Project 2

The Diamondback Terrapin in Alabama: Causes for Decline and Strategy for Recovery

Final Performance Report

State: Alabama **SWG Grant Number: T-3-**03

Period; October 1, 2007 to September 30, 2010

Need:

A) Historic Decline

Historic data and anecdotes indicate that the diamondback terrapin was once abundant in coastal waters of Alabama (Carr, 1952; Jackson and Jackson, 1970; Nelson and Marion, 2004). This subspecies was historically harvested as the Biloxi terrapin or Gulf terrapin (Carr, 1952). During the late 1800's, one of the largest terrapin farms in the U.S. was located just north of Dauphin Island, AL, and as many as ten thousand terrapins per year were shipped to the northeast to help meet the demand for terrapin stew (Anonymous, New York Times, 1881). The historic abundance and economic impact of the terrapin in Alabama is exemplified by the fact that the State of Alabama Tax Code includes a commercial tax on terrapins.

Although it was once abundant, recent surveys indicate that terrapins are now scarce in the Alabama salt marshes, estuaries and bays (Nelson and Marion, 2004; Borden *et al*., unpublished data; Coleman *et al*., unpublished data). This is despite the fact that there is abundant salt marsh habitat for terrapins in coastal areas of Alabama and state protection for this species. Terrapins have declined in Alabama to the point that it is considered a "Priority One" species of "Highest Conservation Concern" (Mirarchi *et al.*, 2004).

B) Threats

i) Suitable Nesting Habitat

Although there is abundant salt marsh habitat in Alabama, suitable nesting areas may be limited and could be further altered by storm-related erosion. For example, Mount (1975) indicates the number of terrapins around Dauphin Island declined after Hurricane Camille in 1969 due to the loss of nesting beaches and habitat on the west end of the island. Over the past five years we have surveyed habitat for terrapins throughout Alabama (Borden *et al*., unpublished data; Coleman *et al*., unpublished data). High ground nesting beaches adjacent to salt marshes are scarce and are often in various states of storm-related erosion. Through recent surveys, we have identified nesting beaches that could represent critical habitat. These areas vary widely in their characteristics such as height, substrate, and state of erosion. These range from beaches that are regularly inundated by high tides to high ground areas that would be washed over only during the most severe storms. Thus, the salt marshes in Alabama provide a model system for simultaneously evaluating the suitability and use by terrapin of various types of nesting beaches.

ii) Predation of Eggs and Hatchlings on the Nesting Beach

Various predators are known to eat terrapin eggs including raccoons, skunks, foxes, ghost crabs, crows, and gulls (Ernst and Barbour 1989, Burger 1977). Further, the detrimental effect of predators may be magnified if nesting is confined to specific locations due to the scarcity of suitable nesting habitat. We have identified a high ground nesting beach near Cedar Point that appears to be the most important diamondback terrapin nesting beach in Alabama. We have surveyed that beach for several nesting seasons and have identified approximately 150 depredated nests in a single season (presumably depredated by raccoons). Its location adjacent to the mainland (it is connected to the mainland by Highway 193), and the high ground nature of the beach provides predators such as raccoons easy access to the nesting area. Considering the relatively high number of depredated nests that we have documented, it is possible that very few eggs produce hatchlings, thus limiting the recruitment of young terrapins into the population. Thus, there is a need to document the predators and evaluate the level of depredation on the major nesting areas for diamondback terrapins in Alabama.

iii) Crab Trap Mortality

Another threat that affects the recovery of terrapins in Alabama is mortality in commercial and recreational crab traps. Crab traps are a well-documented source of mortality for terrapins (Roosenburg *et al.*, 1997; Wood, 1997; Roosenburg and Green, 2000) and the crab fishery is well established in Alabama due to its rapid expansion in the last twenty years. Derelict crab traps also pose a major threat to terrapins if not removed; one derelict trap in Maryland was found to have forty-nine dead terrapins (Roosenburg *et al.*, 1997). Crab trap induced mortality can significantly impact the survival status and potentially prevent the recovery of the slowly maturing diamondback terrapin.

Bycatch reduction devices (BRDs or often referred to as turtle excluder devices or TEDs) have been developed and shown to prevent terrapin mortality, yet still allow for crab capture (Wood, 1997; Roosenburg and Green, 2000). Crab trap-induced mortality most probably contributed to the decline of the diamondback terrapin in Alabama. However, no past studies have been conducted in Alabama to quantify the incidental capture rate of terrapins in crab traps. Further, no previous studies in Alabama have evaluated the effect of TEDs on the capture rate of terrapins and crabs.

C) Evaluation of Threats and Development of a Recovery Strategy

This project addressed three primary threats: 1) effect of nesting beach quality on nesting, and survival of eggs and hatchlings, 2) evaluation of predators and the level of depredation of eggs and hatchlings on nesting beaches relative to the beach's location and state of erosion, and 3) evaluation of capture rates of terrapins and crabs in crab traps with and without BRD's. Understanding to what extent that each of these threats contributes to the mortality of the diamondback terrapins is a prerequisite for the development of optimal management strategy for enhancing its recovery. Specifically, the resulting data is providing a mechanism for prioritizing threats, so that management strategy can place emphasis on the factors that have the greatest impact on the recovery of this species.

