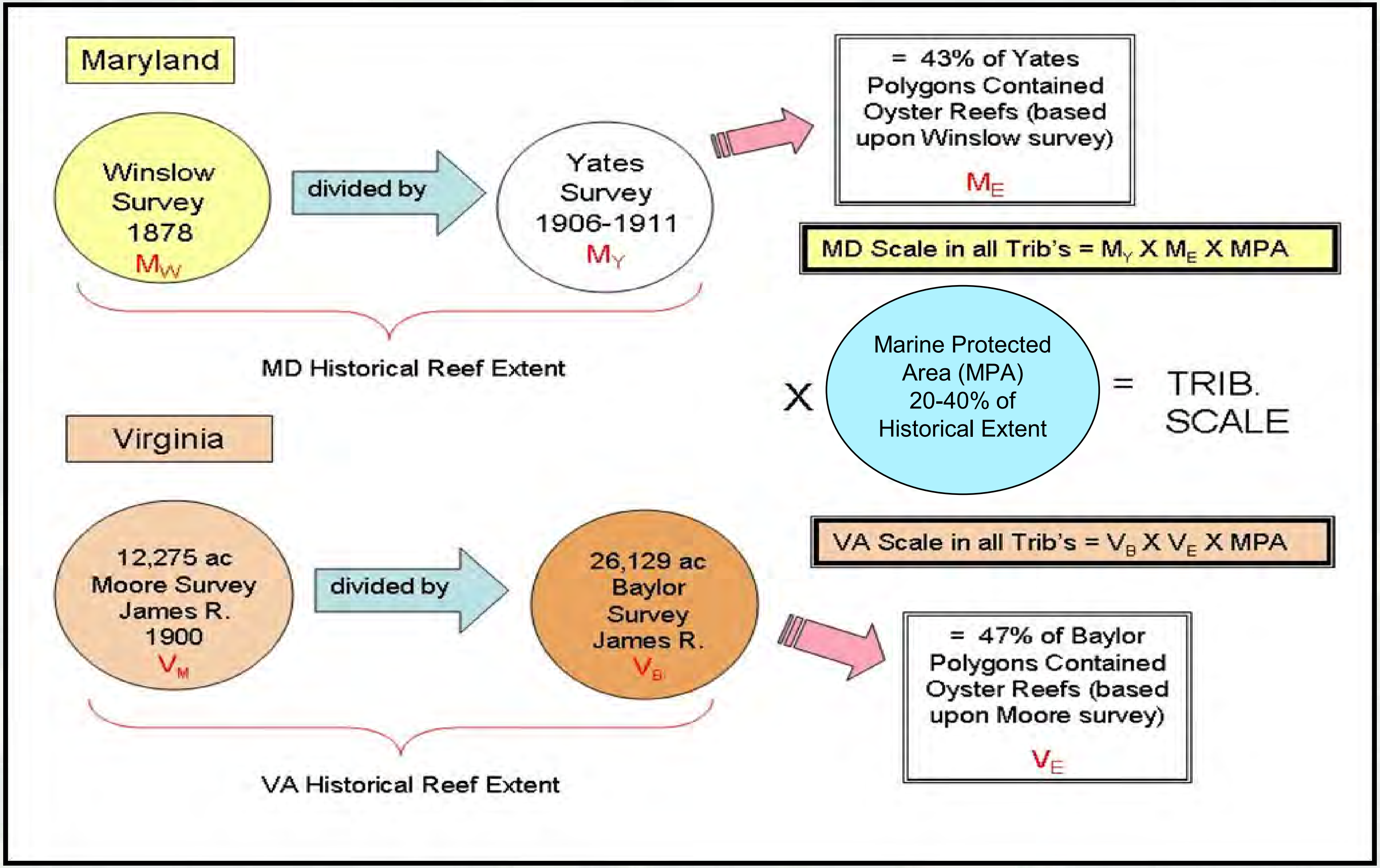
Magothy River
Severn River
South River
Rhode River
West River
Chester River (upper and lower)
Corsica River
Eastern Bay (upper and lower)
Choptank River (upper and lower)
Harris Creek
Broad Creek
Little Choptank River
Honga River
Potomac River (upper, middle, and lower)
St. Mary's River

Tangier Sound (upper and lower)
Fishing Bay
Monie Bay
Manokin River
Big Annemessex River
Little Annemessex River
Patuxent River (upper and lower)
Bay Mainstem- Upper
Bay Mainstem-Middle West
Bay Mainstem-Middle East
Bay Mainstem-Lower West
Bay Mainstem-Lower East

Determining the restoration target

- Step 2: Identify restoration target
  - Estimate acreage of historic reef habitat
    - Compared a broad, state-wide course delineation of historic habitat to a more precise, targeted historic survey in each state
      - MD: Compared the Yates Bars(MD) to the Winslow Survey (Tangier Sound)
      - VA: Baylor Grounds (VA) to Moore Survey (James River, VA)
    - Results
      - MD: 43% of Yates Bars were actual hard reef habitat
      - VA: 47% of Baylor Ground was actual hard reef habitat
  - Restoration goal = **20-40%** of historic (corrected) habitat
    - Equates to roughly 8 to 16 percent of the Yates and Baylor Grounds (if not adjusted). Should be refined during detailed tributary plan development.
    - Larger-scale reefs may be needed in lower salinity waters

BUILDING STRONG®

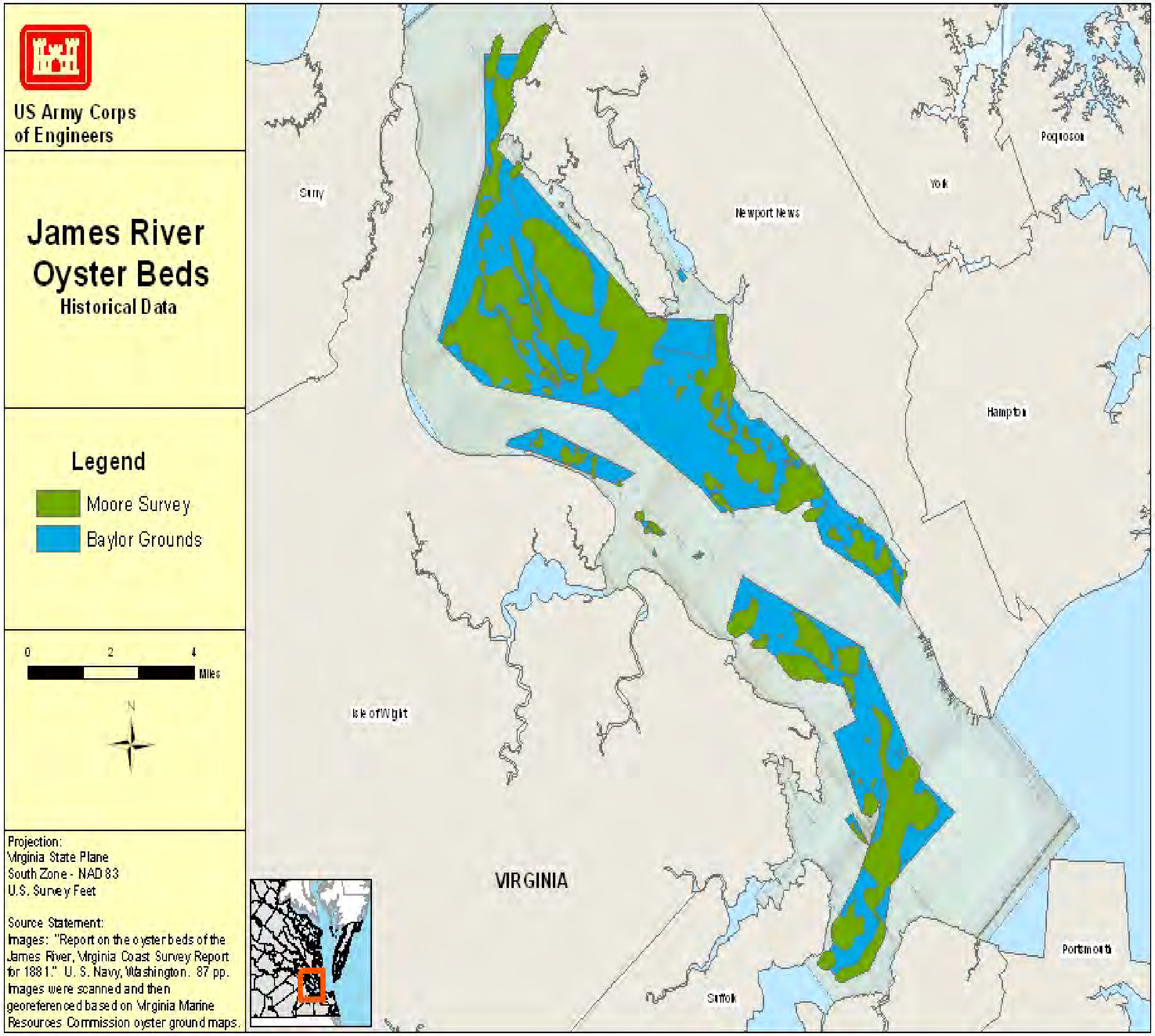


Maryland
Winslow Survey 1878
M_W
divided by
Yates Survey 1906-1911
M_Y
= 43% of Yates Polygons Contained Oyster Reefs (based upon Winslow survey)
M_E
MD Scale in all Trib's = M_Y X M_E X MPA
MD Historical Reef Extent
X
Marine Protected Area (MPA) 20-40% of Historical Extent
= TRIB. SCALE
Virginia
12,275 ac Moore Survey James R. 1900
V_M
divided by
26,129 ac Baylor Survey James R.
V_B
VA Scale in all Trib's = V_B X V_E X MPA
= 47% of Baylor Polygons Contained Oyster Reefs (based upon Moore survey)
V_E
VA Historical Reef Extent

Scale- Step 1: Historic Baseline

- Determine how much of 'historic' acreage was true oyster habitat.

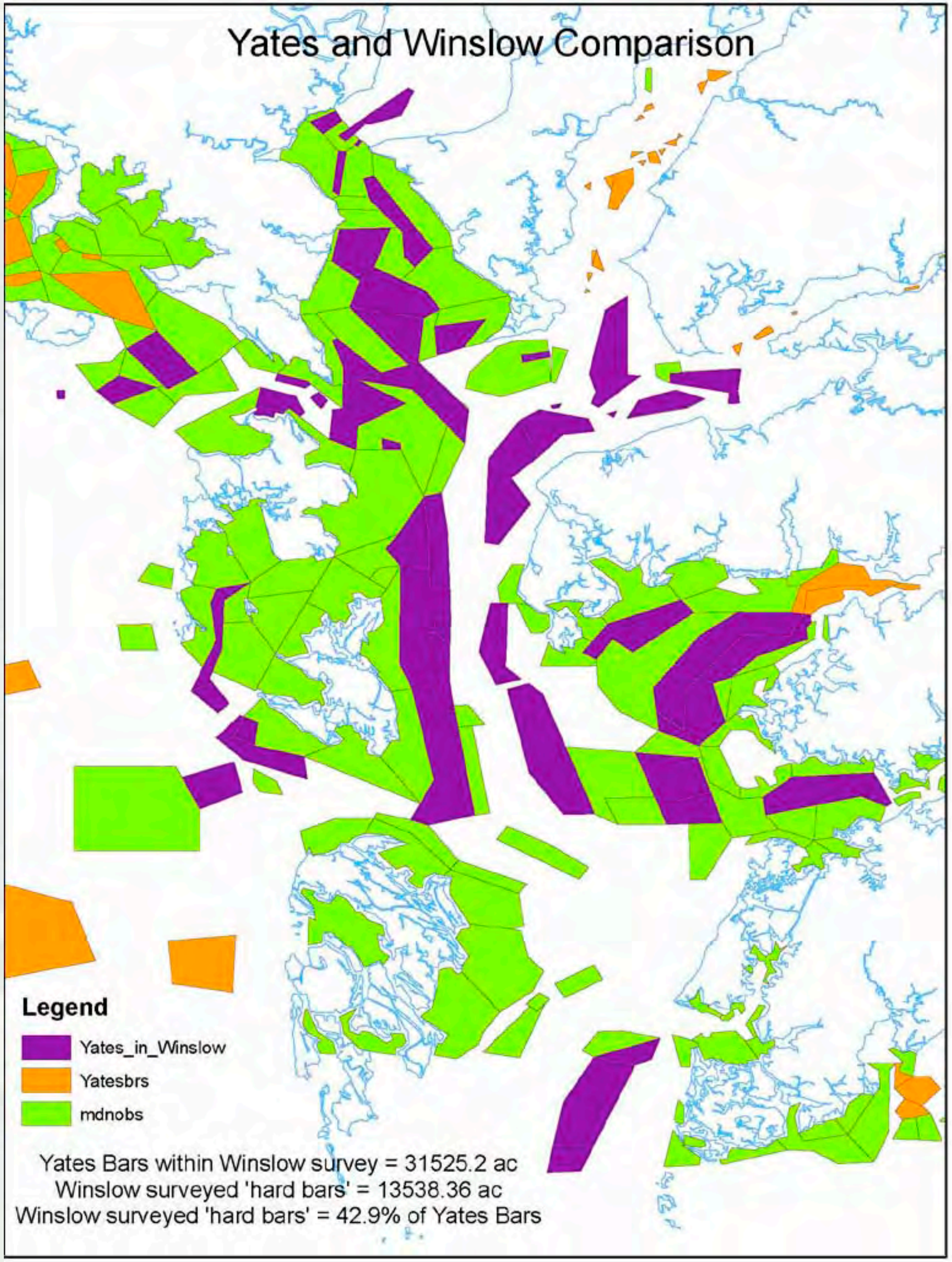
- By comparing Baylor to Moore (1900) only 47% of the Baylor grounds contained oyster habitat



Scale

.

