CONSERVATION BIOLOGY OF THE DIAMONDBACK TERRAPIN IN NORTH AMERICA: POLICY STATUS, NEST PREDATION, AND MANAGING ISLAND POPULATIONS

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Wildlife and Fisheries Biology

---

by
Amanda Dianne Hackney
May 2010

Accepted by:
Dr. Robert Baldwin, Committee Chair
Dr. Patrick Jodice
Dr. David Guynn

ABSTRACT

Reptiles are experiencing global declines and pond turtles (Emydidae) are particularly vulnerable. The diamondback terrapin uses multiple habitats to fulfill its life history requirements, in the estuarine environments of the Gulf Coast and Atlantic states (US). Interacting effects of coastal development, overharvesting, abandoned crabbing gear, road mortality, climate change, and nest predation are likely causing population declines throughout its distribution. Protection levels were assessed by referencing each state's Wildlife Action Plan for the species' Conservation Status Ranking Code. At least 7 federal laws directly or indirectly regulate take, wetland, and/or coastal activities (Lacey Act, CWA, FWCA, NAWCA, WPFPA, CBRA, NEPA). I propose the use of a new term (policy hub species) to describe species that could be used to bring together currently unused laws and protect an entire ecosystem. The majority of terrapin studies have focused on nesting success, road mortality, or incidental take in crab pots or other fishing gear. Patches of upland habitat could facilitate cover for common terrapin nest predators on Virginia barrier islands and high rates of depredation on nests would be encountered near the edges of these patches or other habitat features utilized by these predators. GIS analysis was used to determine if there were any relationships between a depredated nest's location and habitat variables that could increase the likelihood of predation. As a case study of terrapin management in an island marsh system, I summarized three years of field research on the diamondback terrapin population of Fisherman Island National Wildlife Refuge.

DEDICATION

For my father, Danny Hackney. You set an example I try to follow every day. Also for Ady, my best friend through hard times and good times.

ACKNOWLEDGMENTS

I want to thank the U.S. Fish and Wildlife Service, the USFWS STEP Program, and the staff of the Eastern Shore of Virginia National Wildlife Refuge for all of their support throughout the years. I especially want to say thanks to Pamela Denmon, who gave me my first chance at a biology job, taught me the nuts and bolts of field research, introduced me to my future study species, helped me in too many ways to list and has been a great friend.

Thanks to my professors at Louisiana State University that gave me a great foundation for the future and supported me during and after my undergraduate career. I appreciate comments and time from my committee members, Drs. Patrick Jodice and David Guynn. And finally, many thanks to Dr. Robert Baldwin, for giving me a chance and taking in a kid from Texas with a crazy idea for a turtle project.

TABLE OF CONTENTS

Table of Contents (Continued)

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

HOW THE DIAMONDBACK TERRAPIN (*Malaclemys terrapin*) COULD ENHANCE PROTECTION AT THE ECOSYSTEM SCALE: USING A POLICY HUB SPECIES TO ASSEMBLE EXISTING LAWS IN MULTIPLE JURISDICTIONS

Introduction

Effective species conservation of wildlife usually results from thorough understanding of life history and habitat requirements, maintaining sufficient protected habitats, and laws and policies regarding exploitation (Hunter & Gibbs 2007). The traditional bias in conservation biology is towards creation of protected lands and less effort has been invested on laws and policy unless the focus is an endangered or threatened species. Policies regarding the protection of land and wildlife are difficult to pass and enforce without public involvement. A major underlying issue in natural resources policy is finding appropriate means to clarify and secure the common interest of both wildlife managers and the public, including policy and legal mechanisms to meet the increasing demands of humans on natural resources while sustaining resources at a viable level (Clark et al. 2000). Species with extensive distributions that span multiple political jurisdictions, especially those that have or once had economic importance, may have multiple layers of regulations (at the local, county, state, federal and international levels) that can be applied to their conservation. However, conservationists are sometimes unaware of those specific policies at regional and local scales that pertain either directly or indirectly to the species. In such cases, a critical task for wildlife managers and conservationists is to recognize existing protections and enforce them, thereby avoiding species decline and potentially divisive endangered species listing.

