TERRAPIN MONITORING AT THE PAUL S. SARBANES ECOSYSTEM RESTORATION PROJECT AT POPLAR ISLAND

2010

Final Report submitted to the
United States Army Corps of Engineers

Willem M. Roosenburg, Emily Dustman, and Nicholas Smeenk
Department of Biological Sciences
Ohio University
Athens Ohio 45701

740-593-9669
roosenbu@ohio.edu

Overwintering hatchlings digging out of nest, discovered while the nest was being excavated. Photo by Nick Smeenk

BACKGROUND

The Paul S. Sarbanes Ecosystem Restoration Project at Poplar Island, formerly known as the Poplar Island Environmental Restoration Project (PIERP), is a large-scale project that is using dredged material to restore the once-eroding Poplar Island in the Middle Chesapeake Bay. As recently as 100 years ago, the island was greater than 400 hectares and contained uplands and high and low marshes. During the past 100 years, the island eroded and by 1996 only three small islands (<4 hectares) remained before the restoration project commenced. The Project Sponsors, the United States Army Corps of Engineers (USACE) and the Maryland Port Administration (MPA), are rebuilding and restoring Poplar Island to a size similar to what existed over 100 years ago. A series of stone-covered perimeter dikes facing the windward shores of PIERP were erected to prevent erosion. Dredged material from the Chesapeake Bay Approach Channels to the Port of Baltimore is being used to fill the areas within the dikes. The ultimate goals of the project are: to restore remote island habitat in the mid-Chesapeake Bay using clean dredged material from the Chesapeake Bay Approach Channels to the Port of Baltimore; optimize site capacity for clean dredged material while meeting the environmental restoration purpose of the project; and protect the environment around the restoration site. Ultimately, this restoration will benefit the wildlife that once existed on Poplar Island.

After completion of the perimeter dikes in 2002, diamondback terrapins, *Malaclemys terrapin*, began using the newly formed habitat as a nesting site (Roosenburg and Allman 2003; Roosenburg and Sullivan, 2006; Roosenburg and Trimbath, 2010; Roosenburg et al., 2004; 2005; 2007; 2008; 2010). The persistent erosion of Poplar and nearby islands had greatly reduced the terrapin nesting and juvenile habitat in the Poplar Island archipelago. Prior to the initiation of the PIERP, terrapin populations in the area likely declined due to emigration of adults and reduced recruitment because of limited high quality nesting habitat. By restoring the island and providing nesting and juvenile habitat, terrapin populations utilizing the PIERP and the surrounding wetlands could increase and potentially repopulate the archipelago. The newly restored wetlands could provide the resources that would allow terrapin populations to increase by providing high quality juvenile habitat.

The PIERP is a unique opportunity to understand how large-scale ecological restoration projects affect terrapin populations and turtle populations in general. In 2002, a long-term terrapin monitoring program was initiated to document terrapin nesting on the PIERP. By monitoring the terrapin population on the PIERP, resource managers can learn how creating new terrapin nesting and juvenile habitat affects terrapin populations. This information will contribute to understanding the ecological quality of the restored habitat on the PIERP, as well as understanding how terrapins respond to large-scale restoration projects. The results of seven years of terrapin nesting surveys and juvenile captures are summarized herein to identify how diamondback terrapins use habitat created by the PIERP and how it has changed during that time.

The 2006 PIERP Framework Monitoring Document (FMD) identifies three reasons for terrapin monitoring:

1) Quantify the use of nesting and juvenile habitat by diamondback terrapins on Poplar Island, including the responses to change in habitat availability as the project progresses.
2) Evaluate the suitability of terrapin nesting habitat by monitoring nest and hatchling viability, recruitment rates, and hatchling sex ratios.
3) Determine if the project affects terrapin population dynamics by increasing the available juvenile and nesting habitat on the island.

The terrapin's charismatic nature makes it an excellent species to use as a tool for environmental outreach and education. Some of the terrapin hatchlings that originate on the PIERP participate in an environmental education program in the Anne Arundel, Dorchester, and Talbot County schools in Maryland, sponsored by the Arlington Echo Outdoor Education Center (AE), the Maryland Environmental Service (MES), and the National Aquarium in Baltimore (NAIB). These programs provide students with a scientifically-based learning experience that also allows Ohio University (OU) researchers to gather more detailed information on the nesting biology of terrapins, in addition to providing an outreach and education opportunity for the PIERP. As part of the terrapin research program at the PIERP, OU researchers are collaborating with staff at AE, MES, and NAIB to foster both a classroom and field experience that uses terrapins to teach environmental education and increase awareness for the PIERP. The students raise the terrapins throughout their first winter and they attain a body size that is comparable to 2-5 year old wild individuals, thus "headstarting" their growth. The specific goals of the terrapin outreach program are:

1) Provide approximately 250 terrapin hatchlings to AE, MES, and NAIB to be raised in classrooms.
2) Obtain sex ratio data from the hatchlings as increased bodysize allows.
3) Conduct a scientifically-based program to evaluate the effectiveness of head-starting.

METHODS

Specific details of differences in surveys and sampling techniques used during 2002 - 2009 can be found in Roosenburg and Allman (2003), Roosenburg and Trimbath (2010), and Roosenburg et al. (2004; 2005; 2008). Since 2004, survey efforts to find nests were consistent and thorough. Details of the general survey methods and specific techniques employed during 2010 are described below.

Identification of terrapin nests: From 26 May to 30 July 2010, OU researchers surveyed the following areas on PIERP daily: beaches in the Notch area (surrounding the northwestern tip of Coaches Island near Cell 4AB), areas between Coaches Island and the PIERP (outside of Cell 5AB), the western edge of Cell 4D, and the beach outside the dike near Cell 3B in Poplar Harbor (Figure 1). The researchers also occasionally searched the periphery of Cell 4D and the dike surrounding Cells 3D and 1A for signs of terrapin nesting. A geographic positioning system (GPS) recorded nest positions and survey flags identified the specific nest locations. Upon discovering a nest, researchers examined the eggs to determine the age of the nest. If the eggs were white and chalky, they considered the nest greater than 24 hours old and no further excavation was conducted because of increased risk of rupturing the allantoic membrane and killing the embryo. Researchers excavated recent nests (less than 24 hours old, identified by a pinkish translucent appearance of the eggs) to count the number of eggs, and from 2004 through 2010 weighed the individual eggs. Researchers marked nests with four 7.5 cm^2 survey flags, and beginning in 2005, laid a 30 cm by 30 cm, 1.25 cm^2 mesh rat wire on the sand over the nest to deter avian nest predators, primarily crows.