•By comparing Yates to Winslow (1881) only 43% of the Baylor grounds contained oyster habitat



NORMP – Scale Issue

- What do we know?
  - Baylor (1894) and Yates (1906-1911) – the most comprehensive surveys of oyster grounds in VA and MD, respectively, but done on a broad resolution
  - Based on ORET (2009), ecosystem restoration efforts have focused on approximately 1% of Baylor grounds (VA) and 1.6% of Yates bars (MD)
  - Marine protected areas (MPA) typically protect 20 to 70% of habitat
  - There are various descriptive accounts of historic oyster bar coverage, but no investigations into what acreage needs to be restored to recover sustainability
  - Great Wicomico River project has restored approximately 40% of the original reef acreage in the tributary

Tributary Evaluation and Prioritization

Baseline

Total Tributary Area (ac) = T_{SA}

Required Restore Scale (ac) = T_{RS}

Layer 1: GIS Overlays Give Amount
Suitable Acreage = Total Restorable Acreage (T_{RA})

Historic Habitat

Salinity <5 ppt

D.O. <5 mg/l

Depth >20 ft

Layer 2

Is $T_{RA} \geq T_{RS}$?

NO

Set Aside for Future Resolution of Constraints

YES

Layer 3

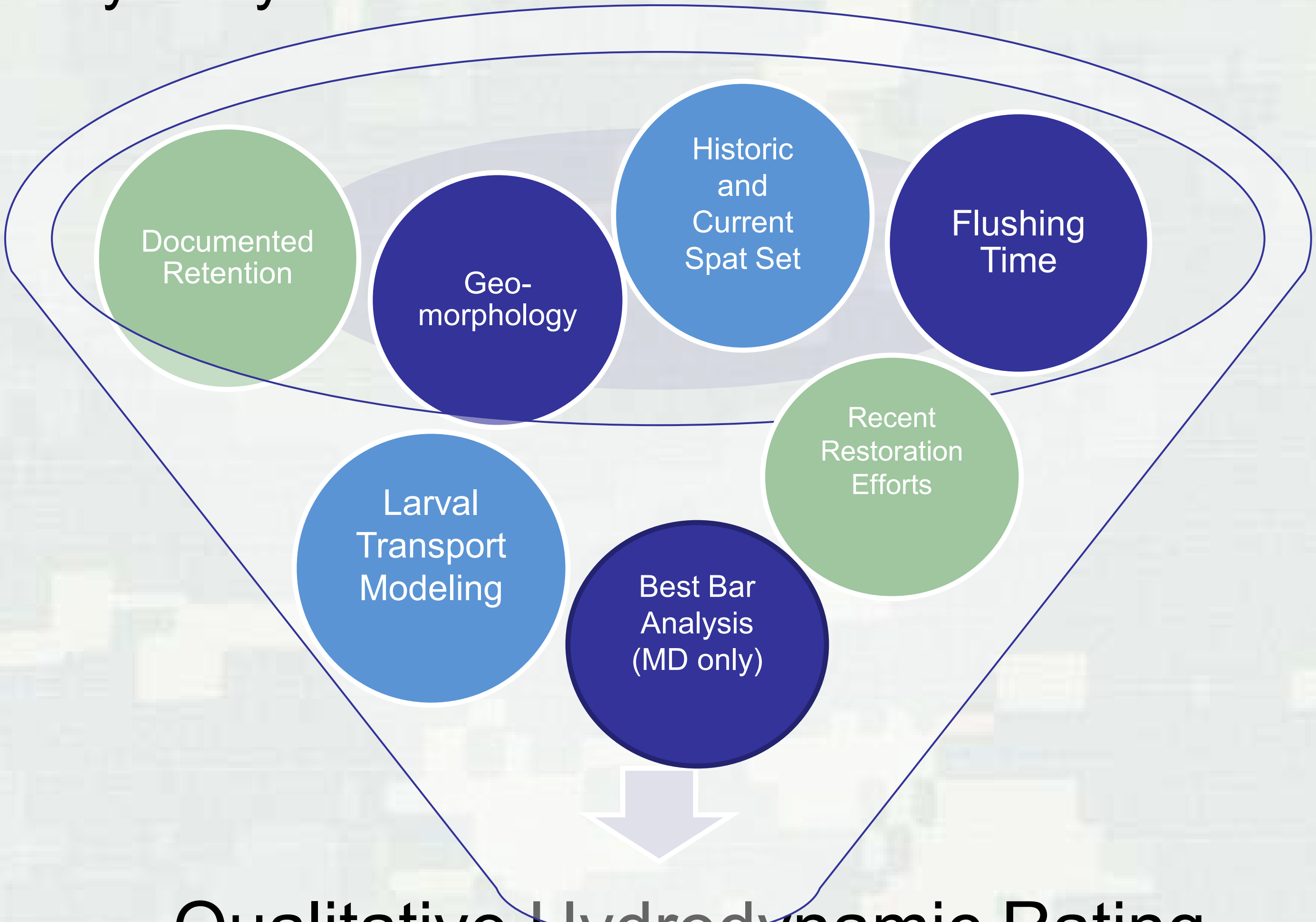
Hydrodynamics: What is the "retentiveness" of tributary? (High, Medium Low)

High = Tier 1
Medium or Low = Tier 2

BUILDING STRONG®

Step 5: Tributary Evaluation and Prioritization

- Layer 3: Hydrodynamics



Qualitative Hydrodynamic Rating

Step 5: Tributary Evaluation and Prioritization

- Layer 4: Qualitative Data

These factors are to be considered further during development of specific tributary plans.

- Hard Bottom
- Local Water Quality
- Currents/ Water Flow
- Sedimentation Rate
- Watershed Suitability
- Harmful Algal Blooms
- Freshets
- Phytoplankton/ Food Availability
- Shellfish Harvesting Closures
- Location Relative to Other Habitats
- Proximity to and Quantity of Existing Broodstock Populations

Master Plan Recommendations

Specific Tributary Plan

- Develop with restoration partners
- Parameters to consider identified in master plan
- Additional surveys = population, bottom condition, hydrodynamic, larval transport, and recruitment

Construction

- Construct a portion of target (25, 50, or 100 acres) per year
- Funding dependent
- Continue until success metrics reached

Target Higher Salinities for Development of Disease Resistance

- Initial efforts in mesohaline-polyhaline (higher) salinities
- Special attention given to mid-river reefs

Research Needs

Monitoring Protocols

Use Adaptive Management

Reef Design Recommendations

- Reef morphology, fragmentation, height, size, etc.
- Climate change considerations
- Substrate

Concentrate Resources and Funding

Follow Success Metrics Defined by Oyster Metrics Workgroup

Documented efforts at quantifying the economic benefits of restored oyster habitat include:

- Newell et al. (2004) estimated the value of the current oyster population (1 oyster/m^2) in the upper Choptank River at $1.5 million if it were to be harvested with a value of $750,000 to harvesters when adjusted. The value of existing Choptank River oyster stock to remove 13,080 kg N/yr is $314,836 (based on the average cost of $24.07 to remove 1 kg of N from the Chesapeake Bay); and over a 10-year lifetime equates to $3.1 million.
- Kahn and Kemp (1985 as cited by Grabowski et al. 2007) estimated that a 20 percent decrease in SAV in the Chesapeake equaled a loss of $1-4 million annually in fishery value; Cerco and Noel (2007) determined that an increase in oyster biomass of 10 percent resulted in a 20 percent increase in summer SAV biomass.
- On a restored reef with 10 oysters /m^2 expected nutrient removal is 6 percent N and 80 percent P of annual inputs and ~50 percent N and ~350 percent P of monthly summer inputs (Newell et al. 2004).
- A 10 m^2 restored reef in the southeast U.S produced 2.6 kg/yr of additional fish and crustacean production (Peterson et al. 2003).
- Grabowski and Peterson (2007) estimated that preserving a 1 acre oyster sanctuary for 50 years would result in an additional value of ~$40,000 from commercial finfish and crustacean fisheries.
- Example of value associated with improvements in water quality- Survey of Balt-Washresidents in 1984 (Bockstael et al. 1984) showed that a 20 percent increase in water quality (relative to 1980 conditions) is worth $188 million for beach users, $26 million for recreational boaters, and $8 million for striped bass sportsfishermen [price adjusted to 2002 by NRC (2004)].

Implementation Considerations for Tributary Plans

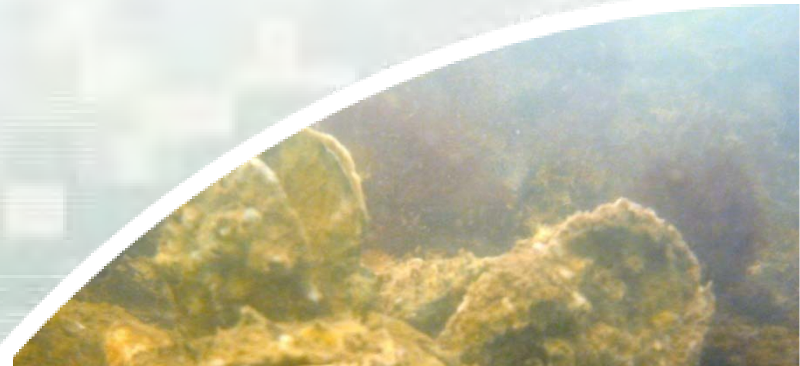
- Bottom condition surveys,
- Population surveys,
- Hydrodynamic and larval transport modeling,
- Bathymetric surveys,
- Recruitment surveys, and
- Biological and ecosystem benefit modeling.

USACE Native Oyster Restoration Master Plan

Public Meeting

Hampton, VA

17 April 2012



US Army Corps of Engineers
BUILDING STRONG®

Presentation Outline

- USACE Oyster Restoration Program
- Native Oyster Restoration Master Plan
  - Goals and Purpose
  - Plan Formulation
  - Results
  - Recommendations
- Path Forward
- USACE VA Oyster Restoration Activities
- Questions

USACE Oyster Restoration Program

Established in Section 704(b) of the Water Resources Development Act of 1986

- 75% Federal, 25% non-Federal funding
- First year of funding = FY1995
- Initially focused on Maryland; first report was in 1996, with cooperation agreement signed in 1997
- Maryland project sponsor is Maryland Department of Natural Resources
- Project has received up to $1-5 million Federal per year for MD+VA

Amended in 1996, 2000, 2002, 2006, and 2007

- Added Virginia to project location, Virginia project sponsor is Virginia Marine Resources Commission
- Increased authorization limit to $50 million
- Identifies specific type of construction activities
- Purpose: To establish sanctuaries and harvest management areas
- USACE activities to be consistent with other plans and strategies

Construction Summary
Maryland
1997-2011

- 459 acres of substrate placed
- 22 additional acres at Harris Creek to be constructed May-June 2012
- Locations:
  - Magothy, Severn, and Patuxent Rivers
  - Chester and Choptank Rivers (includes Harris Creek), Eastern Bay
  - Kedges Strait
- Material Used:
  - Dredged fossil shell (1997-2006)
  - Alternative substrate (2009-2011)
- Periodic project monitoring

Construction Summary
Virginia
2001-2011

- 389 acres of substrate placed
- Locations:
  - Rappahannock River (Section 510 authority), Tangier/Pocomoke Sound
  - Great Wicomico and Lynnhaven Rivers
- Material Used:
  - Dredged fossil shell (2001-2011)
- Periodic project monitoring

Native Oyster Restoration Master Plan

Long-Term Restoration Goal:

Throughout the Chesapeake Bay, restore an abundant, self-sustaining oyster population that performs important ecological functions such as providing reef community habitat, nutrient cycling, spatial connectivity, and water filtration, among others, and contributes to an oyster fishery.

Operational Goal:

Identify tributaries/regions most likely to develop sustainable populations of oysters with the implementation of reef construction, seeding, and other oyster restoration activities.

Purpose

Implementation

- The master plan ensures that USACE-implemented oyster restoration is conducted in a logical, science-based, and cost-effective manner with the greatest potential for success in achieving the restoration goal.

Strategic Plan

- The master plan will present a strategic plan for pursuing long-term, wide-scale restoration throughout the Bay that complements the States' oyster restoration programs as well as other Bay-wide restoration efforts and future uses of the Chesapeake Bay.

Oyster Locations

- It will not define specific projects for specific locations; locations will be determined in future tributary plans.