Successfully understanding and implementing all relevant policies and laws that may pertain to an individual species becomes particularly challenging when that species requires habitats in both terrestrial and aquatic systems. Many chelonians as well as amphibians require specific combinations of wetland and upland habitat types that can make delineating and protecting necessary locations difficult. Reptiles are experiencing a global decline primarily due to habitat destruction (Gibbons et al. 2000). Turtle life histories are characterized by low annual recruitment rates, high adult survival, delayed sexual maturity, and dependence (for many) on both aquatic and terrestrial habitats (Ernst et al. 1994). Due to these traits, many turtle species populations are threatened: habitat destruction, overharvesting, subsidized predation, and road mortality have caused the decline of populations of many species (Browne & Hecnar 2007). Gibbons (et al. 2000) cites loss of suitable habitat as the largest single factor contributing to reptile declines. Available wetland areas for reptiles are on the decline, some regions of the United States retain less than 20% of the wetland acres they once had (Gibbons et al. 2000). Even if a wetland area is reserved for wildlife and protected, the surrounding habitat needed by semi aquatic reptiles for nests, hibernation sites and other refuge is often not protected (Burke & Gibbons 1995).

Additional threats come with increases in human populations. Many turtles and their eggs are at risk from predation by subsidized predators including the raccoon, feral dogs, feral hogs, and other vertebrates including crows (Ernst et al. 1994). Finally, the life cycles of many turtles require seasonal, terrestrial movements (Gibbons 1986) and individuals are killed frequently on roadways due to their slow travel and propensity to bask and nest on sandy roadsides (Steen & Gibbs 2004). Pond turtles (the family Emydidae that includes diamondback terrapin) are particularly vulnerable to infrastructure because of their seasonal migratory movements, dependence on wetlands, and vulnerability to nest predation (Ernst et al. 1994).

The diamondback terrapin (Emydidae *Malaclemys terrapin*) is native to estuarine environments of the Atlantic seaboard and Gulf Coast of the United States (Carr 1952). The diamondback is the lone American turtle adapted to brackish water, and its seven subspecies are distinguished by varying morphological features (Ernst et al. 1994). Overharvesting in the early 1900s caused many diamondback terrapin populations to decline, but now other modern threats have become more important. Coastal development and pollution destroy feeding grounds, extirpate its shellfish prey, make the habitat more attractive to raccoons and make nesting beaches unsuitable (Ernst & Lovich 2009). Traffic on salt-marsh area roadways have killed nearly 10% of females during seasonal nesting migrations (Szerlag & McRobert 2006). Crab pots (commercial and most importantly, recreational) drown adults and juveniles; in a Maryland study 15-78% of a local population may be captured in crab pots in one year (Roosenburg et al. 1997). Recreational crabbers are thought to have more impact on terrapins due to their access to smaller creeks where populations are dense and the likelihood of not checking crab pots as often, and may capture 6-11% of an area's terrapin population (Hoyle & Gibbons 2000). Other predation threats face nests, hatchlings and juveniles. As a result of these risk factors, a number of regional "working groups" have been established to explore viability of terrapin populations and policy, educational, and regulatory options for mitigating these declines (e.g., Mid Atlantic and Southeastern Diamondback Terrapin Working Groups or DTWG).

Focal species have been used as a tool for determining the minimum size for conservation areas, selecting sites to be included in reserve networks, and setting minimum standards for the composition, structure, and processes of ecosystems (Roberge & Anglelstam 2004). I propose a radically different type of focal species in this article. Instead of relying on information of a species' ecological requirements and the assumption that it's individual needs will cover the community, I propose looking to legal policies that can be drawn together to protect specific habitat types. Use of a "political hub species" could allow managers to access funding and protection for an ecosystem by concentrating existing laws and regulations through the promotion of a single species. By using existing policies, time can be saved and actual research and restoration effects can begin sooner that going through more traditional channels (i.e. listing of a species as endangered/ threatened or acquiring land for reserves). I will explain how the diamondback terrapin is an excellent example of a policy hub species, and how this reptile can focus, draw together and utilize policies pertaining to estuarine environments.

The purpose of this paper is to review the existing federal and state laws that pertain to the diamondback terrapin including its coastal habitats, and to propose a means to use the terrapin as a focal species for conservation planning in these environments. To assess jurisdictional distribution of the species, a more accurate species distribution map was needed than was available. Thus I constructed a habitat-based range map and used it to assess relevant laws and policies at state and federal levels. Finally, I introduce the concept of a "policy hub species" in light of the terrapin's broad range, historical roles in society, and complex habitat needs.

Methods

Habitat-based range map:

To accurately map policy conditions for the species across the multiple jurisdictions making up its geographical range, I first needed to determine how much potential habitat is available. To the best of my knowledge, a georeferenced habitat-based map for the range of the terrapin did not exist. The first step taken to accurately map the species range was to determine the specific amount of bays and estuaries (coastal habitat) along the Atlantic and Gulf of Mexico coastlines from Cape Cod, MA to Corpus Christi, TX. This coastline has traditionally been referred to as the known range of the species since 1952 (Carr 1952). All of these waterbody types were assumed to be viable habitat. Most areas near developed and metropolitan areas were not classified by USGS as an estuary, but bays in these areas were included in the calculation. Total potential habitat area by state was calculated by transforming this layer into Alber's polyconic projection and tallying the area of these coastal habitats. Total coastline within the species' range was determined with the use of a NOAA map derived from nautical charts (WGS 84). This coastline vector file was projected into Alber's polyconic projection and then intersected with the states included in the terrapin's range and was further refined by deleting coastline north of Cape Cod, MA and south of Corpus Christi, TX. All possible coastline was included in the calculation, no exceptions were made for metropolitan areas or areas not consisting of sand dune or estuarine habitat.