Figure 1. Red indicates areas on the PIERP that were monitored daily for terrapin nests by the research team. Green areas were monitored 3-4 times per week.

Monitoring nesting and hatching success: After 45 to 50 days of egg incubation, researchers placed an aluminum flashing ring around each nest to prevent emerging hatchlings from escaping. Anti-predator (1.25 cm^2) wire also was placed over the ring to prevent predation of emerging hatchlings within the ring. Beginning in late July, the researchers checked ringed nests at least once daily for emerged hatchlings. Researchers brought newly emerged hatchlings to the onsite storage shed where they measured and tagged the hatchlings.

Researchers excavated nests ten days after the last hatchling emerged. For each nest, they recorded the number of live hatchlings, dead hatchlings that remained buried, eggs with dead embryos, and eggs that showed no sign of development. To estimate hatching success, researchers compared the number of surviving hatchlings to the total number of eggs from only the nests that were excavated within 24 hrs of oviposition, which provided an exact count of the number of eggs. Additionally, researchers determined if the nest was still active – with eggs that appeared healthy and had not completed development. The researchers allowed nests containing viable eggs or hatchlings that had not fully absorbed their yolk sac to continue to develop; however, researchers removed fully developed hatchlings from nests, further described in the next section.

Capture of hatchlings: Researchers collected hatchlings from ringed nests and also from un-ringed nests that were discovered by hatchling emergence. Additionally, researchers found a small number of hatchlings on the beach, which they collected and processed (see method below). Because 47 nests over-wintered during 2010-11 (hatchlings remaining in the nest until spring of the following year), researchers traveled to the PIERP on 30 March and 31 March 2011 to excavate and determine the fate of the over-wintering nests.

Measuring, tagging, and release of hatchlings: Researchers brought all hatchlings back to the MES shed onsite where they placed hatchlings in plastic containers with water until they were processed (measured, notched, and tagged), usually within 24 hours of capture. Researchers marked hatchlings by notching with a scalpel the 9th right marginal scute and 12th left marginal scute, establishing the cohort ID 9R12L for 2010 fall emerging hatchlings. OU personnel gave spring 2011 emerging hatchlings a different cohort ID of 12R10L (notching the 12th right marginal scute and 10th left marginal scute) to distinguish fall 2010 from spring 2011 emerging hatchlings upon later recapture. Researchers implanted individually marked coded wire tags (CWTs, Northwest Marine Technologies®) in all hatchlings. The CWTs were placed subcutaneously in the right rear limb using a 25-gauge needle. The CWTs should have high retention rates (Roosenburg and Allman, 2003) and in the future researchers will be able to identify terrapins originating from the PIERP for the lifetime of the turtle by detecting tag presence using Northwest Marine Technologies' V-Detector.

Researchers measured plastron length, carapace length, width, and height (± 0.1 mm), and mass (± 0.1 g) of all hatchlings. Additionally, they checked for anomalous scute patterns and other developmental irregularities. Following tagging and measuring, researchers released all hatchlings in either Cell 4D or Cell 3D. On several occasions, large numbers (>50) of hatchlings were simultaneously released, but dispersed around the cell to minimize avian predation.

Measuring, tagging, and release of juveniles and adults: All juvenile and adult turtles captured on the island were transported to the onsite shed for processing. Researchers recorded plastron length, carapace length, width, and height (±1 mm), and mass (±1 g) of all juveniles and adults. Passive Integrated Transponder (PIT, Biomark Inc.) tags were implanted in the right inguinal region, the loose skin anterior to the hind limb where it meets the plastron. Additionally, a monel tag (National Band and Tag Company) was placed in the 9th right marginal scute. The number sequence on the tag begins with the letters PI, identifying that this animal originated on Poplar Island.

Terrapin Education and Environmental Outreach Program: During 2010, 240 PIERP hatchlings were reared in the terrapin education and environmental outreach programs at AE, the NAIB, and MES. In April 2011, researchers traveled to AE to implant PIT tags in 225 head-started individuals. Researchers also measured and weighed all animals at this time. From late May through July 2011, the head-started terrapins were returned to the PIERP and released in the Notch.

Researchers summarized and processed all data using Microsoft Excel® and Statistical Analysis System (SAS). Graphs were made using Sigmaplot®. Institutional Animal Care and Uses Committee at OU (IACUC) approved animal use protocols (#L01-04) and Maryland Department of Natural Resources (MD DNR) – Wildlife and Heritage issued a Scientific Collecting Permit Number SCO-48456 to Willem M. Roosenburg (WMR).

RESULTS AND DISCUSSION

Nest and Hatchling Survivorship: During the 2010 terrapin nesting season (May – July), the researchers located 166 nests on the PIERP (Table 1, raw nest data provided in Appendix 1). Of these 166 nests, 125 successfully produced hatchlings and 34 nests were unsuccessful, of which predators destroyed 11 nests (Table 1). Eleven nests failed because the eggs did not develop or were thin-shelled, which results in nest failure.