As indicated in our 2008 and 2009 annual reports, we have also initiated a study that is evaluating a potential method for circumventing the high level of nest depredation that we have observed. We routinely capture female terrapins on the nesting beach and we typically hold them for up to 24 hours in captivity to obtain measurements, blood samples, and to apply permanent PIT tags prior to releasing them back on the nesting beach. We are often able to obtain eggs from these terrapins while they are in captivity and have successfully incubated the eggs to produce hatchings.

Objectives of this study were:

1) Evaluate the abundance and distribution of terrapins in the estuaries of Alabama.
2) Quantify amount of nesting and egg survival on a range of nesting beaches.
3) Identify predators on each nesting beach and quantify the level of egg and hatchling depredation.
4) Quantify capture rates for terrapins and crabs in crab traps with and without bycatch reduction devices BRDs.
5) Evaluate captive incubation of eggs and subsequent rearing and release of post hatchlings as a method for circumventing the high depredation rate of eggs and hatchlings by raccoons and birds.
6) Propose recommendations for optimal management strategy for enhancing the recovery of the diamondback terrapin in Alabama.

Results and Benefits:

The proposed research evaluated the abundance and distribution of diamondback terrapins in Alabama, and specifically addressed the potential threats that may be limiting the recovery of this species in Alabama. The results provide information that is vital to the development of an effective recovery program for the diamondback terrapin in Alabama.

Activities and Accomplishments

1) Abundance and Distribution of Diamondback Terrapin

Over the past several years we have performed periodic surveys of salt marsh areas in Alabama ranging from the Mississippi border to Mobile Bay. Prior to 2007 we conducted a few surveys on the eastern side of Mobile Bay (i.e. the Bon Secour area) but did not detect any signs of terrapin abundance. Therefore, we concentrated our surveys in the area from west Mobile Bay to the Mississippi border. This included 1) direct observation surveys (i.e. head surveys) of terrapins in the water, 2) sampling with modified crab traps in the water and drift fences with pitfall traps in nesting areas, 3) nesting beach surveys, and 4) trawling of specific channels. All surveys included the recording of GPS locations for each sighting or capture of a terrapin. Additionally, a GPS location was recorded for all nest locations. For each year, the capture location data have been entered into the AL Department of Conservation and Natural Resources Heritage Database, and all observational survey and all nest survey results have been forwarded to the AL DCNR.

As a general synopsis of the activities over the three year study, we have conducted 174 direct observation in-water surveys looking for terrapins at the surface and 72 beach surveys looking for terrapin nests. To date, we have also tagged and released approximately 97 terrapins that were captured in the wild through the use of modified crab traps, trawling, and bucket traps. All of these terrapins are tagged with shell tags and with permanent PIT tags. Finally, we have been able to obtain approximately 10 to 13 clutches of eggs each of the three nesting seasons from the Cedar Point Marsh nesting beach which were used for the headstarting of approximately 60 to 80 hatchings per year. These hatchlings are reared for approximately 1 year and then released into the salt marsh at Cedar Point. To date we have released 48 headstarted yearlings (all with permanent PIT tags), and we currently have approximately 150 terrapins which will be released during the upcoming spring and summer.

The results of our survey activities have provide insight on the location and abundance of terrapins in the salt marshes of Alabama. We have identified nesting locations, visually identified terrapins, or captured terrapins in modified crab traps or trawls in the following locations: Barton Island, Point of Pines, Mon Luis, Airport Marsh (Dauphin Island), Jemison's Marsh, Cedar Point Marsh, and Little Dauphin Island. However, the terrapins do not appear to be abundant in any of these locations relative to historic information or relative to data from well-documented terrapin populations along the east coast of the U.S. Of all the locations examined in Alabama, the largest aggregation of terrapins is located in Cedar Point Marsh. The shell hash beach bordering that marsh is the most important nesting area for terrapins that we have identified in Alabama. We have consistently seen more terrapins, documented more terrapin nests, and have the highest CPUE for pit-fall traps on the nesting beach and higher CPUE for modified crab traps in the channels in Cedar Point Marsh in comparison to any other location we have surveyed in Alabama.

Based on our nesting surveys we have identified the following locations with a relative abundance of nesting for terrapins:

1) Cedar Point Marsh (shell hash beach on western border of marsh)
2) Airport Marsh adjacent to Airport on Dauphin Island (multiple small beaches)
3) Mon Louis Island (shell hash beach that is south of West Fowl River)
4) Point Aux Pines (sand beach on southeastern tip of the point)
5) Little Dauphin Island (sand beaches adjacent to Confederate Bay)
6) Barton Island (located near Grand Bay)

The highest nesting recorded to date has consistently been on the shell hash beach bordering the western portion of Cedar Point Marsh (Figure 1). We have been able to record approximately 100 to 150 nests per season on this beach during the last three nesting seasons (2008-2010). This is by far the highest nesting activity that we have observed in Alabama. This is also one of the longest and highest beaches in the Alabama portion of the Mississippi Sound. The next highest nesting activity we have observed is in the salt marsh adjacent to the airport on Dauphin Island. There are a variety of nesting areas located in Airport Marsh and collectively we documented a maximum of approximately 40 nests in a single season. We have recorded scattered nesting at the other four locations, but the number of nests we have recorded is usually low, ranging from approximately 5 to 10 nests.