State and Federal Policies

Using publically available sources, I conducted a search of policy information related to the diamondback terrapin. I first conducted internet searches of government and state natural resource websites, then followed these up with email and in-person queries with regional terrapin conservation experts. A variety of state-level sources were used to obtain data, including on-line records of official state-level policies concerning diamondback terrapin protection, harvest and use of by-catch reduction devices on crab-pots (BRDs)specific laws or published pamphlets for hunting and fishing. I then conducted a search through a database of federal wildlife policy (http://www.fws.gov/laws/lawsdigest/Resourcelaws.html) to locate those current federal-level laws that directly or indirectly affect terrapin or their habitat. Online versions of each individual state's Wildlife Action Plan (http://www.wildlifeactionplans.org) were used to determine the species state-level Natural Heritage Program status and information. Searches of state and federal protections related to potential terrapin habitat, i.e., coastal zones, estuaries, beaches, and tidal marshes. Email queries were conducted with members of the Diamondback Terrapin Working Group (DTWG) and in-person conversations at the Mid-Atlantic and Southeast regional 2008 and 2009 meetings were used to insure that the most current version of state regulations were included and to understand regional nuances that were unclear in the publically-available databases. To try and assess the impacts of commercial harvests, phone calls were made to New York and New Jersey wildlife departments to gather any available information on large scale harvests (as they are the only states without daily limits). Lastly, all State Natural Heritage Statuses, harvest regulations, BRD regulations and additional state statuses were re-checked in August of 2009 to ensure recent changes were recorded.

Policy Maps

To understand variation in policies relative to the range of the species, policy information from these searches was integrated into ArcView 9.2. I created fields for protection level, harvest status and by-catch reduction device use, then made a series of maps to demonstrate state and regional differences.

Results

Habitat-based range map

According to the habitat-based range map, potential habitat for the diamondback terrapin spans 16 states with a total coastline length, including all of the linear distance of bays, coastal islands, and peninsulas, of 124,193 km (Figure 1.1). Total potential habitat (i.e., bays and estuaries in the 16 states that comprise the species' range) was 56,409 km^2 (Table 1.1). North Carolina had the greatest amount of available habitat (12,358 km^2) followed by Florida, Louisiana and Maryland.

FIGURE 1.1: Potential habitat distribution for the diamondback terrapin (*Malaclemys terrapin*).

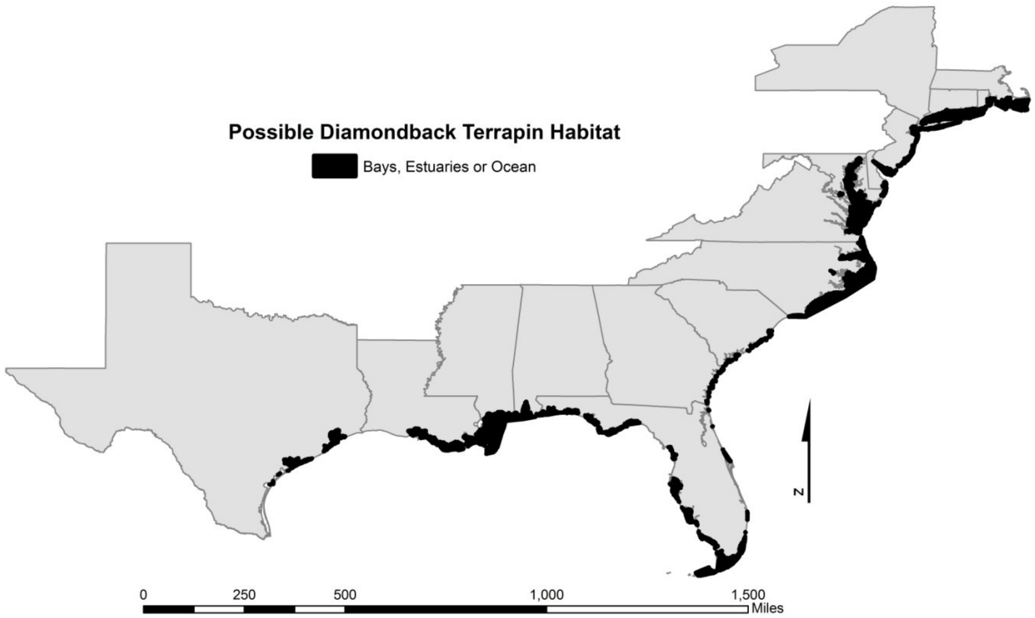


TABLE 1.1: Potential habitat area of states (in km^2) in the diamondback terrapin's range. Area was calculated by computing the area of bays and estuaries in a USGS waterbodies shapefile for each state.