YEAR	2002	2003	2004	2005	2006	2007	2008	2009	2010
TOTAL NESTS	68	67	182	282	191	225	218	189	166
NESTS PRODUCED HATCHLINGS	38	50	129	176	112	166	180	145	125
NESTS THAT DID NOT SURVIVE	1	7	17	70	69	44	28	34	42
DEPREDATED (ROOTS OR ANIMAL)	0	0	12	46	54	18	12	10	9
WASHED OUT	1	6	3	11	13	2	6	3	4
UNDEVELOPED EGGS, WEAK SHELLED EGGS, OR DEAD EMBRYOS	0	1	0	12	1	19	10	12	11
DESTROYED BY ANOTHER TURTLE OR NEST WAS IN ROCKS	0	0	2	0	0	3	0	0	2
DESTROYED BY BULLDOZER	0	0	0	1	0	0	0	0	0
DEAD HATCHLINGS	0	0	0	0	1	2	0	2	6
FATE OF NEST UNKNOWN	29	10	36	36	10	19	10	10	17

Table 1 - Summary of the diamondback terrapin nests found and their fate on the PIERP from 2002 to 2010.

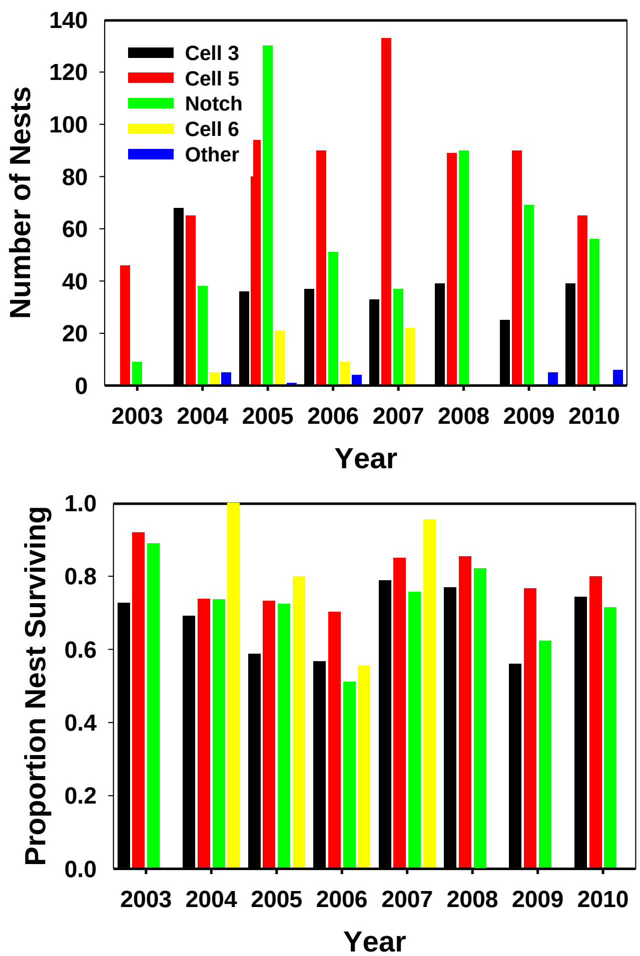

Figure 2 – The number of nests in each of the major nesting areas for each year of the study and the proportion of nests surviving.

Four nests were lost due to inundation by the high tide or washed out due to heavy rains because the nest site was in an area of high erosion.

The number of terrapin nests on the PIERP has averaged 207 nests per year since 2004 (Table 1). The number of nests located on the PIERP has declined during the past 4 years from a high of 225 in 2007 to 166 during 2010. During the fall of 2007, the perimeter dike closure resulted in eliminating access to nesting areas inside Cell 6, and consequently no nests have been found there since 2008 (Figures 2 and 3). However, four nests were found around Cell 4D, most of which were on the center dike between Cell 6 and Cell 4D, but these females emerged from Cell 4D (Figure 3). Consistent with the closure of the perimeter dike of Cell 6, the number of nests in the Notch has increased, suggesting that those females formerly nesting in Cell 6 still may be nesting on the PIERP.

Nesting activity outside of Cell 3C increased relative to the previous years to 39 nests (Figure 2). This represents the greatest number of nests in this area since 2004, when the available nesting habitat in this area was considerably greater than it is currently. In 2004, the beach outside Cell 3 was continuous outside the dike from Cell 3B to Cell 3D; it now lies only in front of Cell 3C, and the decrease in size of this nesting area is the most likely explanation for the decrease in nesting observed since 2004.

The number of nests decreased in the Notch and outside of Cell 5. The decline in nesting in these areas coincides with an increase in the vegetation. Areas with vegetation typically support fewer terrapin nests in the Chesapeake Bay region (Roosenburg, 1996) and pose a threat to terrapin nests because the roots of grasses can either entrap hatchlings and prey on the eggs by extracting nutrients and water (Stegmann et al., 1988). The import of major sand deposits into Cell 4A-B during the summer of 2010 and the subsequent movement of sand by the wind has dramatically altered nesting habitat at the northern corner of the Notch, creating large open sandy areas that during the 2010 nesting season were dominated by vegetation.

Figure 3 – Terrapin nesting locations on the PIERP during 2010

Thus during the 2011 nesting season an interesting comparison of nesting activity can be made between the newly created opens sandy areas and the remainder of the notch and cell five where vegetation has become dense. Nests in the "Other" category (Figure 2) include 4 nests along Cell 4D, 1 nest inside Cell 3D, and 2 nests in Cell 1A. The locations of these nests indicate that terrapins are using the wetlands as a route to access potential nesting areas in the interior of Poplar Island, but may also be spending a greater portion of their time inside the cells.

Survivorship of nests (the proportion of nests producing hatchlings) increased from 2009 to 2010. Researchers continued to place hardware cloth over the nests to prevent crow predation during 2010. An Eastern king snake, *Lampropeltis getulus*, was observed for the second consecutive year depredating terrapin nests, and currently this species accounts for most of the nests that are depredated outside Cell 5 and the Notch. Six nests were partially depredated (not all the eggs eaten) and markings around the nests indicated the king snake was responsible for five of the predation events. The lack of raccoons and foxes combined with researchers protecting nests from crows contributed to the continued high nest survival on the PIERP. Interestingly, the within-nest survivorship saw a dramatic decline during 2010 (x = 0.429; proportion of eggs within-nest surviving). Previous years had higher average within-nest survivorship (2009 = 0.697). This decline in survivorship was most likely the result of the unusually hot and dry weather that occurred during June and July of the 2010 nesting season. During hot and dry conditions soil water potentials drop, and eggs can become desiccated and die. During the summer of 2010, researchers documented a higher number of eggs that had not completed development and died within the nests; desiccation was the suspected primary cause for this within-nest mortality. Possibly contributing to the increase in mortality is the increasing presence of vegetation on the nesting beaches, particularly in the Notch and outside of Cell 5. Vegetation competes with turtle eggs for soil moisture, and plants can tolerate lower soil water potentials than eggs, in addition to the roots being able to encase eggs and draw the moisture out (Stegmann et al., 1988).