The results of our in-water observation surveys (i.e. “head surveys) have also provided insight on the location and abundance of terrapins. We have observed a relative abundance of terrapins in the water at the following locations.

1) Cedar Point Marsh (in main channel that travels through the marsh)
2) Airport Marsh adjacent to Airport on Dauphin Island (multiple channels)
3) Little Dauphin Island (in the two westernmost channels)
4) Heron Bay in the marsh forming the northern border (in the main channel through the marsh)
5) Southwest Mon Louis (in the channels across from Cat Island)

We have consistently had the highest number of sightings in the channel at Cedar Point Marsh. At all locations, the ability to observe terrapins is variable and depends on a variety of factors such as time of year, tide, and weather. During the spring, summer and early fall, we normally see at least a few terrapins on each survey of Cedar Point Marsh, and under good observation conditions, we have observed approximately 5 to 10 terrapins per survey. At the other four locations we frequently did not see any terrapins during many surveys, but would periodically see approximately one or two terrapins. An itemized list of all sightings during these surveys including location and date of each sighting has been forwarded to AL DCNR. Although we have recorded nesting at Point Aux Pines and Barton Island we have not been able to document terrapins in the water adjacent to those nesting beaches.

Cedar Point Marsh has a number of characteristics which may contribute to the relatively high number of terrapins in that location. Specifically, it has a long and high beach bordering it which can facilitate terrapin nesting. Additionally, it is a relatively wide marsh with a long internal channel that is normally not used by crab fisherman due to its shallow mouth entrance. Therefore, terrapins inhabiting the marsh may not be exposed to crab trap-induced mortality, thus greatly increasing the level of recruitment into the adult reproductive pool. Additionally, terrapins in Cedar Point Marsh have ready access to a nesting area. Our radio tracking data indicate that at least some of the terrapins using that nesting beach reside in Cedar Point Marsh. Additionally, we have examined orientation in hatchling terrapins and they move from the nest into that marsh, rather than out into the bay. As such, Cedar Point Marsh can potentially support the entire terrapin life cycle, and those terrapins may not be exposed to high crab trap-induced mortality. Interestingly, the location chosen for the large terrapin farm back in the late 1800’s was in the Cedar Point area. It is plausible that this area was chosen for the terrapin farm because the characteristic of this marsh are well suited for supporting the life cycle of the terrapin.

We have utilized a variety of sampling methods to assess the population size at Cedar Point Marsh. These methods include pitfall traps on nesting beaches, modified crab traps in the marsh channels, and trawling surveys (Figure 2). Using all of the sampling data, our best estimate for a population size is approximately 383 terrapins (not including hatchlings) (using the Schnabel method, maximum estimate = 540, minimum estimate = 270). Additionally, our data estimate a total of approximately 46 adult females (using the Schnabel method, maximum estimate = 72, minimum estimate = 29). Population size estimates for Cedar Point Marsh are shown in Figure 3.

These population studies have included the tagging of all captured terrapin. All terrapins are tagged with both a shell tag and an internal passive integrative transponder (PIT) tag under the skin of the left leg. To date we have tagged and released 96 wild caught terrapins and 47 headstart terrapins (see below) into Cedar Point Marsh (Figure 4). Of the 96 wild caught terrapins released into Cedar Point Marsh, we have had 40 recaptures (this includes pitfall traps on the beach, as well as modified crab traps and trawls).

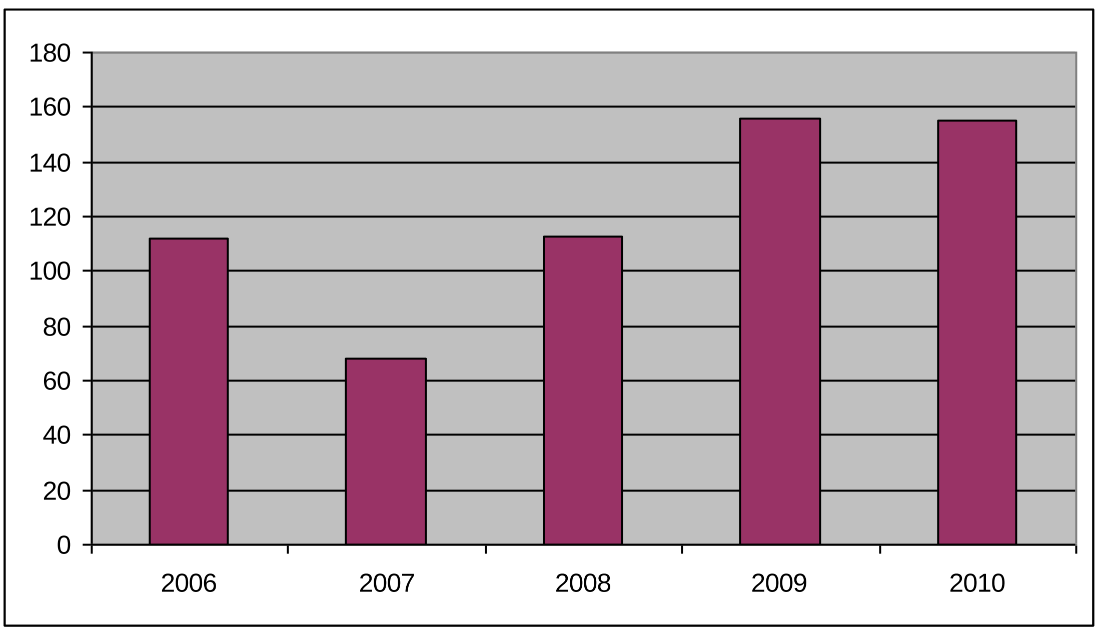

Figure 1. Number of terrapin nests identified on the Cedar Point Nesting Beach each nesting season, 2006-2010. During 2009 and 2010 our surveys have included a northern section of the beach which was not regularly surveyed during early years.