Plan Formulation Process

1. Develop formulation white papers

2. Adopt salinity-zone, disease, and reproduction strategies

3. Identify distinct sub-segments of the Chesapeake Bay for evaluation and prioritization

4. Determine the appropriate scale at which restoration should be undertaken

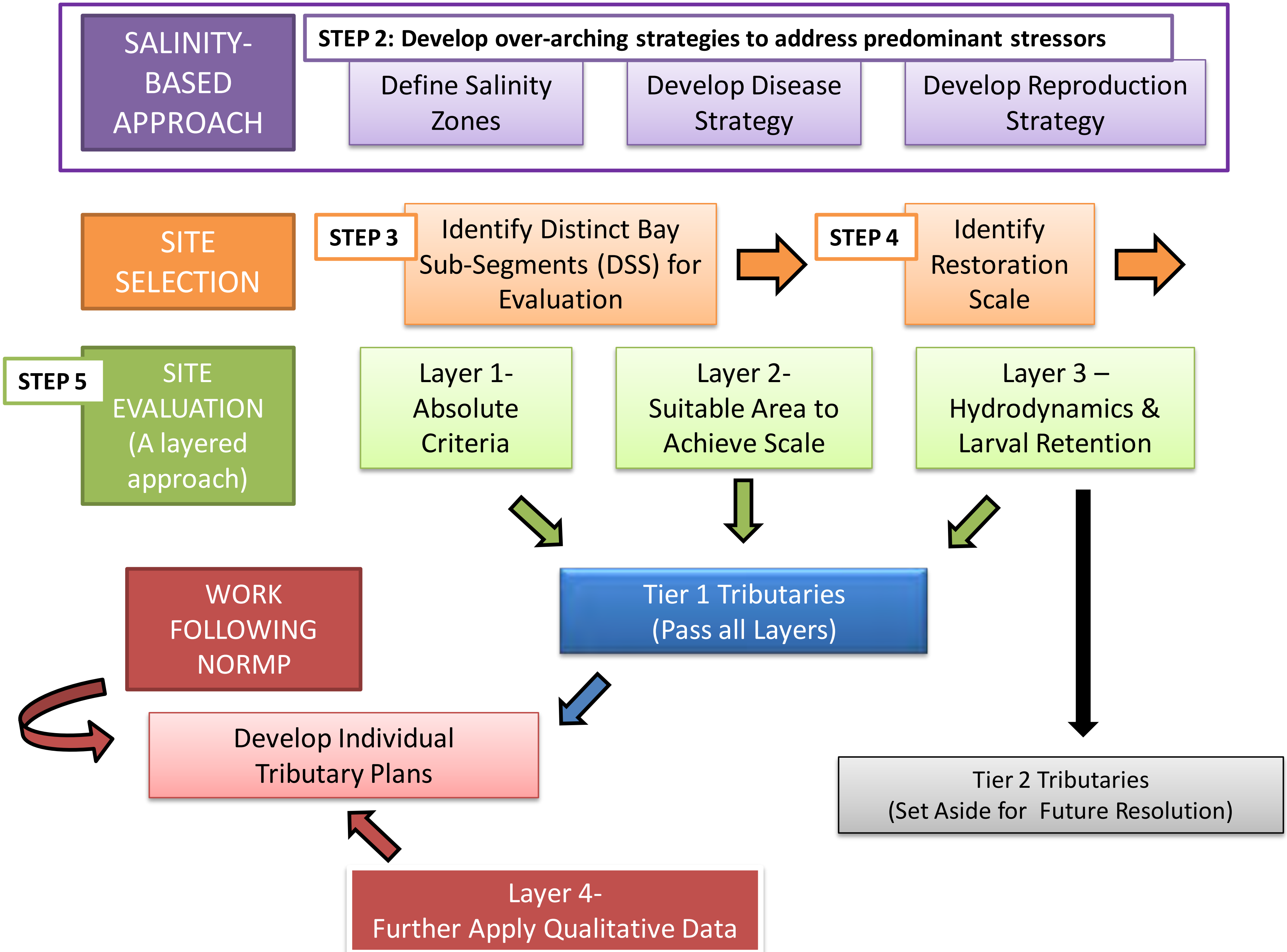
5. Tributary evaluation and prioritization:

A layered formulation evaluation	Identify Tier I and II Bay segments

Step 1- Develop White Papers

- Scale
- Disease
- Populations – bayscape setting
- Populations - individual reefs
- Physio-chemical factors
- Hydrodynamics
- Reproduction

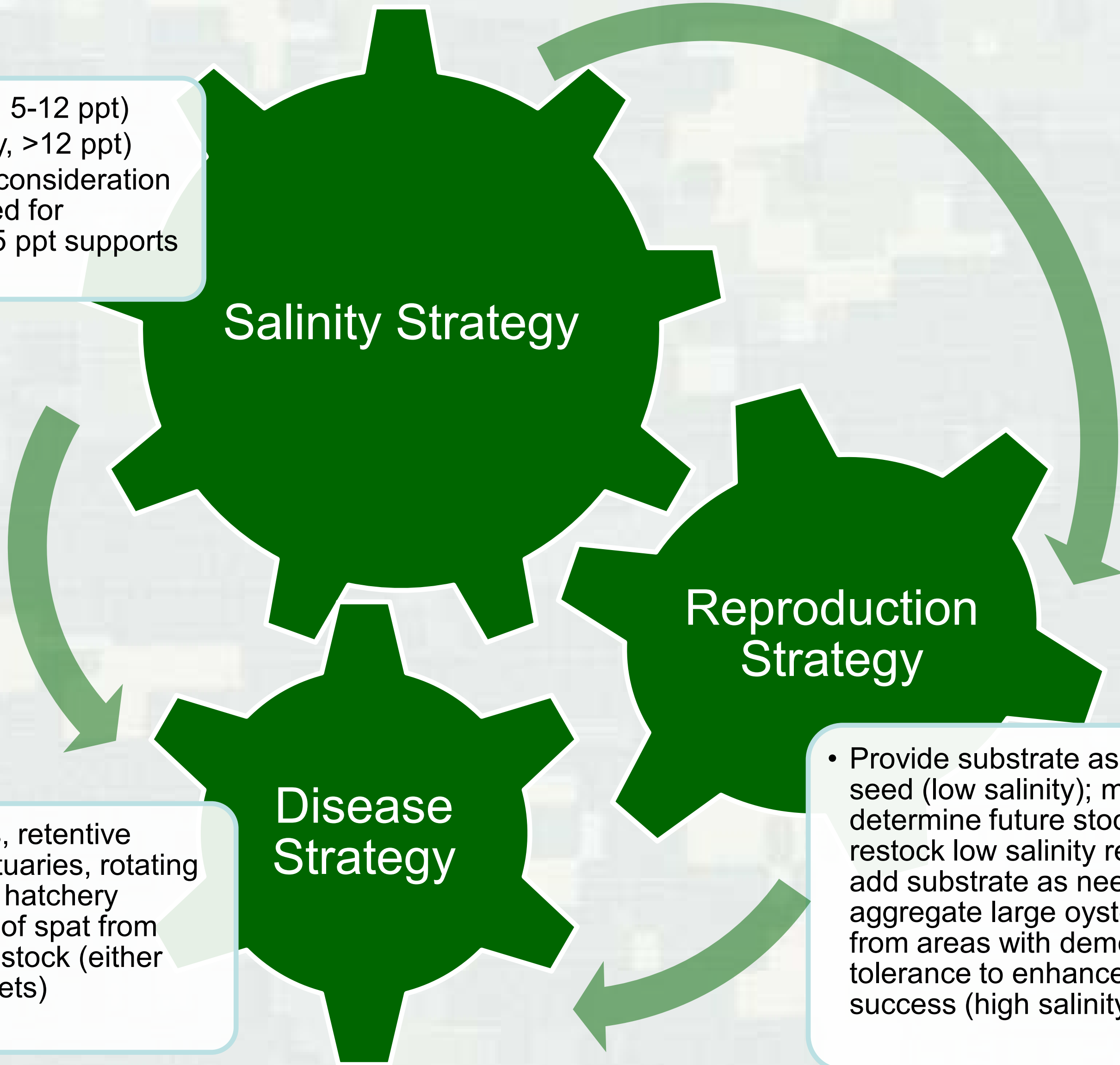
- ➢ Significance to oyster restoration and master plan
- ➢ Scientific basis and state of knowledge
- ➢ Application to the master plan
- ➢ Reviewed and coordinated with resource agencies



SALINITY-BASED APPROACH
STEP 2: Develop over-arching strategies to address predominant stressors
Define Salinity Zones
Develop Disease Strategy
Develop Reproduction Strategy
SITE SELECTION
STEP 3
Identify Distinct Bay Sub-Segments (DSS) for Evaluation
STEP 4
Identify Restoration Scale
STEP 5
SITE EVALUATION (A layered approach)
Layer 1- Absolute Criteria
Layer 2- Suitable Area to Achieve Scale
Layer 3 – Hydrodynamics & Larval Retention
WORK FOLLOWING NORMP
Tier 1 Tributaries (Pass all Layers)
Develop Individual Tributary Plans
Tier 2 Tributaries (Set Aside for Future Resolution)
Layer 4- Further Apply Qualitative Data

Step 2: Salinity-Based Approach

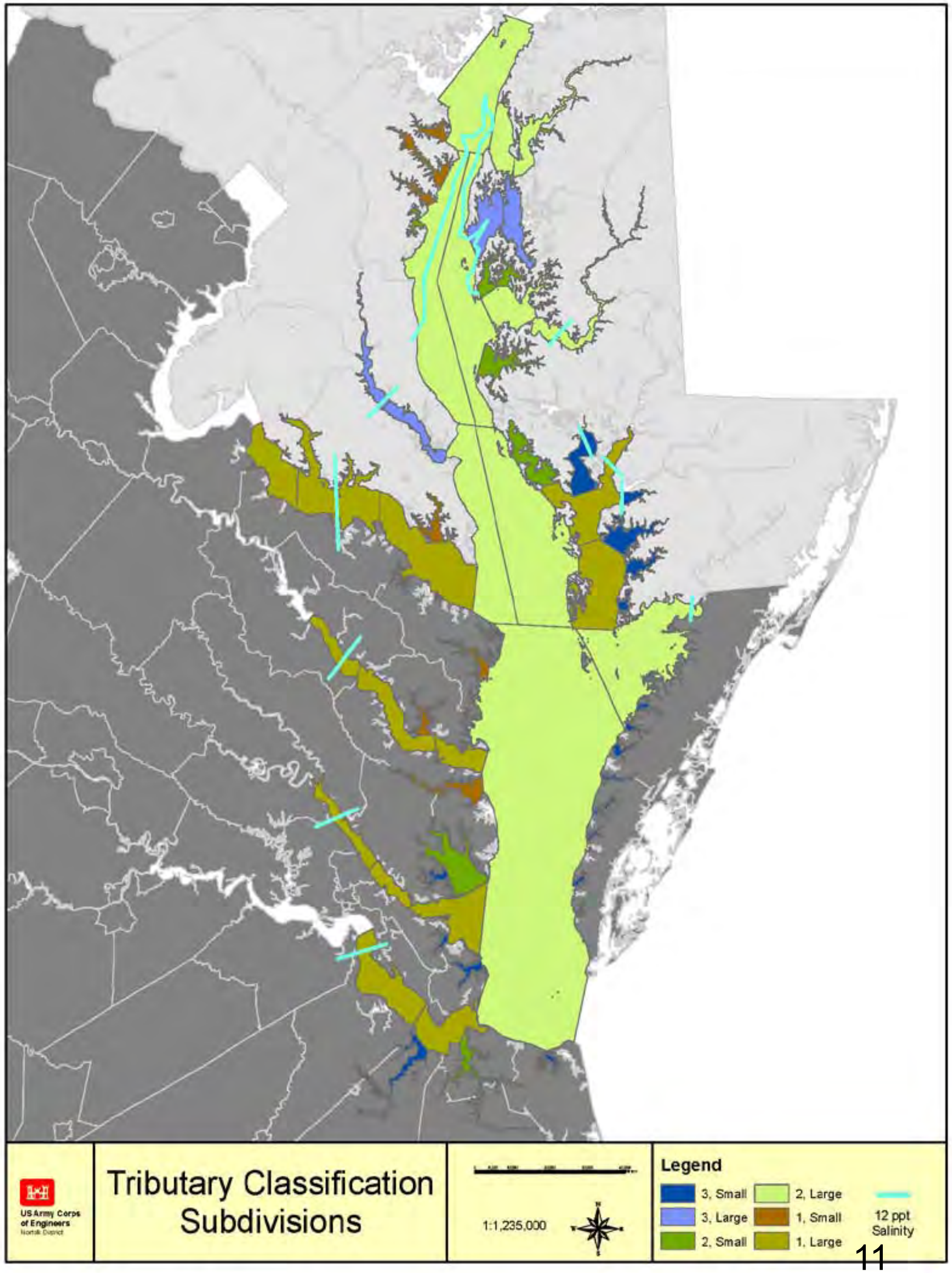
- Zone 1 (low salinity, 5-12 ppt)
- Zone 2 (high salinity, >12 ppt)
- Plans will take into consideration that >8 ppt is needed for reproduction, but >5 ppt supports growth



- Incorporates sanctuaries, retentive systems such as trap estuaries, rotating broodstock approach for hatchery production, and planting of spat from disease-resistant parent stock (either from hatcheries or wild sets)

- Provide substrate as needed and seed (low salinity); monitor to determine future stocking needs; restock low salinity reefs at 2-3 years; add substrate as needed; Stock and aggregate large oysters harvested from areas with demonstrated disease tolerance to enhance fertilization success (high salinity)

BUILDING STRONG®



Step 3: Distinct Sub-Segment Delineations

34 Maryland segments
29 Virginia segments

Step 4: Scale

Scale = the approximate number of acres of functioning habitat in a given tributary or sub-region required to develop a self-sustaining oyster population. Not "one size fits all."