Researchers noted three nests with thin-shelled or kidney shaped eggs at the time of laying. Thin-shelled eggs also have been observed in the Patuxent River terrapin population (Roosenburg, personal observation). In all three clutches only a few of the eggs were thin-shelled or miss-shaped. In previous years, OU researchers have noted nests in which all of the eggs have thin shells; these eggs are frequently broken during oviposition and seldom hatch. The cause of the thin-shelled eggs is unknown at this time, but it is not unique to the PIERP. Two possible causes that remain to be evaluated include a toxicological effect by a factor ubiquitous in the Chesapeake Bay, or a resource limitation that affects the females' ability to sequester sufficient amounts of calcium to shell the eggs.

Reproductive Output: Clutch size (Analysis of Variance; ANOVA, $F_{6,707} = 1.64$, $P > 0.05$), clutch mass (ANOVA, $F_{6,709} = 1.73$, $P > 0.05$), and average egg mass (ANOVA, $F_{6,709} = 0.89$, $P > 0.05$) did not differ significantly from 2004 through 2010 (Table 2). Interestingly, since 2004 clutch size had been decreasing slightly, but then increased by almost 1 from 2008 to 2009. During 2002 and 2003, researchers did not collect these data. These findings indicate that there is no difference in per-clutch reproductive output from one nesting season to the next.

Year	Clutch Size	Clutch Mass (g)	Egg Mass (g)
2004	13.68 (0.379)	127.55 (4.372)	9.80 (0.110)
2005	13.62 (0.245)	133.11 (2.541)	9.92 (0.087)
2006	13.48 (0.248)	133.28 (2.570)	9.97 (0.081)
2007	13.11 (0.241)	127.4 (2.502)	9.86 (0.086)
2008	12.90 (0.260)	128.0 (2.890)	10.06 (0.092)
2009	13.85 (0.242)	137.1 (2.335)	10.02 (0.091)
2010	13.33 (0.364)	133.1 (3.850)	10.10 (0.198)

Table 2. Average and standard error of clutch size, clutch mass, and egg mass from 2004-2010 on the PIERP.

Hatchlings: Researchers captured, tagged, and notched 785 terrapin hatchlings on the PIERP between 24 July 2010 and 31 March 2011 (Table 3, Appendix 2). All hatchlings were caught at their nests. Researchers found 30 nests by the evidence left when the hatchlings emerged and recovered one live hatchling from these nests. Hatchling carapace length and mass were similar among all years of the study (Table 3). From 2002-2010, 9,946 hatchlings have been captured, tagged, and notched on the PIERP (Table 3). The 2010 hatchling number was the lowest since 2004 when the detailed nest monitoring began on the PIERP (Table 3). A comparable low number of hatchlings (855) were recovered in 2006 prior to the use of hardware cloth protection to prevent crow predation. Why were the hatchling numbers down in 2010? Although researchers cannot directly test this question, there are several contributing factors supported by data collected by OU personnel. First, during the 2010 nesting season, the number of nests found on the PIERP was the lowest since detailed daily searches began in 2004 (fewer nests results in fewer hatchlings). The decrease in nests can be attributed to two factors, one related to the manner in which terrapins produce eggs, the other related to long term increase in vegetation on the nesting beaches. The summer of 2010 had a long hot, dry period during June and July that may have caused females that normally produce three clutches per year to forgo their third nesting event and improve their chances of survival by reabsorbing the energy in the developing eggs. Researchers observed the last nesting event on 23 July, and a dramatic decline in nesting after 14 July, which supports this suggestion. Increasing vegetation on the nesting beaches also affects the nesting behavior of terrapins and the researchers' ability to find nests. Terrapins prefer to nest in open areas (little vegetation) and the increasing vegetation in Cell 5 and the Notch may decrease the use of these areas by nesting females, resulting in a decrease in nesting in the areas most intensively surveyed. The decline in nests seen in the Notch and Cell 5 during the last three years supports this hypothesis. Second, increasing vegetation decreases the ability of researchers to locate nests, as the nests are more cryptic. The large number of nests found after hatchlings emerged supports that a higher number of freshly laid nests were missed, and potentially contributes to the low number of hatchlings caught in 2010. The third factor contributing to the reduction in hatchling number is the reduction of within-nest survivorship. During 2010 within-nest survivorship decreased (see above), reducing the number of hatchlings emerging from surviving nests. Although a large number of nests were suspected of overwintering because they had not yet emerged in the fall, when researchers excavated many of the unsuccessful nests they discovered eggs that had died during development. Because all eggs hatch in the late summer or fall, the dead eggs found in many of the nests support that the eggs had died because they were too hot and /or too dry during development. Many of these excavated eggs had collapsed shells and appeared dehydrated. Additional data that supports physiological stress during development is revealed by the examination of mean egg mass and mean hatchling mass for each clutch. In previous years (2004-2008) there was no difference in this relationship among years (Roosenburg et al., 2010), however in 2010 this relationship changed (ANCOVA; $F_{5,223} = 3.86$; $P < 0.003$) such that the slope of this line decreased (Figure 4). Although this has never been previously documented for any turtle species, one valid interpretation of these data is that the unusually dry conditions during of the summer of 2010 resulted in the

YEAR	NUMBER OF HATCHLINGS	MEAN CARAPACE LENGTH (MM)	MEAN MASS (G)
2002	**565**	**31.28 (1.61)**	**7.52 (0.96)**
2003	**387**	**31.13 (1.50)**	**7.50 (0.99)**
2004	**1,337**	**31.57 (1.47)**	**7.61 (0.89)**
2005	**1,526**	**30.98 (1.94)**	**7.45 (1.10)**
2006	**855**	**30.95 (1.71)**	**7.38 (1.01)**
2007	**1,616**	**31.26 (1.72)**	**7.50 (0.91)**
2008	**1,443**	**31.03 (1.34)**	**7.42 (0.14)**
2009	**1,430**	**30.99 (1.83)**	**7.33 (0.99)**
2010	**785**	**30.45 (0.06)**	**7.38 (0.04)**
Total	**9,946**		

Table 3 - Number of hatchlings, mean and standard error of carapace length, and mean mass of terrapin hatchlings caught on the PIERP from 2002-2010.

observed effect; that suggests that greater resources were used during development resulting in a change in the egg size / hatchling size relationship.