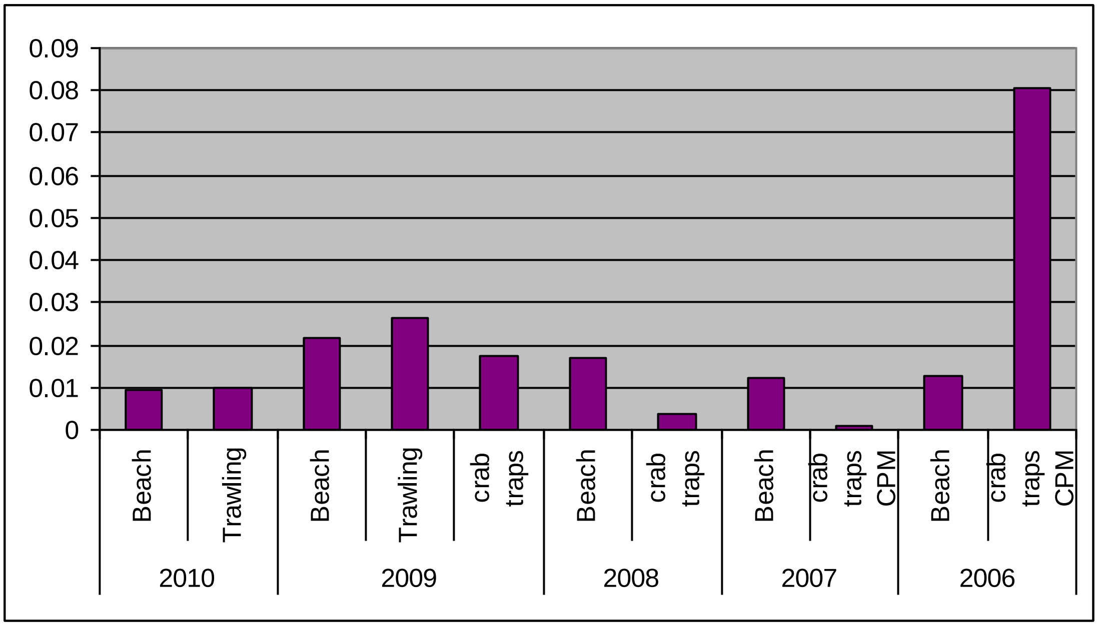

Figure 2. CPUE for various sampling methods used at Cedar Point Marsh. Beach is in “trap days”, trawling is in “trawl hours”, crab traps are in “trap days”.

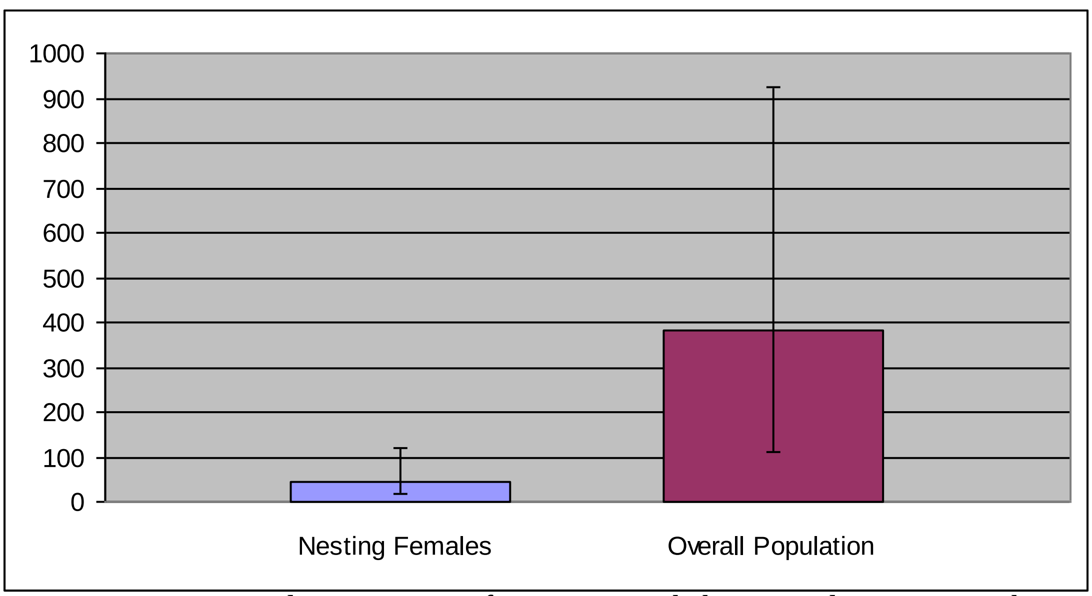

Figure 3. Population estimate for terrapins inhabiting Cedar Point Marsh. Schnabel method using sampling data for beach pitfall traps, modified crab traps, and trawls.