What do we know???

- Past restoration efforts have been too small to impact system
- Need to concentrate resources

Define historic habitat baseline

Identify the percent of historic habitat that needs to be restored to achieve goals.

Restoration goal = **20-40%** of historic (corrected) habitat

BUILDING STRONG®

Step 5: Site Evaluation and Prioritization

Layer 1 → Absolute Criteria →

Identify absolute criteria. Determine the number of suitable acres for restoration available.

Layer 2 → Scale →

Determine if there is enough suitable acreage available to meet the scale targeted for sustainable restoration.

Layer 3 →Qualitative Hydrodynamic Rating →

Indicates whether a tributary has high, medium or low indicators of the hydrodynamic properties preferred for restoration.

Layer 4 → Qualitative Data →

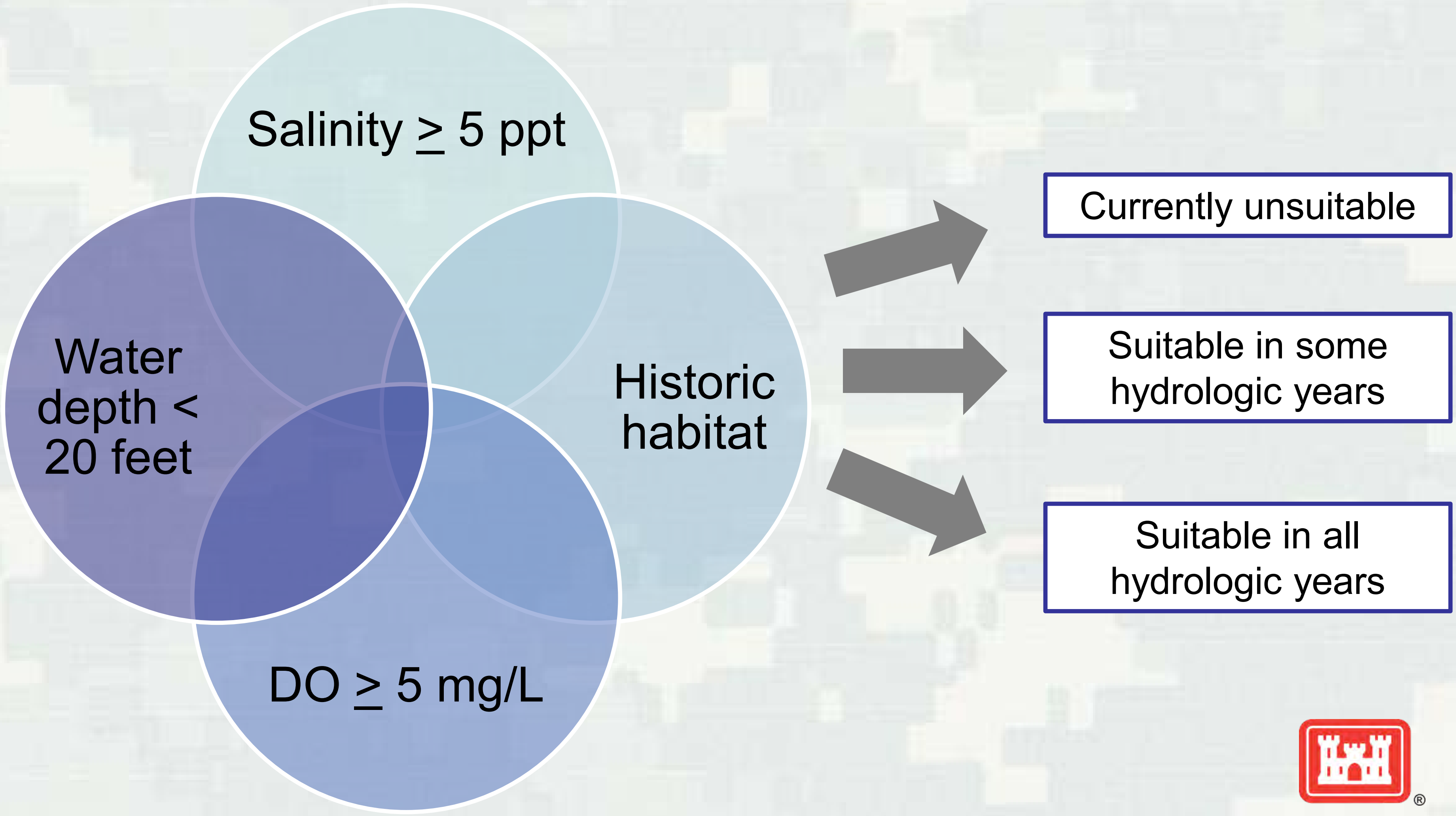
Additional considerations that are important for restoration, but are not as well documented or quantified.

→

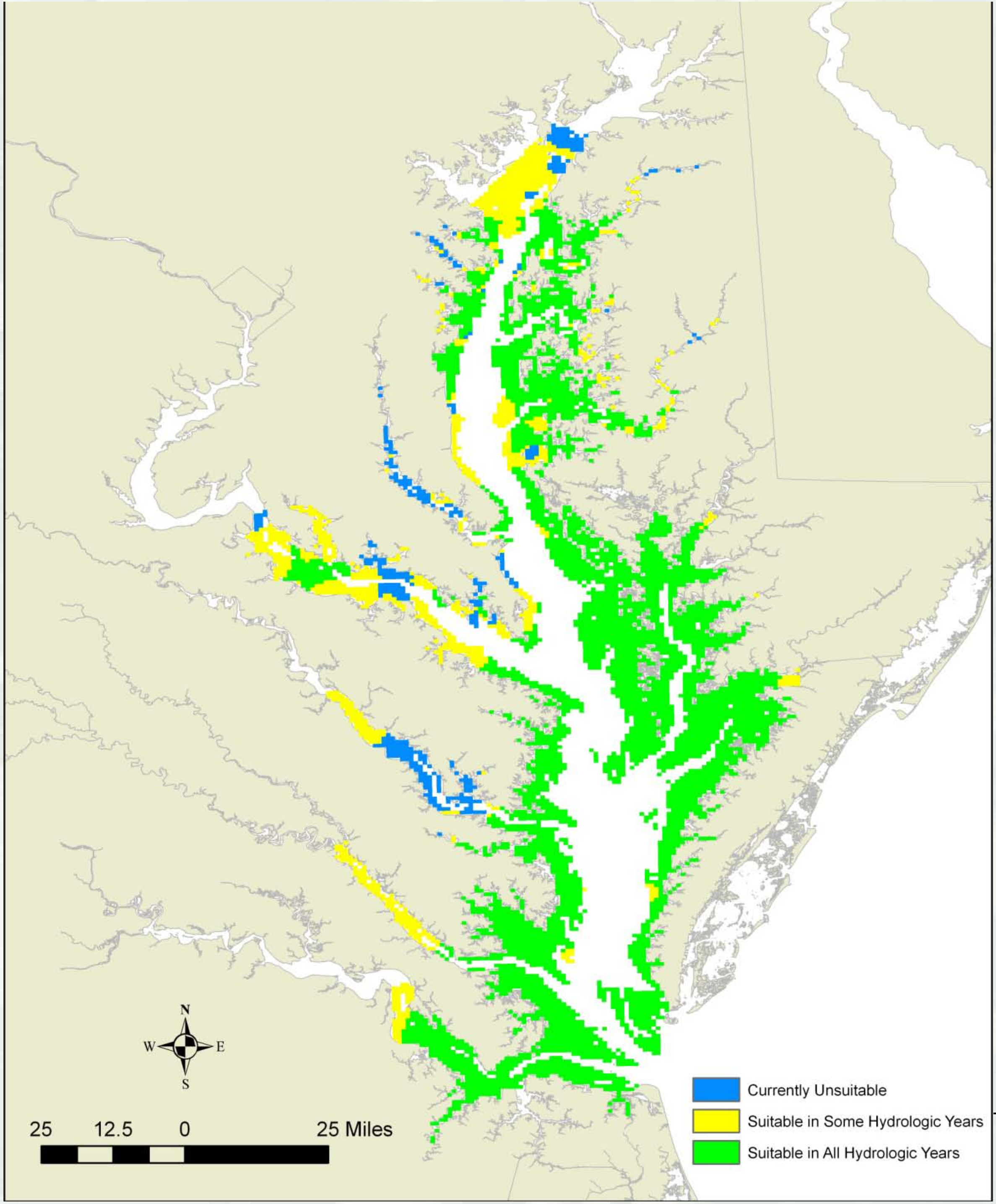
List of Tier 1 and Tier 2 Tributaries

Step 5: Tributary Evaluation and Prioritization

Absolute Criteria



Suitability Analysis Results

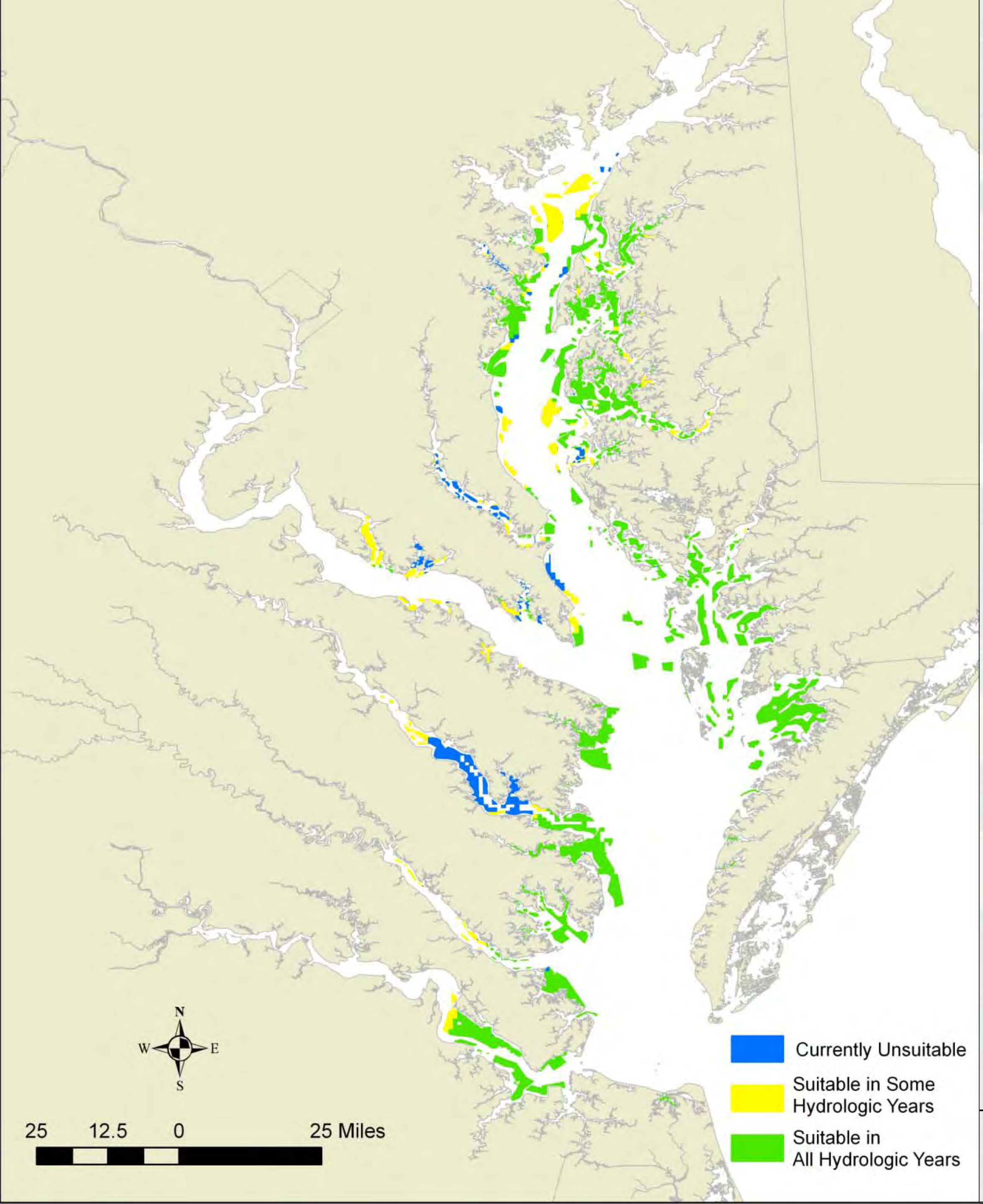


- Salinity
  - Surface
  - Bottom
- Bottom DO
- Water Depth

<u>Total Suitable Area</u>

MD= 513,000 acres

VA= 580,000 acres



Suitability Analysis Results within Yates/Baylor Boundaries

- Salinity
  - Surface
  - Bottom
- Bottom DO
- Water Depth
- Yates and Baylor Grounds