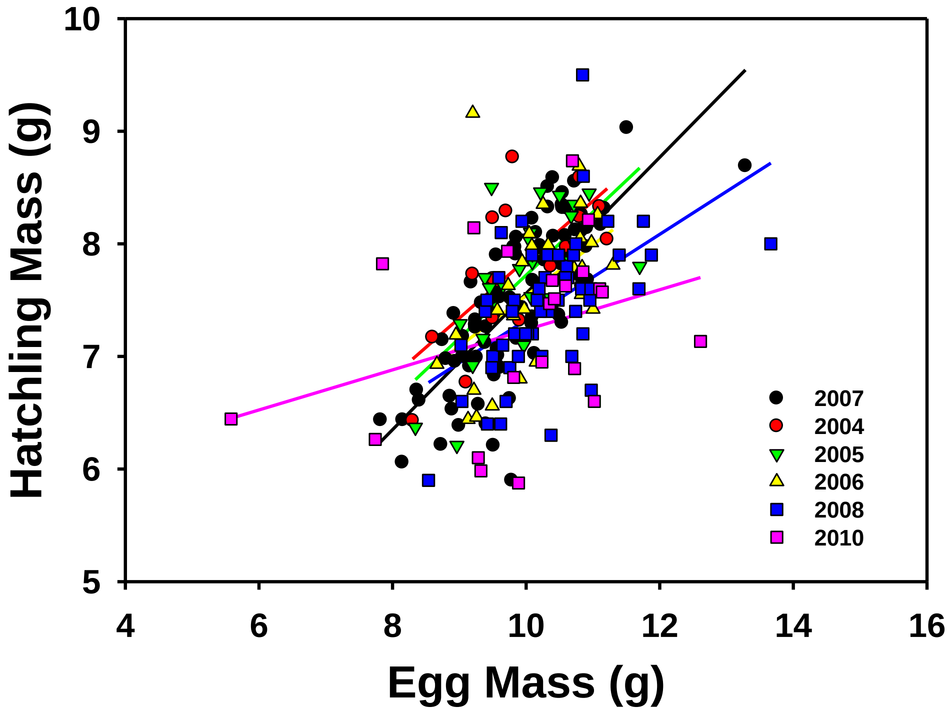

Figure 4. The relationship between average egg mass by clutch and average hatchling mass by clutch for 6 years on the PIERP. The relationship is similar for all years except 2010 when the slope of the relationship decreased substantially.

	2006	2007	2008	2009	2010
Total Nests - Notch & Outside of Cell 5	146	170	183	159	124
Depredated Nests and Nests destroyed before fall emergence	47 (32.2%)	18 (10.6 %)	17 (9.3%)	12 (7.5%)	4 (3.2%)
Fall Emerging Nests	49 (33.6%)	92 (54.1%	113 (61.7%)	68 (42.8%)	77 (62.1%)
Nests Over-wintering	44 (30.1%)	60 (35.3%)	44 (24.0%)	74 (46.5%)	21 (16.9%)
Spring Emerging Nests	33 (22.6%)	50 (29.4%)	40 (21.9%)	66 (41.5%)	21 (16.9%)
Over-wintering Nests that did not Emerge	6 13.6%	4 (2.4%)	4 (2.2%)	8 (5.0%)	0 (0.0%)
Unknown Nests	11 (7.5%)	6 (3.5%)	9 (4.9%)	5 (3.1%)	5 (4.0%)
Both Fall & Spring Emerging Nests	1 (0.7%)	0 (0%)	1 (0.5%)	4 (2.5%)	4 (3.2%)

Table 4 – Nest fate and over-wintering percentage of the nests during the 2006 –2010 nesting seasons on the PIERP.

Over-wintering: OU researchers let 47 nests overwinter during the winter of 2009-2010. Of these 47 nests, 21 successfully overwintered and produced 78 hatchlings (Table 4). Eight of the 47 nests that failed to emerge contained eggs that did not develop, indicating that the eggs in these nests died during the developmental period in the summer, and death was not caused by overwintering mortality. Another 12 nests emerged in the fall and produced no additional hatchlings in the spring. The 4 remaining unaccounted nests were buried by the sand that accumulated in the Notch during the 2010-11 winter. Researchers recovered only a single dead hatchling from one nest, suggesting that despite a low number of nests overwintering, overwintering success was high. Many of the over-wintering nests contained large numbers of dead eggs, indicating that most of the mortality occurred while the eggs were developing, and not in the nest post-hatching. Also of interest was that 4 nests had hatchlings emerging in both the fall and the spring.

Researchers also PIT tagged terrapins that were part of the AE, NAIB, and MES head-start programs. Researchers tagged and processed 225 terrapins in April 2011 (Appendix 3). During May, June, and July the head-started hatchlings were transported to the PIERP and were released in the Notch area. Fifteen hatchlings died during the rearing phase of the project; once again the higher than normal mortality rate suggests that many of the hatchlings may have been under stress during their incubation/ development on the PIERP. This year for the first time head-started terrapins were released inside Cell 4D and Cell 3D in addition to the traditional release site in the Notch.