Figure 4. Shell tag on terrapin being released into Cedar Point Marsh. Each terrapin also receives a PIT tag. 96 wild-caught terrapins and 48 headstart terrapins have been tagged and released into Cedar Point Marsh to date.

Figure 5. Example of depredated terrapin nest on Cedar Point Beach.

2) Evaluation of Predators

Recovery of the diamondback terrapin in Alabama is dependant upon the recruitment of young terrapins into the population. High predation of eggs and hatchlings on the nesting beaches appears to be a major factor limiting recruitment. Therefore, evaluation of predation on nesting beaches is a crucial step in assessing the survival status of a terrapin population. Past studies of other terrapin populations have indicated that raccoons are a major nesting predator in addition to fish crows, laughing gulls, and ghost crabs. In our surveys on the beach bordering Cedar Point Marsh, we have recorded as many as approximately 150 depredated nests per season (the majority of nests shown in Figure 1 were recorded as depredated, also see Figure 5). We have also recorded depredated nests on a wide variety of beaches throughout our study area. Cedar Point Beach is mostly composed of shell hash, so it is not possible to identify predators via tracks. However, we suspect that raccoons are the primary nest predator. We have seen raccoons on the nesting beach, recorded them with wildlife cameras during the night, and consistently find scat on the beach indicating the presence of raccoons. We have also seen terrapins with wounds on their limbs that were possibly inflicted by raccoons (Figure 6).

We see little evidence of emergence from nests on Cedar Point Beach. The shell hash beach prevents the identification of hatchling tracks leading away from nests. We infrequently find a nest with mostly intact but empty eggshells which may be indicative of emergence, but it is speculative at this point, and it is a rare occurrence. This suggests that the majority of nests laid at Cedar Point may be depredated. This hypothesis is supported by the number of depredated nests that we find (approximately 150 per season) versus our population estimate of adult females (estimate of 46 adult females, maximum estimate = 72, minimum estimate = 29), since a terrapin typically nests two or three times per nesting season. Thus our data suggest that nest depredations represent a major threat to the diamondback terrapin in Alabama.

Figure 6. Terrapin with limbs that appear to have been chewed by a predator.

3) Capture of Terrapins in Crab Traps and Effects of Terrapin Excluder Devices (i.e. TEDs, also called Bycatch Reduction Devices, BRDs)

We have examined the capture rates of terrapins in crab traps and evaluated the effectiveness of TEDs in preventing such captures. Terrapin catch rates were compared between modified crab traps fitted with TEDs and modified crab traps without TEDs. One trap was fitted with a 5.0 x 14.5 cm TED (Figure 7), the other was not. Traps were checked periodically for terrapins and crabs. Various measurements, such as weight, straight-line carapace length, and plastron length, were recorded for each captured terrapin. All captured terrapins received permanent PIT tags, thus facilitating tag/recapture studies for estimating population size in Cedar Point Marsh (as discussed above). Measurements were also obtained for each captured crab and their marketability assessed (Roosenburg and Green, 2000). TEDs have previously been used in numerous studies along the east coast of the U.S., and their results indicate they significantly decrease terrapin capture in crab traps. The modified crab traps we used were approximately 1.5 m tall, so the top of the trap is above the water surface to prevent drowning of any captured terrapins. Sampling was conducted in 2007-2009 during the spring and early summer (mid April through mid July), coinciding with the mating season and initial nesting period. Cedar Point Marsh was used since it was the only location we know of in Alabama with a CPUE that could yield statistically relevant results during those time periods. Sampling was conducted at eight different locations with two traps per locations. At each location traps were deployed side by side (Figure 8), one with a TED and one without. As shown in Figure 9, significantly more terrapins were captured in traps that did not have TEDs. Of the 25 terrapins captured during that study, 23 were captured in the crab traps without TEDs, and 2 were captured in traps with TEDs (Figure 9). Thus, in our study, we observed an approximate 90% reduction in terrapin capture in traps fitted with TEDs.

We also evaluated crab capture during this study. We observed a significant reduction in the number of blue crabs captured in traps with TEDs versus without TEDs. However, the capture of crabs in the Cedar Point Marsh channel was very low (less than one crab per trap per day), and our results contrast with several much larger scale studies in Mississippi and in states along the Atlantic coast which have detected no such differences (Wood, 1997; Roosenburg and Green, 2000; Mississippi Department of Marine Resources, unpublished data). Therefore it may be advantageous to increase our sample size in future studies by utilizing areas with higher crab catch per unit effort when testing for effects of TEDs on crab capture.

Figure 7. Terrapin Excluder Device (TED, also called Bycatch Reduction Device or BRD). The TEDs were 2 by 6 inch metal rectangles placed in the funnel opening of the crab traps. The TEDs reduce the size of the funnel opening preventing a large number of terrapins from entering the traps yet still allowing crab capture.

Figure 8. Traps were placed side by side in 8 locations in Cedar Point Marsh for the TED versus no TED comparison study.