<u>Total Suitable Area</u>

MD= 132,000 acres

VA= 121,000 acres

Subsequent Tributary Plans

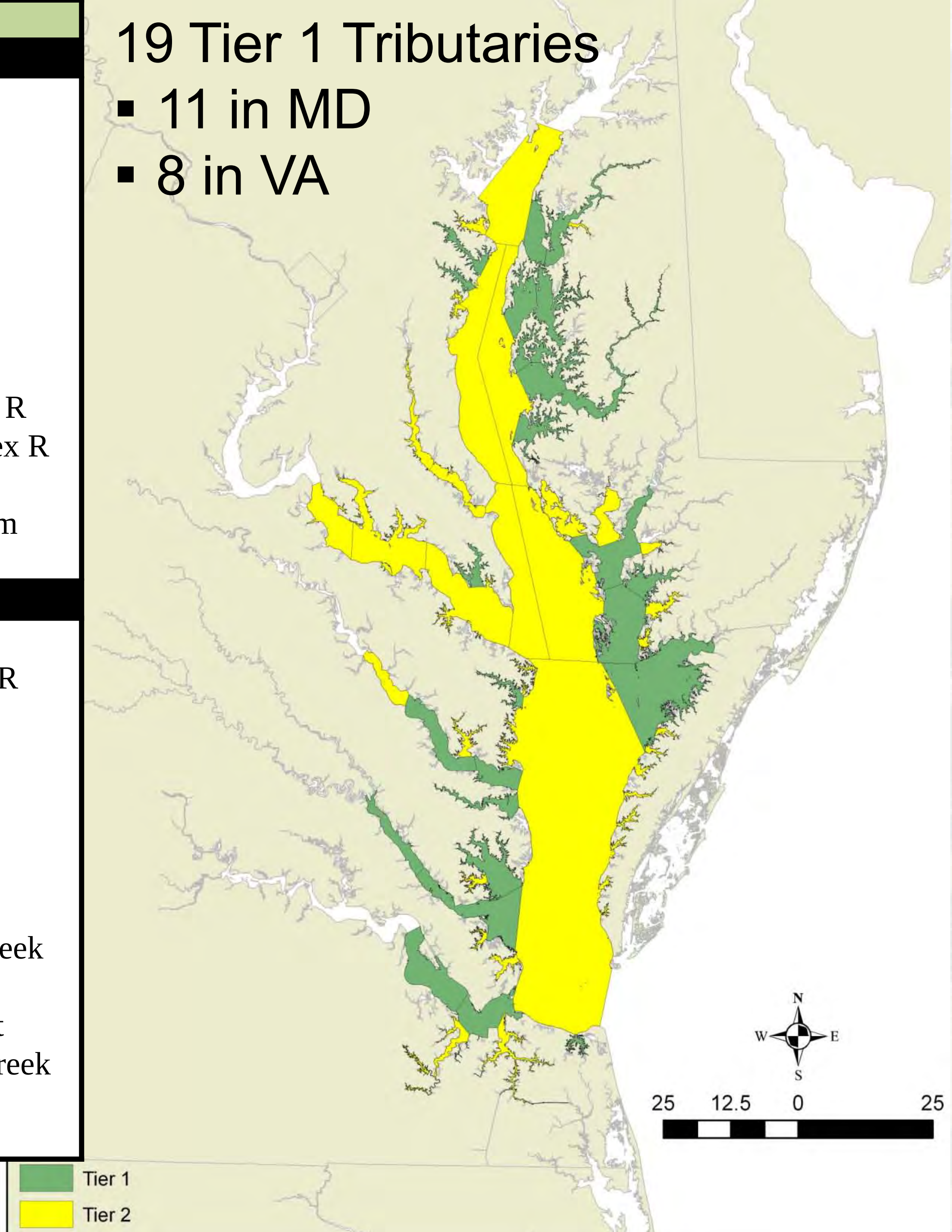
These factors are to be considered further during development of specific tributary plans.

Hard Bottom	Local Water Quality	Currents/ Water Flow
Sedimentation Rate	Watershed Suitability	Harmful Algal Blooms
Freshets	Phytoplankton/ Food Availability	Shellfish Harvesting Closures
Location Relative to Other Habitats	Proximity to and Quantity of Existing Broodstock Populations	

19 Tier 1 Tributaries

- 11 in MD
- 8 in VA

Tier 1	Tier 2
Maryland	
Severn R (S)	Magothy R (S)
South (S)	Rhode R
Chester R (S)	West R
Eastern Bay (S)	Corsica R (S)
Choptank R (S)	Honga R
Harris Creek (S)	Potomac R
Broad Creek	Fishing Bay
Little Choptank (S)	Monie Bay
St. Mary's R (S)	Big Annemessex R
Tangier Sound (includes Nanticoke R (S))	Little Annemessex R
Manokin R (S)	Patuxent R (S)
	All MD Mainstem Segments (S)
Virginia	
Rappahannock R (lower, middle)	VA Mainstem
Great Wicomico R (S)	Little Wicomico R
Piankatank R	Cockrell Creek
Mobjack Bay	Corrotoman R
York R	Severn R
Pocomoke/Tangier Sound	Poquoson R
James R	Back R
Lynnhaven R	Onancock Creek
	Nassawaddox Creek
	Hungars Creek
	Cherrystone Inlet
	Old Plantation Creek
	Elizabeth R
	Nansemond R



What Will Large-Scale Restoration Cost?

Cost estimates for restoration need to include habitat construction, seeding, and monitoring

Large-scale restoration is still in the learning mode

Cost range for a tributary reflects the low and high acreage target and the lowest and highest priced alternate substrates

Costs expected to be spread over multiple years for a given tributary

What Will Large-Scale Restoration Cost?

Total cost estimates to achieve restoration targets

Estimates are conservatively high – existing habitat is not included in most estimates.	$3.8 million to $48 million for smallest Tier 1 VA tributary: Lynnhaven River, 40 to 150 acres	$370 million to $1.4 billion for largest Tier 1 VA tributary: Rappahannock River, 3,800 to 7,500 acres	Once quantified, existing habitat would reduce the effort needed to reach restoration targets.

What are the benefits ?

- Oyster Production
- Water Filtration
- Nutrient Cycling
- Reduced Sedimentation
- Reef Habitat
- Carbon Sequestration
- Enhanced Fishery Resources
- Benthic and Intertidal Habitat Stabilization
- Increased Bottom Diversity

Master Plan Recommendations

Specific Tributary Plan

- Develop with restoration partners
- Parameters to consider identified in master plan
- Additional surveys = population, bottom condition, hydrodynamic, larval transport, and recruitment

Construction

- Construct a portion of target (25, 50, or 100 acres) per year
- Funding dependent
- Continue until success metrics reached

Target Higher Salinities for Development of Disease Resistance

- Initial efforts in mesohaline-polyhaline salinities
- Special attention given to mid-river reefs

Reef Design Recommendations

- Bar morphology, reef fragmentation, reef height, reef topography, orientation to flow, water depth, distance between reefs, etc.

Master Plan Recommendations Cont.

Research Needs	• Quantification of benefits, larval transport, development of disease resistance and transmission, site selection with respect to water currents and bottom topography, etc.
Use Adaptive Management	• Such as additional stocking of disease resistant oysters, moving of disease resistant spat-on-shell, addition of fresh substrate, measures to reduce predation, etc.
Monitoring Protocols	• Monitoring element, type of data recorded, method of monitoring, monitoring objective
Concentrate Resources and Funding	• Necessary to establish self-sustaining populations
Follow Success Metrics Defined by Oyster Metric Workgroup	• Biomass, density, and shell accretion

What is the Future of USACE Program?

Master plan will open up USACE's MD restoration program to additional tributaries (currently only eight areas covered by NEPA). Additional VA decision document(s) will be needed to work on new tributaries.

Work with NOAA and other agencies toward achieving E.O. 13508 goal of restoring 20 tributaries by 2025

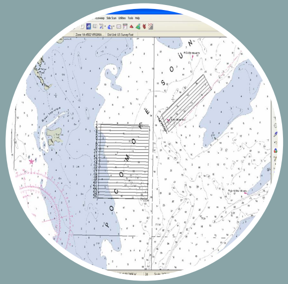
Focus will be on restoring one tributary at a time

Large-scale oyster restoration will only succeed with the cooperation of all agencies and organizations involved. Resources and skills must be leveraged to achieve the most from restoration dollars.

Virginia Oyster Restoration Activities

Monitoring of Prior Restoration Sites

Common Ground Items



Fossil Shell Survey

Oyster Benefits Modeling – Sanctuaries and Rotational Harvest Areas

Rehabilitation of Great Wicomico Reefs

BUILDING STRONG®

Restoration Construction Activities

Rappahannock and Tangier/Pocomoke

- Decision Document Complete.
- Construction complete. No additional construction currently planned.

Great Wicomico

- Decision Document Complete.
- Phase I Constructed. Monitoring and adaptive management ongoing
- Phase II. Not yet initiated

Lynnhaven

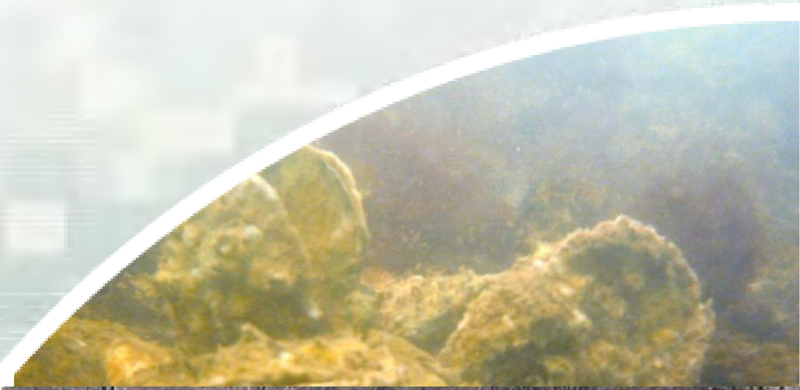
- Decision Document Complete.
- Phase I Constructed. Monitoring and adaptive management ongoing.
- Phase II planning underway.

Future Tributaries

- No Decision Document currently exists. May combine multiple tributaries for additional flexibility.
- No construction possible until decision document complete.

Any Questions?

USACE Native Oyster Restoration Master Plan



Briefing to Shellfish Advisory Committee

April 2012

US Army Corps of Engineers
BUILDING STRONG®

Presentation Outline

- USACE Oyster Restoration Program
- Native Oyster Restoration Master Plan
  - Goals and Purpose
  - Plan Formulation
  - Results
  - Recommendations
- Path Forward
- USACE VA Oyster Restoration Activities
- Questions

BUILDING STRONG®

USACE Oyster Restoration Program

Established in Section 704(b) of the Water Resources Development Act of 1986

- 75% Federal, 25% non-Federal funding
- First year of funding = FY1995
- Initially focused on Maryland; first report was in 1996, with cooperation agreement signed in 1997
- Maryland project sponsor is Maryland Department of Natural Resources
- Project has received up to $1-5 million Federal per year for MD+VA

Amended in 1996, 2000, 2002, 2006, and 2007

- Added Virginia to project location, Virginia project sponsor is Virginia Marine Resources Commission
- Increased authorization limit to $50 million
- Identifies specific type of construction activities
- Purpose: To establish sanctuaries and harvest management areas
- USACE activities to be consistent with other plans and strategies

Construction Summary
Maryland
1997-2011

- 459 acres of substrate placed
- 22 additional acres at Harris Creek to be constructed May-June 2012
- Locations:
  - Magothy, Severn, and Patuxent Rivers
  - Chester and Choptank Rivers (includes Harris Creek), Eastern Bay
  - Kedges Strait
- Material Used:
  - Dredged fossil shell (1997-2006)
  - Alternative substrate (2009-2011)
- Periodic project monitoring

Construction Summary
Virginia
2001-2011

- 389 acres of substrate placed
- Locations:
  - Rappahannock River (Section 510 authority), Tangier/Pocomoke Sound
  - Great Wicomico and Lynnhaven Rivers
- Material Used:
  - Dredged fossil shell (2001-2011)
- Periodic project monitoring

Native Oyster Restoration Master Plan

Long-Term Restoration Goal:
Throughout the Chesapeake Bay, restore an abundant, self-sustaining oyster population that performs important ecological functions such as providing reef community habitat, nutrient cycling, spatial connectivity, and water filtration, among others, and contributes to an oyster fishery.

Operational Goal:
Identify tributaries/regions most likely to develop sustainable populations of oysters with the implementation of reef construction, seeding, and other oyster restoration activities.

Purpose

Implementation

- The master plan ensures that USACE-implemented oyster restoration is conducted in a logical, science-based, and cost-effective manner with the greatest potential for success in achieving the restoration goal.

Strategic Plan

- The master plan will present a strategic plan for pursuing long-term, wide-scale restoration throughout the Bay that complements the States' oyster restoration programs as well as other Bay-wide restoration efforts and future uses of the Chesapeake Bay.