CONCLUSIONS

Despite the lower than usual terrapin nesting success on the PIERP during 2010, terrapin hatchling recruitment is still high relative to mainland populations, where nest predators eat most nests. The PIERP continues to provide excellent nesting habitat since the completion of the perimeter dike. Nest survivorship remains high on the PIERP relative to the Patuxent River mainland population (Roosenburg, 1991) because the primary nest predators are absent from the island, and avian predation is reduced by the hardware cloth laid over the nests. Nest survivorship remained high in 2010 and was actually higher than 2009 (Roosenburg et al., 2010), but within-nest survivorship decreased considerably during 2010. Within-nest survivorship was the lowest reported for the PIERP since the beginning of terrapin nesting surveys on the island. Researchers attribute the decreased within-nest survivorship to the warmer and dryer conditions experienced during the summer of 2010. At the writing of this report, after the completion of the 2011 nesting and fall emergence, the number of nests and the within-nests survivorship increased substantially, further supporting that the decreases observed in 2010 were due to environmental variation in the local climate, and unlikely to be associated specifically with the PIERP.

The warm, dry summer of 2010 created challenging conditions for terrapin nests on the PIERP. The number of nests declined, the within-nest survivorship declined, and the proportion of nests over-wintering declined. Dry soil conditions can result in desiccated turtle eggs, because their shells are permeable to water which moves in response to the soil water potential. Dry conditions decrease soil water potential and thereby draw water from the eggs. This starts to occur when soil water potentials drop below -300 kPa (kilopascals, a measure of force per unit area) as determined in laboratory incubation experiments of other turtle species (reviewed in Packard and Packard, 1988). Although soil water potentials were not measured on the PIERP, the dry, powdery soils observed during July of the nesting season at average nest depth are indicative of soil water potentials lower than -300 kPa. Furthermore, the change in the relationship between egg mass and hatchling mass suggests that the incubation conditions experienced during 2010 changed relative to previous years. The lighter hatchlings observed in 2010 may well be a function of hatchlings with lower water content, which can be caused by extremely dry substrates (Packard and Packard, 1988).

During the last five years, terrapin nests observed on the PIERP have averaged more than 200 per year. The success of previous years and the modest success of 2010 nesting season indicate that appropriate habitat is being created by the PIERP project. However, researchers are concerned by the increasing vegetation, particularly outside Cell 5 and in the Notch. The accumulation of sand in the northern portion of the Notch and the southern boundary of Cell 4D will make available large portions of suitable nesting habitat with little vegetation. These areas will be closely monitored during the 2011 nesting season to establish if creating open areas on nesting beaches enhances nesting activity on the island. The number of nests found annually also indicates that between 70-125 adult females are using the PIERP for nesting. This estimate is based on a maximum reproductive output of three clutches per year per female, as has been observed in the Patuxent River population (Roosenburg and Dunham, 1997).

During 2010, the researchers conducted twice daily surveys of the nesting areas. This was possible because one researcher was dedicated full-time to locating terrapin nests and three other OU researchers assisted her throughout the nesting season. The researchers discovered 30 nests by noting hatchlings emerging after the nesting season had ended, and found additional nests in the spring of 2011 by emergence holes that were excavated and confirmed with the presence of egg shells. Many of these nests were probably laid during the weekends of the nesting season when researchers could not complete nesting surveys. Furthermore, the extremely dry conditions during July made it more difficult to locate recently laid nests, because the disturbances in the sand that identify nests erode more quickly in dryer soils.

Raccoons, foxes, and otters are known terrapin nest predators and contribute to low nest survivorship in areas where these predators occur, sometimes depredating 95% of the nests (Roosenburg, 1994). The lack of raccoons on the PIERP also minimizes the risk to nesting females (Seigel, 1980; Roosenburg, pers. obs.). The absence of efficient nest and adult predators on the PIERP generated nest and adult survivorship rates that are much higher compared to similar nesting areas with efficient predators. As was similarly observed in 2002 through 2007 (Roosenburg and Allman, 2003; Roosenburg and Sullivan, 2006; Roosenburg and Trimbath, 2010; Roosenburg et al., 2004; 2005; 2007; 2008), the nest survivorship on the PIERP continues to be higher relative to mainland populations because of the lack of nest predators. The lack of predators and nest protection practices are resulting in strong hatchling recruitment from the PIERP.

The PIERP produced 785 hatchlings during the 2010 nesting season. Hatchlings started emerging from the nests on 24 July 2010; the last hatchlings were excavated on 31 March 2011. This is the earliest hatchling emergence date recorded on the PIERP and again reflects the warmer than normal summer experienced during 2010. Researchers released all of the hatchlings in Cell 4D, Cell 3D, and the recently completed Cell 1A, however many of the hatchlings released in September and October 2010 clearly preferred to stay on land as opposed to remaining in the water.

During the winter of 2010-2011, 21 nests over-wintered successfully. The recovery of 78 hatchlings from 21 over-wintering nests confirms over-wintering as a successful strategy used by some terrapin hatchlings. A total of 47 nests had not emerged by 1 November 2010 and were left to over-winter. However, excavation of many of these nests in the following spring discovered large numbers of dead eggs, indicating that many of these nests never developed successfully, a consequence of the dry summer of 2010. Continued studies of over-wintering and spring emergence will be conducted to better understand the effect of over-wintering on the terrapin’s fitness, life cycle, and natural history. The PIERP offers a wonderful opportunity to study terrapin over-wintering because of the large number of nests that survive predation.

The educational program conducted in collaboration with the AE Outdoor Education Center, the NAIB, and MES successfully head-started the terrapins. Students increased the size of the hatchlings they raised to sizes characteristic of 2-5 year old terrapins in the wild. All hatchlings were PIT tagged to determine the fate of these hatchlings in the future through the continued mark-recapture study. During the summer of 2009 and 2010, mark recapture efforts in the Poplar Island Harbor and the area between Poplar and Coaches Island have relocated several head-start and natural release hatchlings. The preliminary results indicate that some terrapins from the island are remaining within the archipelago and surviving. Researchers eagerly await the return of a hatchling as a nesting adult. Given an age of first reproduction of 8 years this would suggest those individuals from the 2002 and 2003 cohorts could be discovered nesting on the PIERP. The presence of CWTs in these animals allows for the confirmation of individuals that originated from the PIERP.