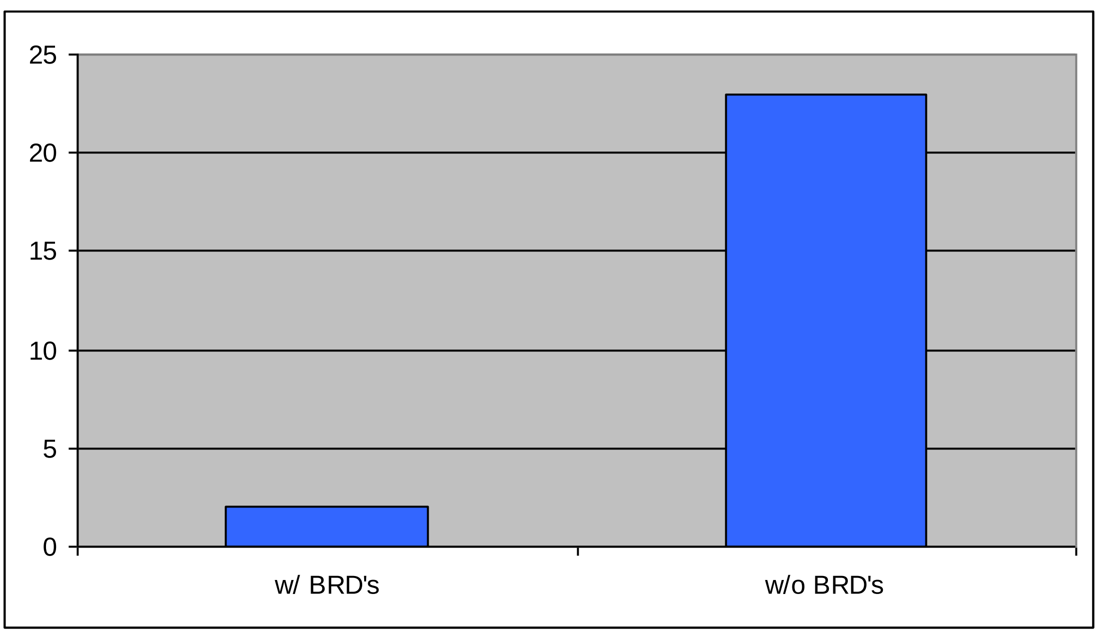

Figure 9. Comparison of number of terrapins capture in traps with TEDs (i.e. BRDs) and without TEDs.

4) Evaluation of HeadStarting as a Method of Circumventing High Mortality of Eggs and Hatchlings.

Headstarting has previously been incorporated into ongoing terrapin conservation programs in New Jersey (Herlands *et al.*, 2004) and Maryland (Smeenk, 2010). We have also initiated a study in which we are evaluating headstarting as a means of circumventing the high level of nest depredation that we have observed. We routinely capture female terrapins on the nesting beach and we typically hold them for 12 to 24 hours in captivity to obtain measurements, blood samples, and to apply permanent PIT tags prior to releasing them back on the nesting beach. We are often able to obtain eggs from these terrapins while they are in captivity and have successfully incubated the eggs to produce hatchings. During the 2008 nesting season we obtained 12 clutches of eggs producing 62 hatchlings, during 2009 we obtained 14 clutches of eggs producing 91 hatchlings, and during the 2010 nesting season we obtained 10 clutches of eggs producing 82 hatchings (Figure10). Based on our observations on the nesting beach, the majority of these eggs would have been depredated by raccoons. We incubate the eggs in incubators at UAB and our hatching success is relatively high, typically 80 to 90% hatching success (Figures 11 and 12).

We have been raising these hatchlings in captivity at UAB and releasing them after they reach a size of approximately 200 g or larger (large enough to prevent predation by birds and most mammals). We are releasing them in the salt marsh adjacent to the nesting beach where the females were captured (Cedar Point Marsh). All receive a shell tag and a permanent PIT tag prior to release. Many of our releases in 2010 were delayed or postponed due to concerns regarding the effects of the Deepwater Horizon Oil Spill. However to date, we have released 48 headstarted terrapins into Cedar Point Marsh.

By the end of 2011, we anticipate releasing approximately 200 headstarted terrapins into a population with an estimated size of 383 individuals. We will be collecting an additional set of terrapin clutches during the summer of 2011 for release in 2012 (funded by a new Coastal Area Management Program grant through the Alabama Department of Conservation and Natural Resources).

The ability to release headstarted terrapins into a relatively restricted marsh system provides an unprecedented opportunity to evaluate the effectiveness of headstarting as a conservation strategy. Further, if effective, it has the potential of significantly increasing the terrapin population size at Cedar Point Marsh.

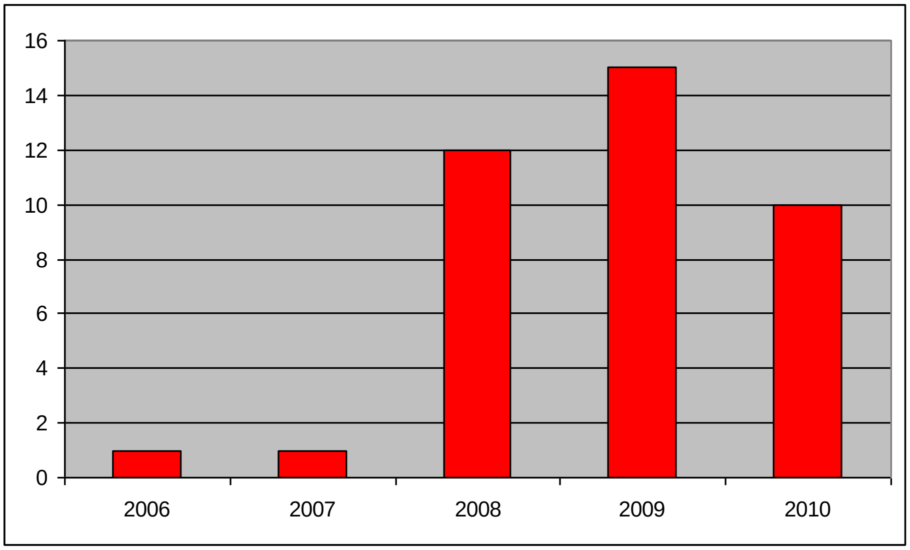

Figure 10. Number of clutches collected for headstarting from terrapins at Cedar Point Marsh.