STATE	Area (km)
NC	12358
FL	8900
LA	8268
MD	7309
MS	4038
CT	2957
TX	2488
MA	2433
AL	1911
NJ	1521
RI	1443
NY	1221
VA	822
SC	448
GA	206
DE	86
Total:	**56,409**

State-level Policies

I found no range-wide, coordinated set of laws or policies to protect the diamondback terrapin but did find that all 16 states regulate harvests to some extent, in the forms of no harvest, limits on animals allowed in possession, or restricted seasons (Table 1.2).

TABLE 1.2: Summary of U.S. states' policy concerning the diamondback terrapin.

State Conservation Status Ranking Codes:

S1	Critically Imperiled	S2	Imperiled
S3	Vulnerable	S4	Apparently Secure
S5	Secure	SNR	Not ranked, under review

Additional Codes: SOC – Species of Concern, CC – Collection Concern

State	Status	State Wildlife Action Plan Status	Additional State Status	Regulated Harvest	By-Catch Reduction Devices on Crab pots
Rhode Island	Protected- No Take	S1	Endangered	Closed	Not Required
Alabama	Protected- No Take	S2		Closed	Not Required
Louisiana	State Regulated- 2 per day limit	S2		June 16-April 14	Not Required
Massachusetts	Protected- No Take	S2	Threatened	Closed	Not Required
Mississippi	State Regulated- no more than 4 in possession	S2	Non-game in need of management	Year-round	Not Required
Connecticut	Protected- No Take	S3		Closed	Not Required
Georgia	Protected- No Take	S3	Medium Priority	Closed	Not Required
New Jersey	State Regulated- no daily limit	S3	SOC	Nov 1-Mar31	Com. & Rec. - 6w 2h
New York	State Regulated- no daily limit	S3	Protected Game	August 1 - April 30	Com. & Rec. - 6w 2h
North Carolina	Protected- No Take	S3	SOC	Closed	Not Required
Texas	Protected- No Take	S3		Closed	Not Required
Delaware	State Regulated- 4 per day limit	S4	SOC	Sept 1-Nov15	Rec. only - 4.75 w 1.75h
Florida	State Regulated- 2 per day limit	S4		Year-round	Not Required
Maryland	Protected- No Take	S4		Closed	Rec. only - 4.75 w 1.75h (Required only for waterfront landowners)
Virginia	Protected- No Take	S4	SOC, CC	Closed	Not Required
South Carolina	State Regulated- 2 allowed in possession	SNR	High Priority	Year-round	Not Required

Twelve of 16 states do not require any BRDs. There is no standardization of BRD size, with two different sizes available. New York and New Jersey require BRDs on both commercial and recreational crab pots, while Delaware only demands recreational pots be equipped.   Maryland enacted a regulation effective April 1, 1999 which requires all recreational waterfront property owners who set crab pots attached by rope, line or pole in front of their property or privately owned pier or dock to attach a BRD to their crab pots (McFaden 2008). Legislation that makes it illegal for an individual to catch terrapin (Speir 2008) seems to imply but not directly require commercial crab pots to have a BRD.

FIGURE 1.2: State regulations concerning crab pot BRDs. (Source: ESRI; Projection: NAD 1983, Created by: Amanda Hackney 12.15.09)