The initial success of terrapin nesting on the PIERP indicates that similar projects also may create suitable terrapin nesting habitat. Although measures are taken on the PIERP to protect nests, similar habitat creation projects should have high nest success even without mechanical protection until raccoons or foxes colonize the project. Throughout their range, terrapin populations are threatened by loss of nesting habitat to development and shoreline stabilization (Roosenburg, 1991; Siegel and Gibbons, 1995). Projects such as the PIERP combine the beneficial use of dredged material with ecological restoration, and can create habitat similar to what has been lost to erosion and human practices. With proper management, areas like the PIERP may become areas of concentration for species such as terrapins, thus becoming source populations for the recovery of terrapins throughout the Bay.

The PIERP FMD identifies three purposes for the terrapin monitoring program. The first purpose is to monitor terrapin nesting activity and habitat use to quantify terrapin activity on the PIERP. The current monitoring program is detailing widespread use of the island by terrapins, evidenced by a comparable number of nests found relative to mainland sites in the Patuxent River, as well as the recovery of several marked individuals in our mark-recapture study. The second purpose is to determine the suitability of the habitat for terrapin nesting. The high nest success and hatching rates on the PIERP indicate the island provides high quality terrapin nesting habitat, albeit limited in availability because of the rock perimeter dike around most of the island. The third purpose is to determine if the project is affecting terrapin population dynamics. The suitability of wetland creation as juvenile habitat remains to be determined because no trapping has yet occurred in the interior of wetland cells. However, the emergence of females from Cell 4D and nesting on the nearby dike along with direct observations of terrapins inside Cells 4D, 3D, and 1A suggests that the wetlands cells do provide suitable terrapin habitat. The success of nesting activity on the PIERP over the past nine years is positive. However, nesting surveys monitor one segment of the life cycle of the long-lived terrapin, and in the upcoming years we hope to begin recovering some of the individuals that originated from the PIERP.

The PIERP FMD also identifies three hypotheses for the terrapin monitoring program. Hypothesis one is that there will be no change in the number of terrapin nests or the habitat used from year to year. This hypothesis is supported with a consistent average of about 200 nests per year. Although there was a decrease in the number of nests during the 2010 nesting season, this decrease is most likely due to the extreme weather conditions during 2010 and is within the range of variation observed in the last 8 years. Hypothesis two states that nest and hatchling survivorship and sex ratio will differ between Poplar Island and reference sites. This hypothesis is supported, as nest success and hatchling survivorship is much higher on the PIERP because of the lack of major nest predators. The sex ratio of hatchlings on the PIERP is highly female biased. Hypothesis three states that there will be no change in terrapin population size on Poplar Island; particularly within cells from the time the cells are filled, throughout wetland development, and after completion and breach of the retaining dike. The status of this hypothesis remains undetermined as there is not enough data currently to form a conclusion.

RECOMMENDATIONS

Terrapin nesting will continue on the PIERP. The expansion of terrapin nesting throughout the island in response to the wetland cells coming on line suggests that the increase in access points to the island interior are benefitting terrapins. Researchers have frequently noted terrapins inside the wetland cells, particularly Cells 4D and 3D. Although the dikes around the new wetland cells, particularly Cells 3D and 1A, are sufficiently elevated for terrapin nesting, the amount of nesting activity potentially could increase in if open sandy areas were created near inlets within the cells. As the nesting beach outside Cell 3C continues to decrease in size and the vegetation continues to increase in the Notch and outside Cell 5, the amount of accessible high quality nesting habitat is decreasing. The accumulation of sand in the Notch during the winter of 2010-11 will create a natural experiment that can evaluate how an increase in open sandy habitat can enhance terrapin nesting activity on the island. The outcome of this experiment may identify short and long-term measures that can be taken to improve nesting habitat, and thereby increase nesting on the island. The following recommendations are suggested with the objective of increasing terrapin nesting and available habitat on the PIERP.

First, researchers recommend the creation of high quality nesting habitat near the tidal inlets of the wetland cells. Figure 5 identifies recommended sites for terrapin nesting inside Cells 3A and 3C in the context of the current plan. Proximity to the inlets and water is suggested to maximize access, and also to reduce overland movement of terrapins between cells as they search for suitable nesting areas. Small, isolated areas would also facilitate fencing the nesting areas if necessary. The nesting areas should be open, with no vegetation, and constructed from sand. The positioning of these nesting areas may prove highly successful, because it is unknown how the changes in erosion patterns will affect the beach outside Cell 3B, which eroded substantially when the inflow to Cell 3D was initiated. The nesting areas should be 1- 1.5 m above mean high water, and have a gradual slope to permit easy access for nesting females.

Figure 5 - Recommended terrapin nesting areas inside Cells 3A and 3C in red.

Second, the northeast expansion of the PIERP, scheduled to be implemented 2015, provides the opportunity to create more terrapin nesting habitat in the sheltered areas of Poplar Harbor. In particular, areas to be built to the northeast of Jefferson Island would be ideal for creating terrapin nesting habitat. The creation of these nesting areas could help offset the loss of nesting habitat that has occurred on the outside of Cell 3C in recent years. Although this area is proposed to be an upland cell, the creation of offshore bulkheads and backfilling of sand as illustrated in Figure 6 could provide a large amount of terrapin nesting habitat in an area where terrapins have been captured in high concentrations. Building structures such as those illustrated in Figure 6 on the outside of the barrier dike would preclude the need to build additional fencing to prevent turtles from getting into the cells under construction. Furthermore, nesting areas without marsh and beach grasses could be provided for terrapin nesting habitat within the cells under construction. Because terrapins avoid nesting in areas with dense vegetation (Roosenburg 1996), providing open, sandy areas on the seaward side of the dikes should reduce efforts by terrapins to enter cells under construction to find suitable, open areas.

Third, predator control on the island will be paramount to the continued success of terrapin recruitment. Minimizing raccoon and fox populations will maintain the high levels of nest survivorship observed in 2002 through 2008. The increase in nest success because of the screens over the nests is also an effective mechanism to reduce crow predation. A sustained program to eliminate mammalian predators and prevent avian predation will facilitate continued terrapin nesting success on the PIERP.