Figure 10. Eggs are placed in laboratory incubators at UAB and then hatchlings are captively reared for approximately 1 year.

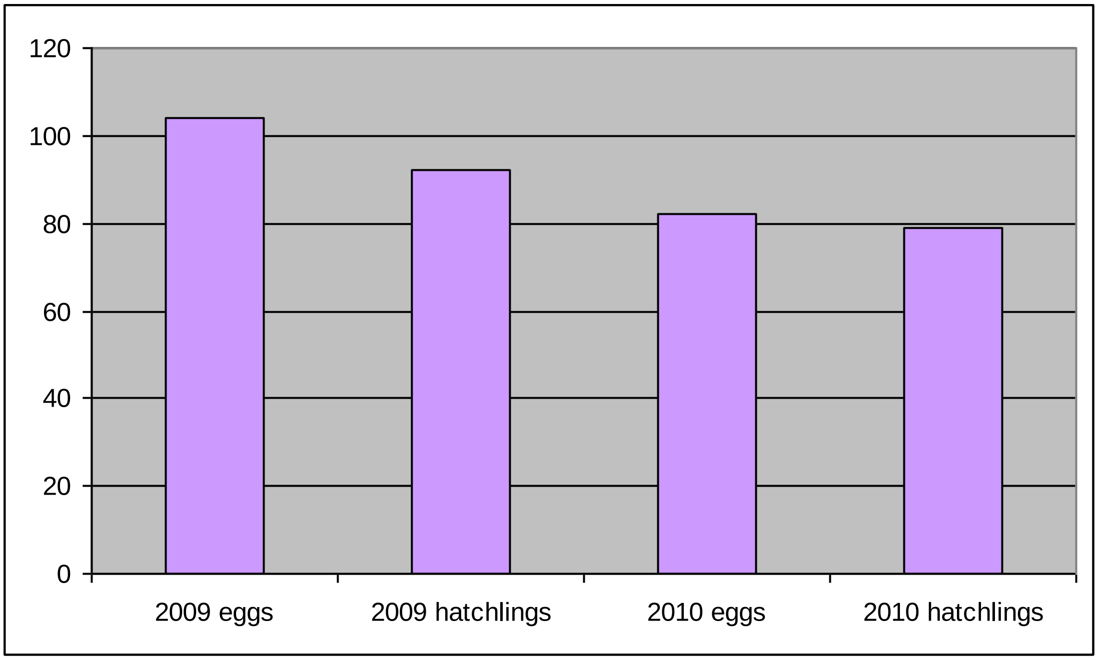

Figure 11. Example of hatching success of terrapins in laboratory incubators at UAB.

Conservation of the Diamondback Terrapin In Alabama: Potential Conservation Strategies for Enhancing the Recovery of This Species

The results of our study indicate that the diamondback terrapin in Alabama is represented by small nesting aggregations scattered throughout a number of locations in the coastal salt marshes. The largest nesting aggregation identified is located at Cedar Point Marsh and is composed of approximately 50 adult females. We estimate the total number of adult and juvenile terrapins in the Cedar Point Marsh to be just under 400 individuals. While we have identified several other nesting locations (e.g. Airport Marsh on Dauphin Island, Mon Louis Island, Point Aux Pines, Little Dauphin Island, Barton Island), these aggregations appear to be significantly smaller than the terrapin population at Cedar Point Marsh. Further, all of these numbers pale in comparison to those suggested from historic anecdotes indicating that terrapins were once very abundant in the salt marshes of Alabama. For example, the Cedar Point Marsh area once supported the worlds largest terrapin farm and an industry that exported approximately 12,000 terrapins per year in the late 1800’s.

The results of our study point to two primary threats that are limiting the recovery of the diamondback terrapin in Alabama: 1) crab trap-induced mortality, and 2) nest and hatchling predation. The increase in coastal development (including increased access and number of associated predators such as raccoons) and proliferation of the crab fishery during the past few decades has probably had a significant impact on the survival rate of terrapins. As such, strategies for enhancing the recovery of the terrapin should focus on decreasing both of these threats. In regards to the first threat, implementation of TEDs on crab traps or limiting the crab fishery near primary nesting areas for the terrapin could significantly enhance the survival of terrapins. In regards to the second threat, strategies could include predator control and/or headstarting (assuming that headstarting proves to be an efficient means of circumventing high mortality associated with the early life stages of terrapins). Ideally, implementation of a state-wide conservation strategy would be optimal. Alternatively, an initial strategy targeting specific aggregations/locations may be more feasible. In the latter case, locations with terrapin populations that were identified in our study such as Cedar Point Marsh would be obvious places for initial implementation of conservation measures. A logical starting point would be enhancing the recovery of the nesting aggregation at Cedar Point Marsh and then extending that methodology to other nesting aggregations. For example, restricting the crab fishery in the tidal creek that flows through Cedar Point Marsh would decrease terrapin mortality while having very little impact on the crab fishery in Alabama (crab traps are rarely used in that channel). Further, the simultaneous headstarting of eggs collected from that beach or predator control on that beach would significantly decrease egg and hatchlings predation. Considering the characteristics of Cedar Point Marsh, it could prove to be an ideal location for effectively evaluating the recovery of terrapins in response to newly implemented conservation measures.