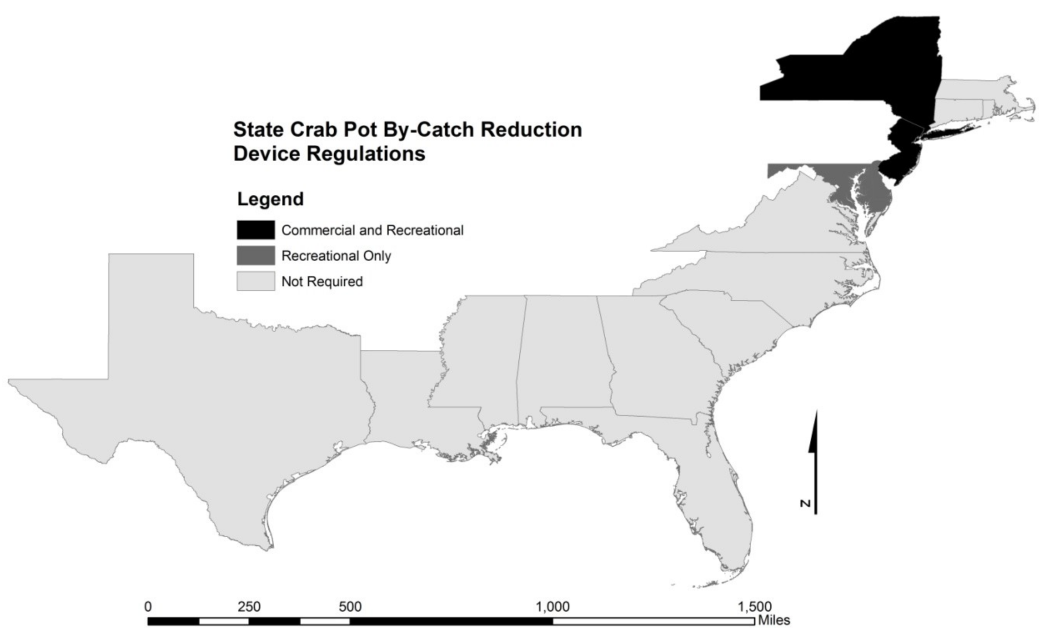
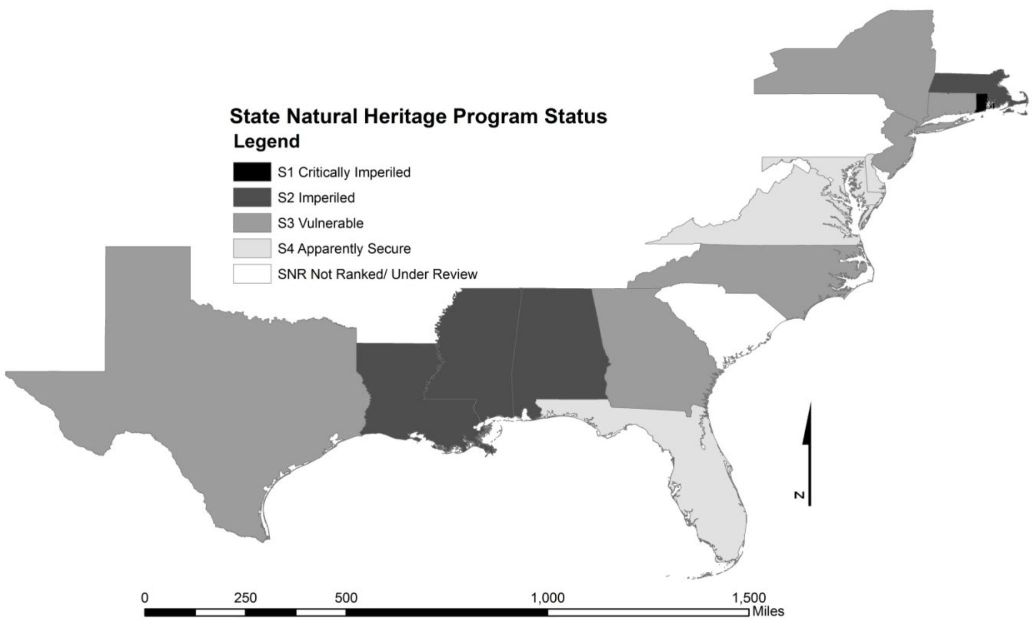
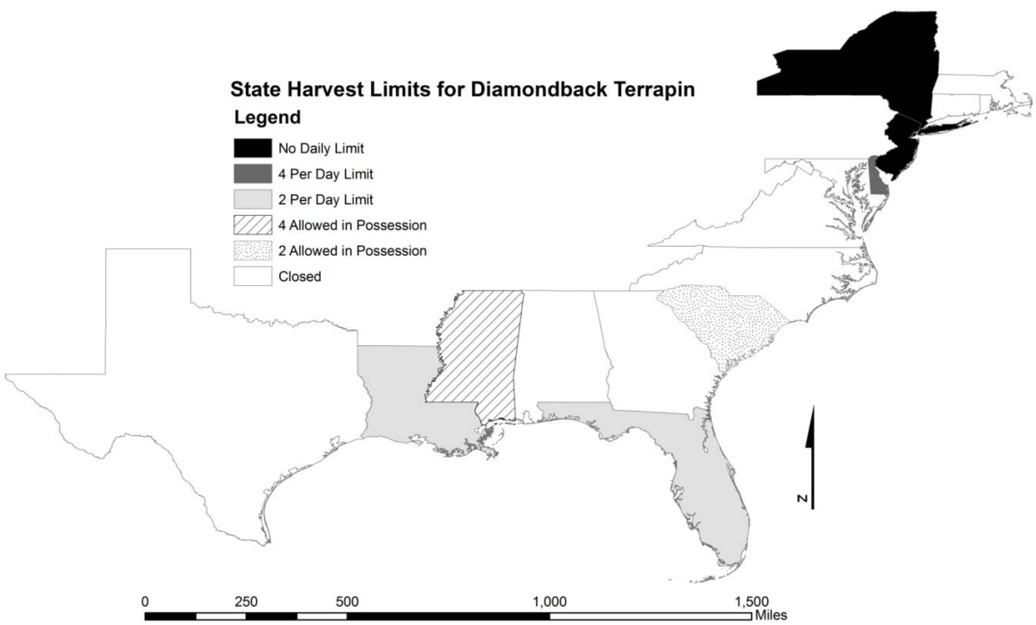