Figure 6 – Shoreline stabilization and the creation of terrapin nesting habitat in Calvert County Maryland – red dots indicate terrapin nests.

Fourth, researchers recommend the continuation of terrapin nesting monitoring on the PIERP. The accumulation of newly deposited sand with little vegetation creates a natural experiment that will allow us to evaluate how the creation of other new nesting areas may benefit nesting activity on the island. Additionally, continued monitoring will document the further expansion and use of terrapin habitat on the island. During 2011, Cell 1C will be opened to tidal exchange, thus allowing access to potential nesting sites around Cell 1C. OU researchers plan to continue to include additional wetland cells as they are developed.

Finally, researchers recommend the continuation of the head-start education program. The terrapin is an excellent ambassador for the island because of its charismatic nature, but also because the project has successfully created habitat for this species. Thus the terrapin education program is an extremely effective mechanism to teach about the PIERP and its environmental restoration. The message that terrapins provide is not only absorbed by K-12 students, but by all visitors to the island, and therefore is an invaluable tool to promote the PIERP. These five recommendations offered by OU will contribute to the continuing and increasing understanding of the effect of the PIERP on terrapin populations and their use as stewards for the PIERP.

ACKNOWLEDGMENTS

We are grateful to Kevin Brennan, Mark Mendelsohn, and Doug Deeter of the USACE for their support and excitement about discovering terrapins on the PIERP. Michelle Osborn and Claire Ewing of MES completed some of the fieldwork in this project. Without their contribution this work could not have been successful. We also are indebted to the MES staff of the PIERP who checked ringed nests during weekends and holidays. We thank Dave Bibo and the staff of the MPA for their continued support of the PIERP terrapin project. Sara Michaels and Brian Walling from OU and Elizabeth Stephenson from the University of Maryland (UMD) participated in fieldwork. This work was supported through an Army Corps of Engineers Contract to Ohio University, two Program for Advanced Career Enhancement (PACE) awards to WMR from OU, and a UMD "Fear the Turtle Internship" awarded to Elizabeth Stevenson. All animal handling protocols were approved by the IACUC at OU (Protocol # L01-04) issued to WMR. All collection of terrapins was covered under a Scientific Collecting Permit number SCO-48456 issued to WMR through the MD-DNR Natural Heritage and Wildlife Division.

LITERATURE CITED

Packard, G. C. and M. J. Packard. 1988. The physiological ecology of reptilian eggs and embryos. In (C. Gans and R. B. Hueyeds.) Biology of the Reptilia, Ecology B. 16:523-606.

Roosenburg, W. M. 1991. The diamondback terrapin: Habitat requirements, population dynamics, and opportunities for conservation. In: A. Chaney and J.A. Mihursky eds. *New Perspectives in the Chesapeake System: A Research and Management and Partnership. Proceedings of a Conference.* Chesapeake Research Consortium Pub. No 137. Solomons, Md. pp. 237 - 234.

Roosenburg, W. M. 1994 Nesting habitat requirements of the diamondback terrapin: a geographic comparison. Wetland Journal 6(2):8-11.

Roosenburg, W. M. 1996. Maternal condition and nest site choice : an alternative for the maintenance of environmental sex determination. Am. Zool. 36:157-168.

Roosenburg, W. M. and P. E. Allman. 2003. Terrapin Monitoring at Poplar Island. Final Report submitted to the Army Corps of Engineers, Baltimore District. Baltimore, MD. pp. 13.

Roosenburg, W. M., R. Dunn, and N. L Smeenk. 2010. Terrapin Monitoring at Poplar Island, 2009. Final Report Submitted to the Army Corps of Engineers, Baltimore Office, Baltimore, MD pp. 23.

Roosenburg, W. M. and A. E. Dunham. 1997. Allocation of reproductive output: Egg and clutch-size variation in the diamondback terrapin. Copeia 1997:290-297.

Roosenburg, W. M., M. Heckman, and L.G. Graham. 2008. Terrapin Monitoring at Poplar Island - 2007. Final Report submitted to the Army Corps of Engineers, Baltimore District. Baltimore, MD. pp.45.

Roosenburg, W. M., E. Matthews, and L.G. Graham. 2007. Terrapin Monitoring at Poplar Island - 2006. Final Report submitted to the Army Corps of Engineers, Baltimore District. Baltimore, MD. pp.45.

Roosenburg, W. M., T. A. Radzio and P. E. Allman. 2004. Terrapin Monitoring at Poplar Island - 2003. Final Report submitted to the Army Corps of Engineers, Baltimore District. Baltimore, MD. pp. 26.

Roosenburg, W. M., T. A. Radzio and D. Spontak. 2005. Terrapin Monitoring at Poplar Island - 2004. Final Report submitted to the Army Corps of Engineers, Baltimore District. Baltimore, MD. pp. 26.

Roosenburg, W. M. and S. Sullivan. 2006. Terrapin Monitoring at Poplar Island - 2005. Final Report submitted to the Army Corps of Engineers, Baltimore District. Baltimore, MD. pp. 54.

Roosenburg, W. M. and R. Trimbath. 2010. Terrapin Monitoring at Poplar Island - 2008. Final Report submitted to the Army Corps of Engineers, Baltimore District. Baltimore, MD. pp. 54.

Seigel, R. A. 1980. Predation by raccoons on diamondback terrapins, *Malaclemys terrapin tequesta*. J. Herp. 14:87-89.

Seigel, R. A.. and Gibbons, J. W. 1995. Workshop on the ecology, status, and management of the diamondback terrapin (*Malaclemys terrapin*), Savannah River Ecology Laboratory, 2 August 1994: final results and recommendations. Chelonian Conservation and Biology 1:240-243.

Stegmann, E. W., R. B. Primack, and G. S. Ellmore. 1988. Absorption of nutrient exudates from terrapin eggs by roots of *Ammophila breviligulata* (Gramineae). Canadian Journal of Botany. 66:714-718.