Terrapin Conservation in Alabama and Global Climate Change

Another threat which was not addressed in the current study (due to the short term nature of the project) is the potential impact of global climate change (IPCC, 2007). Of particular importance, models project significant increases in sea level and temperature over the 21st Century (IPCC, 2007). The potential effects of global climate change on salt marshes have been discussed by a variety of authors (Donnelly and Bertness, 2001; Simas *et al.*, 2001; Hartig *et al.*, 2002; Scavia *et al.*, 2002; Hughes, 2004; Najjar, *et al.*, 2000). Sea level rise has the potential of drowning salt marshes, but it has been suggested that is some cases, salt marshes may be able to survive by accreting sedimentation vertically (Simas *et al.*, 2001). Salt marshes with large tidal ranges and high sediment transport would be predicted to be more capable of compensating for sea level increases, whereas those with small tidal ranges and low sediment transport would be more susceptible to drowning (Simas *et al.*, 2001). Terrapins inhabit a relatively thin strip of estuarine environment in Alabama and in many cases those habitats are now bordered by coastal development. Therefore, if sea level rise negatively impacts salt marsh, this would result in the narrowing or disappearance of terrapin habitats in some locations (Donnelly and Bertness, 2001; Hartig *et al.*, 2002; Hughes, 2004).

In addition to sea level rise, temperature change could also have a variety of impacts on the salt marshes, including primary productivity, eutrophication, and dissolved oxygen content (Najjar *et al.*, 2000; Scavia *et al.*, 2002), all of which could affect the ecology of the diamondback terrapin. Global temperature change could also affect the reproductive ecology of terrapins, including the timing of reproduction (Marion, 1982; Ganzhorn and Licht, 1983; Mendonça, 1987) as well as sex determination. In the case of the terrapin's temperature-dependent sex determination, a 1.0 ºC increase temperature could result in a shift from an approximate 1:1 sex ratio to the production of all female hatchlings (Jeyasuria and Place, 1997; Wibbels, 2003), and current models suggest a temperature increase ranging from 1.8 to 4.0 C during the 21st Century (IPCC, 2007).

Thus, although crab trap-induced mortality and nest predation represent the immediate major threats that are typically addressed when generating a recovery strategy, it should be kept in mind that global climate change could emerge as a major factor threatening the survival of terrapins over the next century. In the case of terrapin in Alabama, it is plausible that specific nesting areas may need to be "renourished" with sand or shell hash to avoid tidal inundation. For example, the primary nesting areas in Alabama (e.g. Cedar Point Marsh, Airport Marsh, Point Aux Pine, etc) should be monitored and renourished if necessary to ensure adequate nesting habitat. Nesting beach temperatures should also be monitored to ensure that egg incubation temperatures are appropriate for the production of both sexes. Additionally, the temporal aspects of the nesting season should be monitored on a long-term basis to assess if the nesting season may be shifting in response to climate change, and what effects such a shift might have on the reproductive ecology of the terrapin. Finally, dynamic changes in the salt marsh associated with sea level rise and/or temperature change will need to be monitored to assess the potential impact on quality of terrapin habitat including factors such as food quality and availability.

Completion Date: September 30, 2010

Significant Problems Encountered:

Our data indicate that terrapin populations in Alabama are depleted. As such, large amounts of effort were required to obtain adequate sample sizes for nesting beach sampling studies, crab trap-based sampling studies, trawling-based sampling studies, and observation-based surveys. The tropical storms during the summer of 2008 significantly eroded some terrapin nesting areas and resulted in the loss of many of the data loggers that were used to monitor beach temperatures.

Significant Deviations:

We requested and obtained a one year "no cost" extension which extended the ending date of this project to September 30, 2010. This extension was requested for two primary reasons: 1) During the initial two years of this project, we have been able to apply permanent PIT tags to a relatively large number of terrapins that we have captured by a variety of techniques. Additionally, we have been able to identify optimal sampling methodology for terrapins. The additional year allowed us to use the optimal sampling methodology and PIT tag database to complete extensive sampling during the spring and summer of 2010 in order to accurately estimate the size of the terrapin population in Alabama. 2) The one year extension allowed us to raise approximately 200 terrapins and release 48 of them to date. We will be releasing the remainder of terrapins during the spring and summer of 2011 after they grow to sizes of approximately 200 g or more (large enough to prevent predation by birds and mammals). The one year extension allowed us to collect one more season of eggs from nesting females that we captured on the nesting beach during 2010, thus preventing the normal egg depredation. Collectively we anticipate releasing a total of 200 terrapins into Cedar Point Marsh which should significantly enhance the size and stability of that population.

Costs: See Grant Agreement, annual cost reflected in SF 269.

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