FIGURE 1.3: Protection levels by state. States were categorized using the Natural Heritage Program State Wildlife Action Plan rating. (Source: ESRI; Projection: NAD 1983, Created by: Amanda Hackney 12.15.09)



As each state's criteria for listing and ranking species of concern differs, consulting the standardized Natural Heritage Program's wildlife action plans allowed a better comparison among states. One state lists the species as S1, or critically imperiled. Four states list the species as S2, imperiled, while six states list it as S3, vulnerable. Four states consider the diamondback terrapin to be S4, apparently secure. The species is listed as SNR, not ranked, under review, in South Carolina. States located around the Chesapeake Bay all list the species as S4, while states on the outer edges of the terrapin's range tend to have more vulnerable populations. No harvest of terrapin are allowed in 9 of the 16 states (Figure 1.4). Maryland passed legislation to close harvests on April 24, 2007 for terrapin (Green 2007). New York and New Jersey allow harvest of diamondback terrapin and have no daily limit. As of September 2009, no data were available from the New Jersey Division of Fish, Game and Wildlife or the New York Department of Environmental Conservation on actual numbers of terrapin harvested each year. Recreational harvests are allowed in some states with Delaware permitting a daily limit of four terrapin, and Louisiana and Florida a limit of two per day. Two states set a limit on how many terrapin an individual can have in their possession: Mississippi allows no more than four terrapin per individual, and South Carolina allows no more than two.

FIGURE 1.4: Harvest status of diamondback terrapin by state. (Source: ESRI; Projection: NAD 1983, Created by: Amanda Hackney 12.15.09)



Federal Policies Influencing the Diamondback Terrapin

I found no federal laws or policies directly related to the conservation or protection of the diamondback terrapin. However, there are 8 major federal environmental laws that partially address terrapin or conservation of the species' coastal and estuarine environments.

(1) The Clean Water Act

33 U.S.C. §§ 1251-1387, October 18, 1972, as amended 1973-1983, 1987, 1988, 1990-1992, 1994, 1995 and 1996.

Summary: The CWA is primarily intended to regulate water pollution and use of navigable waterways and adjacent wetlands. It gave the Environment Protection Agency the right to set and enforce uniform national standards of water quality in order to restore and maintain the chemical, physical, and biological integrity of US surface waters (Park 2007). Section 404 of the act allows for provisions that require permits to dispose of dredged and fill materials into navigable waters (New Mexico Center for Wildlife Law 2007). A site can be prohibited from use if discharges would have an unacceptable adverse effect on municipal water supplies, shellfish beds, fishery areas and wildlife or recreational uses (New Mexico Center for Wildlife Law 2007)

The CWA indirectly benefits terrapin populations because the law focuses on water quality which ultimately affects every organism in an estuary. Although dredging may have adverse effects on estuarine systems, terrapin may benefit from directly from dredging activities. For example, terrapin prefer nesting on soft sandy beaches (Roosenburg 1994), and hence are attracted to islands created by dredging which often support few predators. New sand spits created by dredging may also offer new basking sites for terrapin. However, dredging disrupts the normal flow of water through a channel or bay and could affect erosion or cause additional sediment pollution problems. Overall the CWA will aid in increasing and maintaining terrapin habitat quality.

(2) Fish and Wildlife Conservation Act

16 U.S.C. §§ 2901-2911, September 29, 1980, as amended 1986, 1988, 1990 and 1992.

Summary: The FWCA authorizes financial and technical assistance to the States for the development, revision, and implementation of conservation plans and programs for nongame fish and wildlife (USFWS 2009a). This act was created to protect those species not covered by various game laws, those not ordinarily taken for sport, fur or food (USFWS 2009a). Does the terrapin apply as a non-game species? Harvesting for local and overseas markets has been vastly reduced since the recent passing of legislation to end harvests in Maryland, but will this small amount of food related take prevent coverage under the Fish and Wildlife Conservation Act? Currently, the terrapin is not listed as endangered or threatened under the Endangered Species Act of 1973. If listed, protection under the FWCA act would become void, as federally recognized species are not included (USFWS 2009a). The Fish and Wildlife Conservation Act provides some funding for implementation of diamondback conservation plans, but it is unclear if the species truly qualifies for coverage.