Oyster Locations

- It will not define specific projects for specific locations; locations will be determined in future tributary plans.

Plan Formulation Process

1. Develop formulation white papers

2. Adopt salinity-zone, disease, and reproduction strategies

3. Identify distinct sub-segments of the Chesapeake Bay for evaluation and prioritization

4. Determine the appropriate scale at which restoration should be undertaken

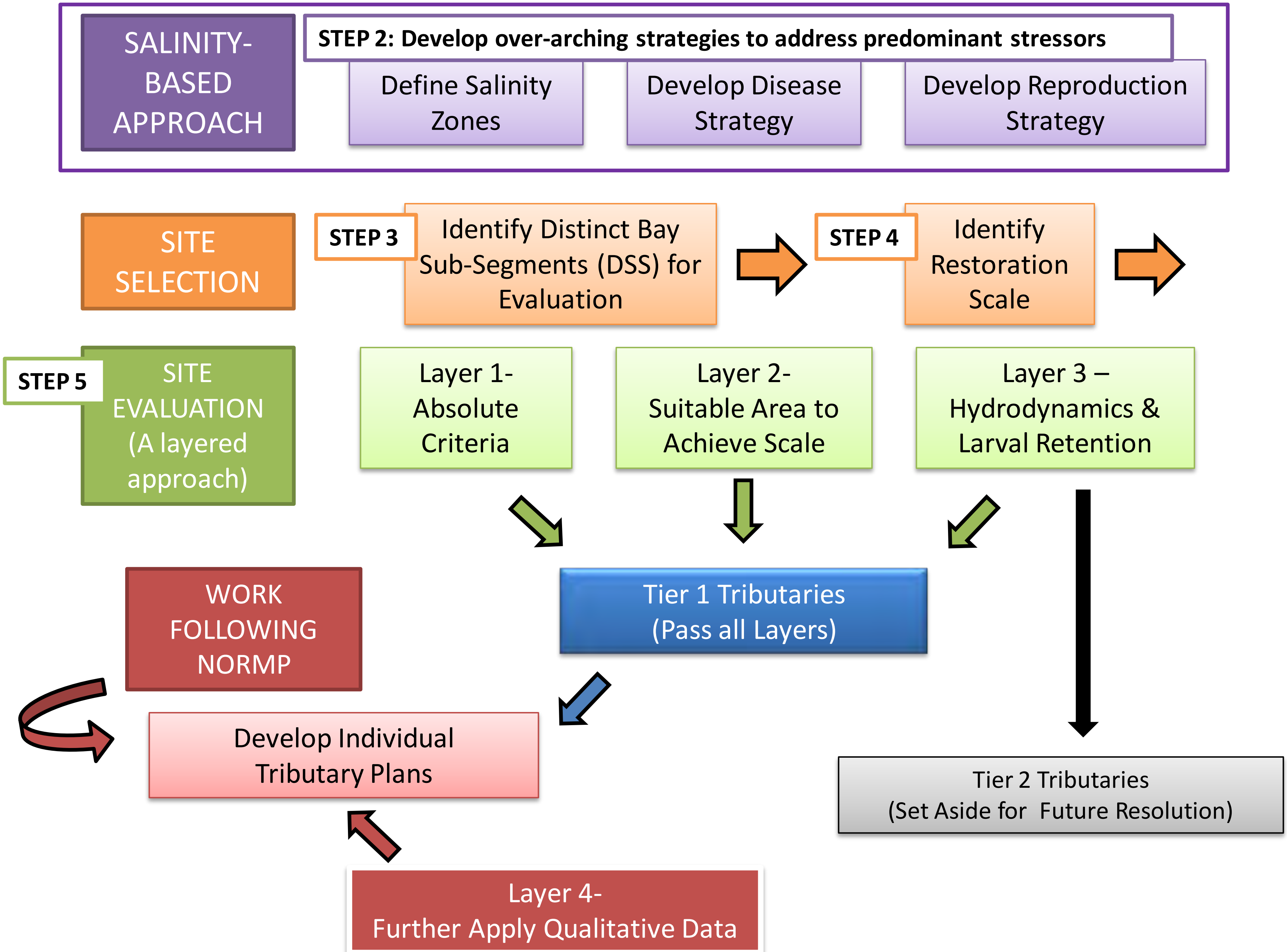
5. Tributary evaluation and prioritization:

A layered formulation evaluation	Identify Tier I and II Bay segments

Step 1- Develop White Papers

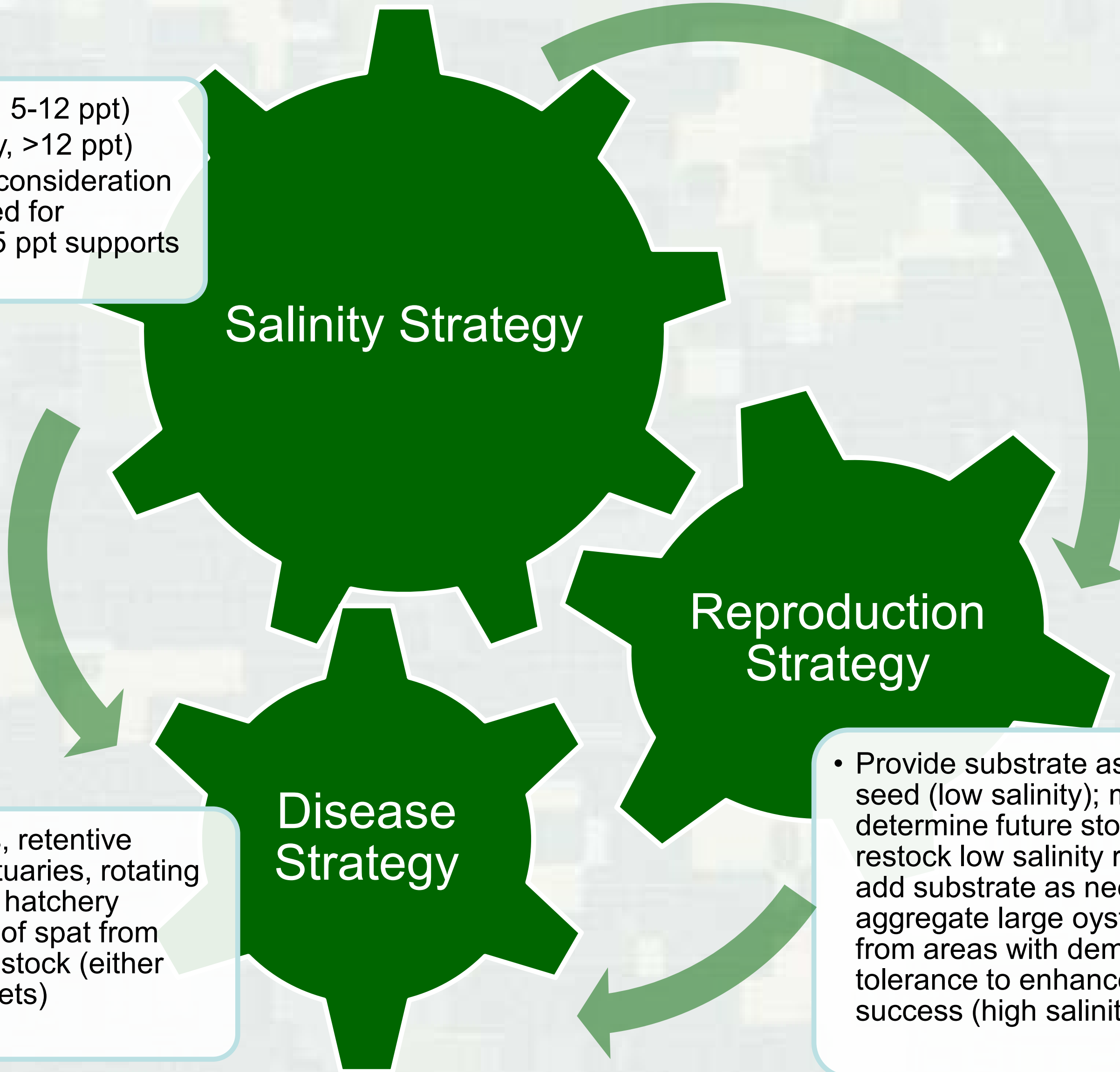
- Scale
- Disease
- Populations – bayscape setting
- Populations - individual reefs
- Physio-chemical factors
- Hydrodynamics
- Reproduction

- ➢ Significance to oyster restoration and master plan
- ➢ Scientific basis and state of knowledge
- ➢ Application to the master plan
- ➢ Reviewed and coordinated with resource agencies


SALINITY-BASED APPROACH
STEP 2: Develop over-arching strategies to address predominant stressors
Define Salinity Zones
Develop Disease Strategy
Develop Reproduction Strategy
SITE SELECTION
STEP 3
Identify Distinct Bay Sub-Segments (DSS) for Evaluation
STEP 4
Identify Restoration Scale
STEP 5
SITE EVALUATION (A layered approach)
Layer 1- Absolute Criteria
Layer 2- Suitable Area to Achieve Scale
Layer 3 – Hydrodynamics & Larval Retention
WORK FOLLOWING NORMP
Tier 1 Tributaries (Pass all Layers)
Develop Individual Tributary Plans
Tier 2 Tributaries (Set Aside for Future Resolution)
Layer 4- Further Apply Qualitative Data

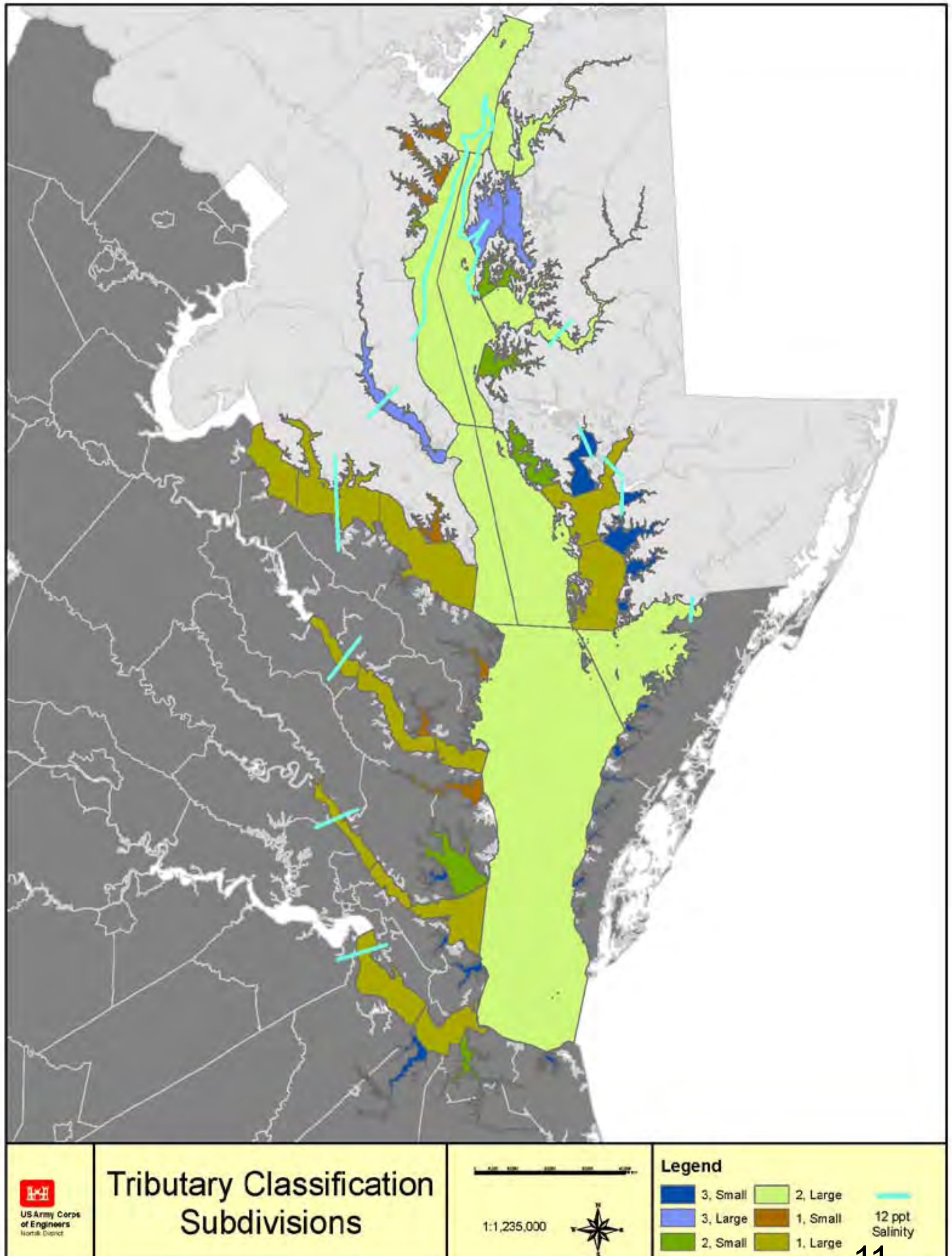
Step 2: Salinity-Based Approach

- Zone 1 (low salinity, 5-12 ppt)
- Zone 2 (high salinity, >12 ppt)
- Plans will take into consideration that >8 ppt is needed for reproduction, but >5 ppt supports growth



- Provide substrate as needed and seed (low salinity); monitor to determine future stocking needs; restock low salinity reefs at 2-3 years; add substrate as needed; Stock and aggregate large oysters harvested from areas with demonstrated disease tolerance to enhance fertilization success (high salinity)

- Incorporates sanctuaries, retentive systems such as trap estuaries, rotating broodstock approach for hatchery production, and planting of spat from disease-resistant parent stock (either from hatcheries or wild sets)



Step 3: Distinct Sub-Segment Delineations

34 Maryland segments
29 Virginia segments

Step 4: Scale

Scale = the approximate number of acres of functioning habitat in a given tributary or sub-region required to develop a self-sustaining oyster population. Not "one size fits all."