(3) North American Wetlands Conservation Act

16 U.S.C. §§ 4401-4414, December 13, 1989, as amended 1990 and 1994

Summary: The NAWCA provides funding and administrative direction for implementation of the North American Waterfowl Management Plan and the Tripartite Agreement on wetlands between Canada, U.S. and Mexico (USFWS 2009a). The Act converts the Pittman-Robertson account into a trust fund, with the interest available without appropriation to carry out the programs authorized by the Act, along with an authorization for annual appropriation of $15 million plus an amount equal to the fines and forfeitures collected under the Migratory Bird Treaty Act (USFWS 2009a). Increasing urban development pressures are occurring throughout the terrapin's range. Protection and management of estuary systems would benefit the species by slowing the rate of habitat loss and increasing the quality of available areas. Migratory birds as a group are a very charismatic faction of wildlife that invokes strong feelings and admiration from the public that could act as an umbrella species to protect other organisms in the estuarine environment (Bortone 2005). Use of a surrogate species such as an umbrella or flagship species will result in favorable conditions for the diamondback terrapin, and in turn will be favorable for most other wildlife in the system (Bortone 2005). By living in wetlands protected through migratory bird programs, the terrapin can benefit from the added funding and management offered through the North American Wetlands Conservation Act.

(4) Watershed Protection and Flood Prevention Act

16 U.S.C. §§ 1001-1009, August 4, 1954, as amended 1956, 1958, 1960-1962, 1965, 1968, 1972, 1975, 1977, 1979, 1981, 1986, 1990, 1994 and 1996.

Summary: Under the WPFPA, the Soil Conservation Service at the Department of Agriculture provides planning assistance and construction funding for projects constructed by local sponsors, often in the form of flood control districts (USFWS). Again, any protection offered to the terrapin's coastal wetland habitat can greatly aid in terrapin conservation. Water quality affects not only the terrapin, but other species needed for its survival such as the invertebrates it preys upon. By protecting and managing land for flood control and water quality, additional habitat is set aside for possible diamondback use and established populations can remain healthier.

(5) Estuary Protection Act

16 U.S.C. §§ 1221-1226

Summary: The Estuary Protection Act highlighted the values of estuaries and the need to conserve their natural resources. It authorized the Secretary of the Interior, in cooperation with other Federal agencies and the States, to study and inventory estuaries of the United States, including land and water of the Great Lakes, and to determine whether such areas should be acquired by the Federal Government for protection (USFWS 2009a).

This act provides government interests in undeveloped coastal areas to protect estuarine habitats from development. Putting aside more coastal marshland will further provide habitat protection for the diamondback terrapin. Estuaries under government ownership may be less affected by human activities, with fewer threats to resident terrapin.

(6) Coastal Barrier Resources Act

16 U.S.C. §§ 3501-3510, October 18, 1982, as amended 1982, 1986, 1988, 1990, 1992 and 1994

Summary: The CBRA designated various undeveloped coastal barrier islands, depicted by specific maps, for inclusion in the Coastal Barrier Resources System. Areas so designated were made ineligible for direct or indirect Federal financial assistance that might support development, including flood insurance, except for emergency life-saving activities. Exceptions for certain activities, such as fish and wildlife research, are provided, and National Wildlife Refuges and otherwise protected areas are excluded from the System (USFWS 2009a).

The act prohibits the use or federal funds or assistance for any purpose in the Coastal Barrier Resources System regarding the construction or purchase of any road, structure, airport, boat landing, bridge, or stabilization of a shoreline area (USFWS 2009a). Exceptions are when shoreline stabilization is deemed critical for the protection of life, land and property, or when funding is needed for facilities for the development of energy resources, projects for the study, management and protection of fish and wildlife resources and habitats, scientific research, road maintenance and repair, and non-structural projects to restore natural stabilization of shorelines (New Mexico Center for Wildlife Law 2009).