What do we know???

- Past restoration efforts have been too small to impact system
- Need to concentrate resources

Define historic habitat baseline

Identify the percent of historic habitat that needs to be restored to achieve goals.

Restoration goal = **20-40%** of historic (corrected) habitat

Step 5: Site Evaluation and Prioritization

Layer 1 → Absolute Criteria →

Identify absolute criteria. Determine the number of suitable acres for restoration available.

Layer 2 → Scale →

Determine if there is enough suitable acreage available to meet the scale targeted for sustainable restoration.

Layer 3 →Qualitative Hydrodynamic Rating →

Indicates whether a tributary has high, medium or low indicators of the hydrodynamic properties preferred for restoration.

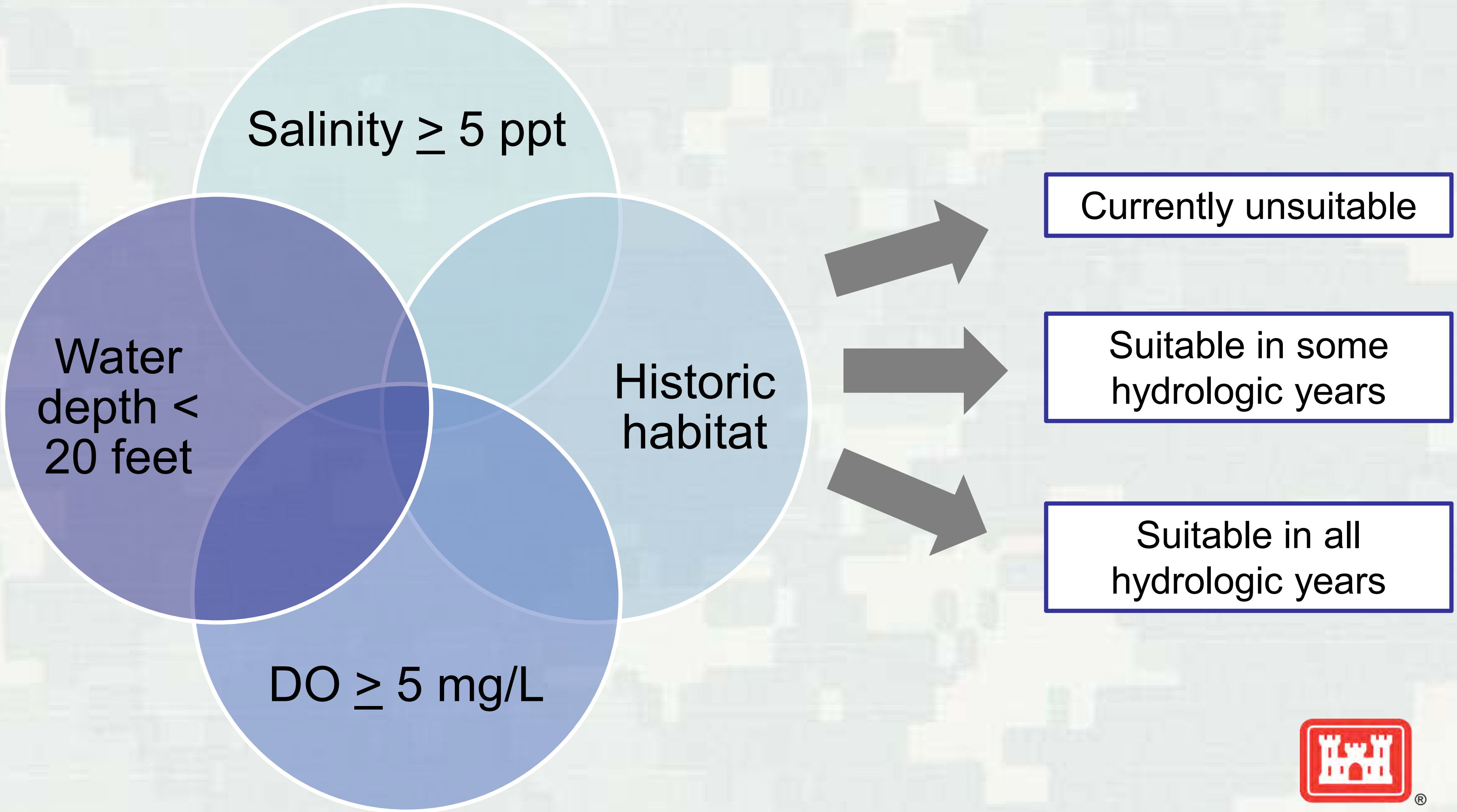
Layer 4 → Qualitative Data →

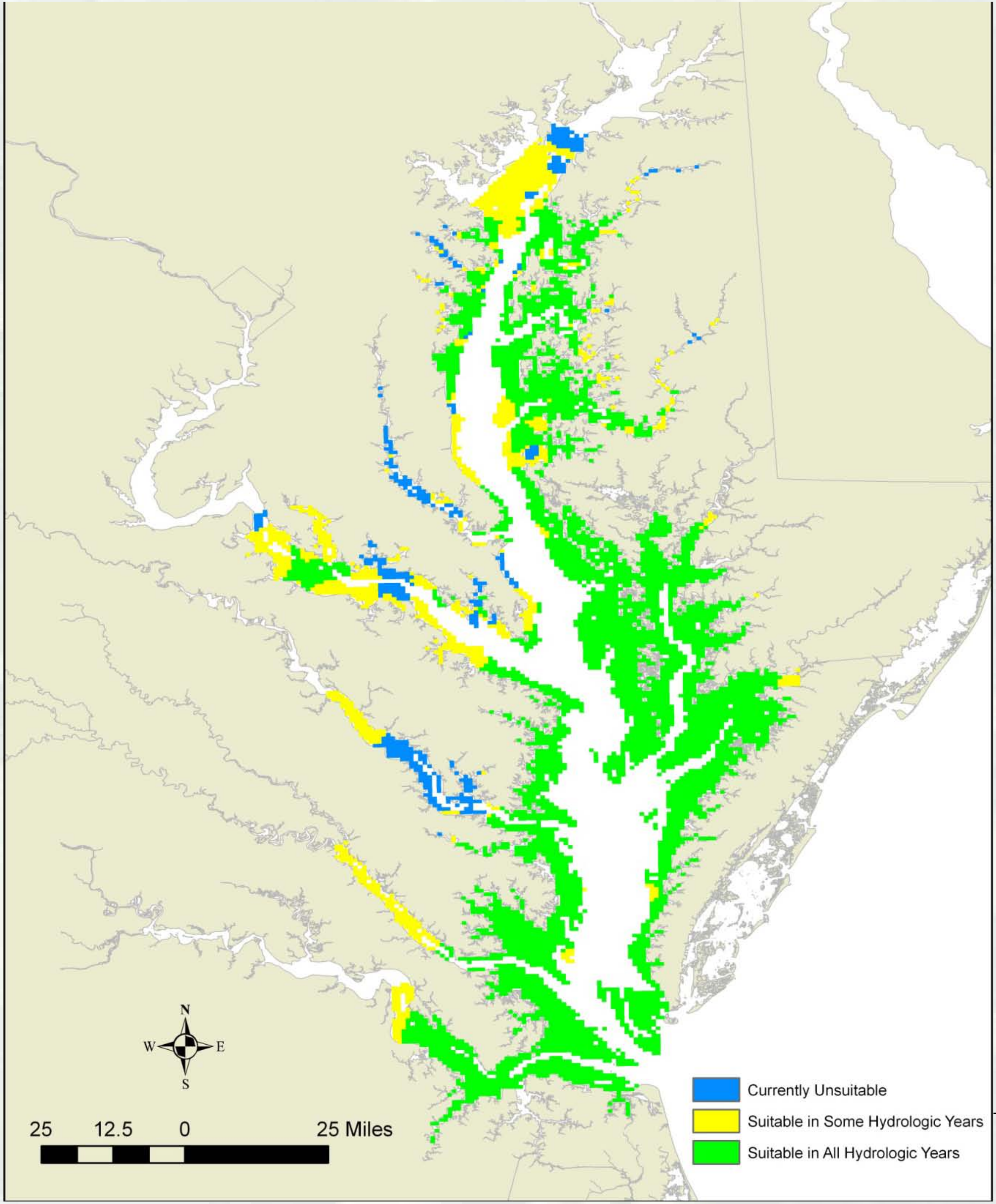
Additional considerations that are important for restoration, but are not as well documented or quantified.

List of Tier 1 and Tier 2 Tributaries

Step 5: Tributary Evaluation and Prioritization

Absolute Criteria





Suitability Analysis Results

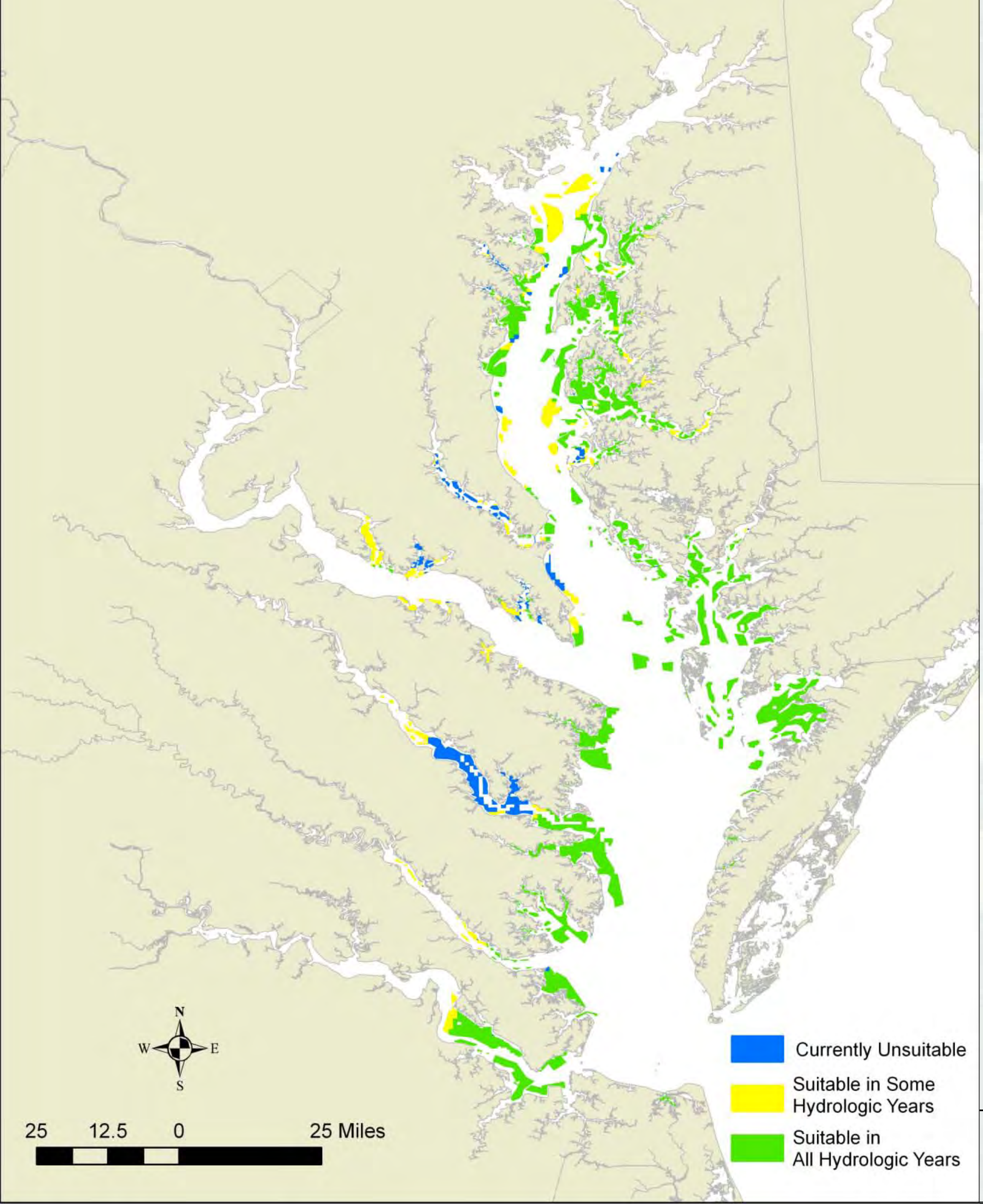
- Salinity
    - Surface
    - Bottom
- Bottom DO
- Water Depth

Total Suitable Area

MD= 513,000 acres

VA= 580,000 acres

Suitability Analysis Results within Yates/Baylor Boundaries



- Salinity
  - Surface
  - Bottom
- Bottom DO
- Water Depth
- Yates and Baylor Grounds

<u>Total Suitable Area</u>

MD= 132,000 acres

VA= 121,000 acres

Subsequent Tributary Plans

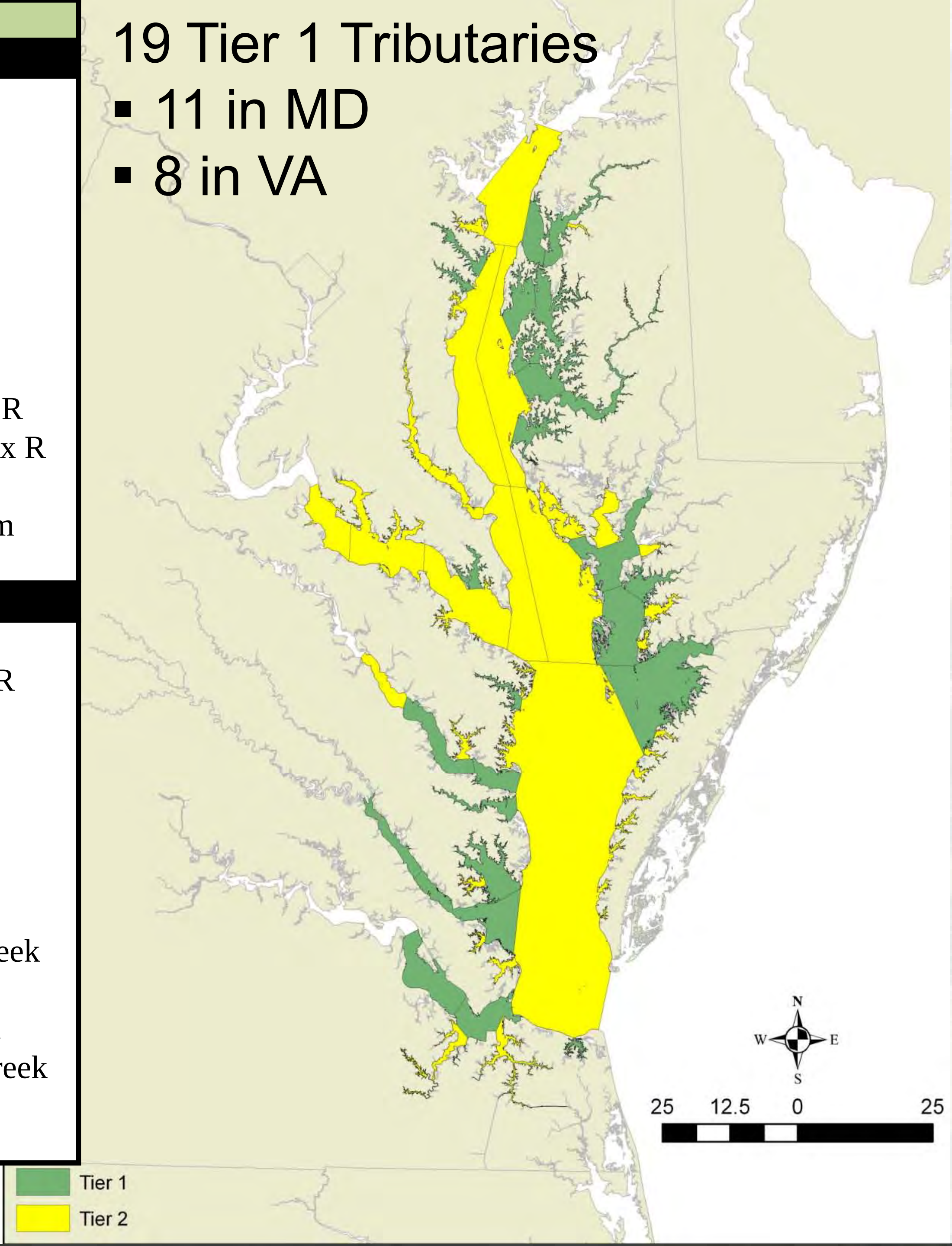
These factors are to be considered further during development of specific tributary plans.

- Hard Bottom
- Local Water Quality
- Currents/ Water Flow
- Sedimentation Rate
- Watershed Suitability
- Harmful Algal Blooms
- Freshets
- Phytoplankton/ Food Availability
- Shellfish Harvesting Closures
- Location Relative to Other Habitats
- Proximity to and Quantity of Existing Broodstock Populations

19 Tier 1 Tributaries

- 11 in MD
- 8 in VA

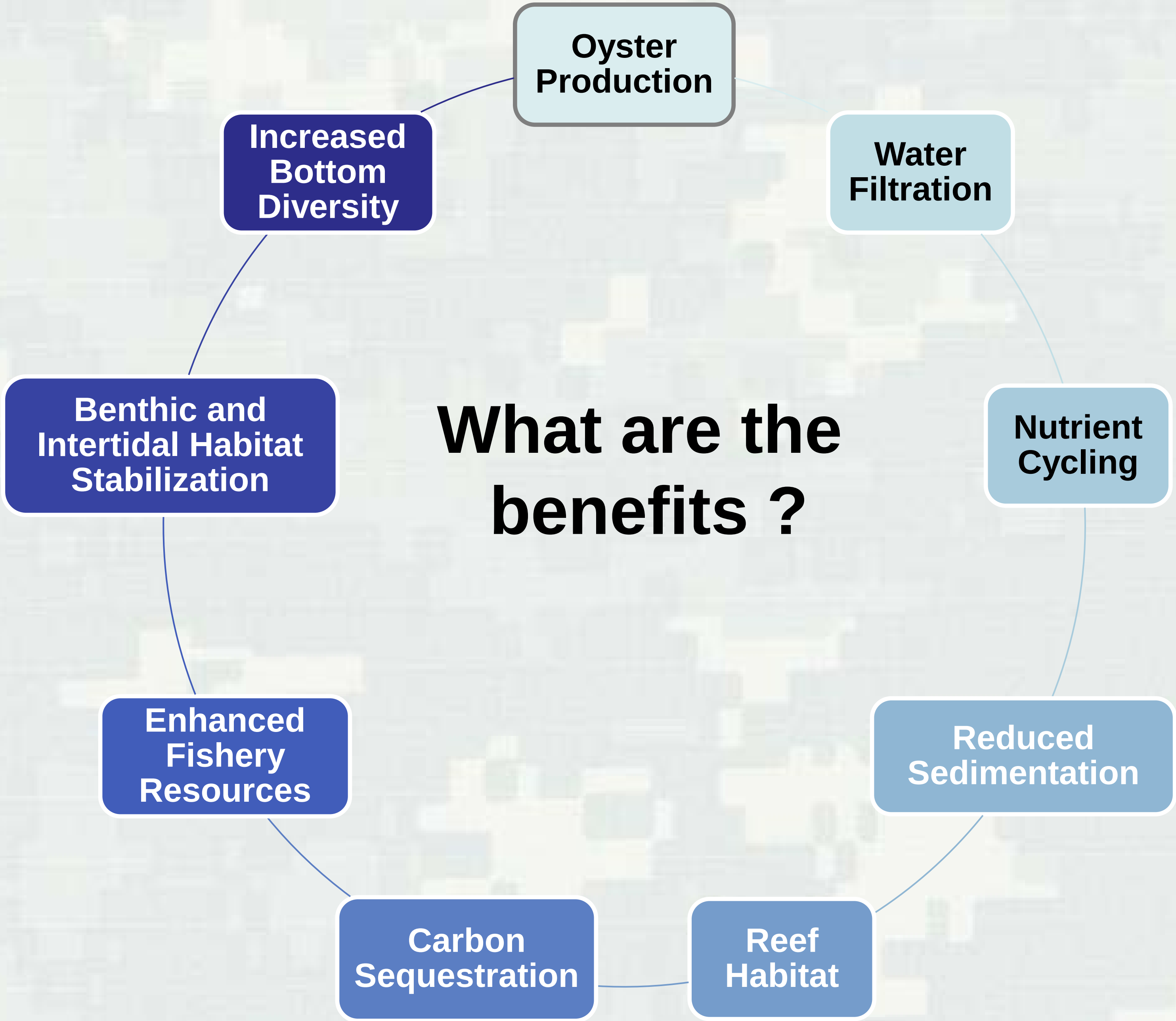
Tier 1	Tier 2
Maryland	
Severn R (S)	Magothy R (S)
South (S)	Rhode R
Chester R (S)	West R
Eastern Bay (S)	Corsica R (S)
Choptank R (S)	Honga R
Harris Creek (S)	Potomac R
Broad Creek	Fishing Bay
Little Choptank (S)	Monie Bay
St. Mary's R (S)	Big Annemessex R
Tangier Sound (includes Nanticoke R (S))	Little Annemessex R
Manokin R (S)	Patuxent R (S)
	All MD Mainstem Segments (S)
Virginia	
Rappahannock R (lower, middle)	VA Mainstem
Great Wicomico R (S)	Little Wicomico R
Piankatank R	Cockrell Creek
Mobjack Bay	Corrotoman R
York R	Severn R
Pocomoke/Tangier Sound	Poquoson R
James R	Back R
Lynnhaven R	Onancock Creek
	Nassawaddox Creek
	Hungars Creek
	Cherrystone Inlet
	Old Plantation Creek
	Elizabeth R
	Nansemond R



What Will Large-Scale Restoration Cost???

- Total cost estimates to achieve restoration targets:
  - $3.8 million to $48 million for smallest Tier 1 VA tributary = Lynnhaven River, 40 to 150 acres
  - $370 million to $1.4 billion for largest Tier 1 VA tributary= Rappahannock River, 3,800 to 7,500 acres
- Estimates include habitat construction, seeding, and monitoring
- Costs would be spread over multiple years
- Cost range for a tributary reflects the low and high acreage target and the lowest and highest priced alternate substrates.
- Estimates are conservatively high – existing habitat is not included in most estimates.
  - Once quantified, existing habitat would reduce the effort needed to reach restoration targets.

What are the benefits ?



Master Plan Recommendations

Specific Tributary Plan	• Develop with restoration partners • Parameters to consider identified in master plan • Additional surveys = population, bottom condition, hydrodynamic, larval transport, and recruitment
Construction	• Construct a portion of target (25, 50, or 100 acres) per year • Funding dependent • Continue until success metrics reached
Target Higher Salinities for Development of Disease Resistance	• Initial efforts in mesohaline-polyhaline salinities • Special attention given to mid-river reefs
Reef Design Recommendations	• Bar morphology, reef fragmentation, reef height, reef topography, orientation to flow, water depth, distance between reefs, etc.

Master Plan Recommendations Cont.

Research Needs	• Quantification of benefits, larval transport, development of disease resistance and transmission, site selection with respect to water currents and bottom topography, etc.
Use Adaptive Management	• Such as additional stocking of disease resistant oysters, moving of disease resistant spat-on-shell, addition of fresh substrate, measures to reduce predation, etc.
Monitoring Protocols	• Monitoring element, type of data recorded, method of monitoring, monitoring objective
Concentrate Resources and Funding	• Necessary to establish self-sustaining populations
Follow Success Metrics Defined by Oyster Metric Workgroup	• Biomass, density, and shell accretion

What is the Future of USACE Program?

Master plan will open up USACE's MD restoration program to additional tributaries (currently only eight areas covered by NEPA). Additional VA decision document(s) will be needed to work on new tributaries.

Work with NOAA and other agencies toward achieving E.O. 13508 goal of restoring 20 tributaries by 2025

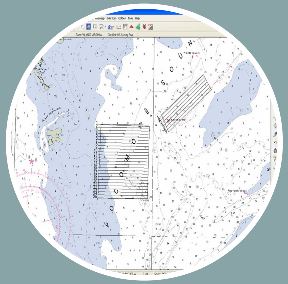
Focus will be on restoring one tributary at a time

Large-scale oyster restoration will only succeed with the cooperation of all agencies and organizations involved. Resources and skills must be leveraged to achieve the most from restoration dollars.

Virginia Oyster Restoration Activities

Monitoring of Prior Restoration Sites

Common Ground Items



Fossil Shell Survey

Oyster Benefits Modeling – Sanctuaries and Rotational Harvest Areas

Rehabilitation of Great Wicomico Reefs

Restoration Construction Activities

Rappahannock and Tangier/Pocomoke

- Decision Document Complete.
- Construction complete. No additional construction currently planned.

Great Wicomico

- Decision Document Complete.
- Phase I Constructed. Monitoring and adaptive management ongoing
- Phase II. Not yet initiated

Lynnhaven

- Decision Document Complete.
- Phase I Constructed. Monitoring and adaptive management ongoing.
- Phase II planning underway.

Future Tributaries

- No Decision Document currently exists. May combine multiple tributaries for additional flexibility.
- No construction possible until decision document complete.