On paper, this act has the potential to greatly benefit the diamondback terrapin and other species in wetlands. However, if federal funding is restricted, state funding may be approved and unregulated for such purposes. Several loopholes seem to exist in this act, particularly when it states "shoreline stabilization is deemed critical for the protection of life, land and property, or when funding is needed for facilities for the development of energy resources, projects for the study , management and protection of fish and wildlife resources and habitats, scientific research, road maintenance and repair, and non-structural projects to restore natural stabilization of shorelines" (USFWS 2009a). For example, destruction of the wetlands along the coast of Louisiana, which should be protected by this act, can be partially attributed to drilling for oil and natural gas and the canals and structures that accompany such work (Davis 1992). Shore stabilization is a risky undertaking, often damaging habitats in one location to save a beach or property with human value. Construction of bulkheads or other barriers to stabilize shorelines effectively function as fences to terrapins, preventing females from accessing prime nesting areas above the high tide line (Roosenburg 1994). Terrapin are philopatric to nesting sites, and exclusion by a newly erected bulkhead may cause crowding of nesting seaward of the obstacle and loss of eggs to high tides (Roosenburg 1990). Beach grasses planted to stabilize dunes can also penetrate terrapin eggs through the use of rhizomes and kill the eggs for the use of nutrients (Roosenburg 1990). Construction aid for existing road ways should also be re-evaluated. Roadways crossing delicate dunes and wetlands cause extensive environmental damage and construction will only increase these problems. Breeding age terrapin females would benefit from the removal of many coastal roads, reducing traffic mortalities during the nesting season. Any slowing or halt to development in highly valuable coastal habitats would also be an advantage to terrapin populations.

The CBRA could become a major tool for protecting terrapin habitat. In 2009, development threatened a well studied population of diamondback terrapin on Kiawah Island in South Carolina. The Friends of the Kiawah River group was working with the Coastal Conservation League and the South Carolina Environmental Law Project to appeal a critical area permit issued by the SC Department of Health and Environmental Control (DHEC) to the potential developers that authorizes a 270 foot long revetment/bulkhead system (Friends of the Kiawah River 2009). The area in question is protected under the federal Coastal Barrier Resources Act and the proposed bulkhead/revetment would radically alter the estuarine environment (Friends of the Kiawah River 2009). In 2008, the USFWS responded in a letter to a developer's request to remove an area of land included in the Coastal Barrier Resource System in Kiawah Island, SC. Congress would have to approve the removal of this land for future houses to be eligible for federally-subsidized flood insurance and to construct protective bulkheads in the development. As of September 2009, the future development was still in question. The CBRA may be the only legal protection this ecosystem has. Preservation of lands through the Coastal Barrier Resource System may be the strongest protection available to the terrapin's habitat.

(7) National Environmental Policy Act of 1969 (NEPA)

42 U.S.C. §§ 4321-4347, January 1, 1970, as amended 1975 and 1994

Summary: Title I of the 1969 National Environmental Policy Act (NEPA) requires that all Federal agencies prepare detailed environmental impact statements for "every recommendation or report on proposals for legislation and other major Federal actions significantly affecting the quality of the human environment”(USFWS 2009a).

NEPA acts as a police force to the federal agencies. In theory, it prevents environmental threats before construction or implementation of a new project begins. However, expansion to cover more development in the private sector, not just federal and state agencies, would result in more responsible construction and healthier habitats near new developments. Terrapin environments are threatened constantly by development of tourist areas or home developments (Brennessel 2006).

(8) Lacey Act

16 U.S.C. §§ 3371-3378

Summary: Under this law, it is unlawful to import, export, sell, acquire, or purchase fish, wildlife or plants taken, possessed, transported, or sold: 1) in violation of U.S. or Indian law, or 2) in interstate or foreign commerce involving any fish, wildlife, or plants taken possessed or sold in violation of State or foreign law (USFWS). The law covers all fish and wildlife and their parts or products, and plants protected by the Convention on International Trade in Endangered Species and those protected by State law (USFWS).

The Lacey Act should greatly reduce interstate trade of terrapin to markets along the east coast. However, state policies would have to be strengthened concerning the terrapin to make this trade illegal. Increasing protection offered internationally by the Convention on International Trade in Endangered Species (CITES) would also benefit the diamondback and could possibly end the exports to Asian markets. As of September 2009, the USFWS was soliciting opinions from the scientific community on possibly listing the diamondback terrapin on Appendix II of CITES (USFWS 2009b).

Discussion

GIS Analysis

Maps created though GIS reveal some of the regional issues facing terrapin. The states near the northern end of the diamondback terrapin's range tend to offer more protection and several have existing BRD laws to reduce crab pot mortality. No states in the southern part of the range have any BRD regulations in place and two still allow harvest. Overall, little information has been collected on the diamondback subspecies in the far extremes of its range as compared to the data from the Mid-Atlantic States.

The habitat estimation maps we derived via GIS are at best an over-estimation of available habitat for the species. Without site visits, I cannot be sure all of the estuarine habitats selected by our analysis are suitable for terrapin populations. This coastline estimation may also be an over-estimation. Using the NOAA maps, each state's total coastline was calculated, whether it was available habitat or not. In the case of the coastlines for Texas and Massachusetts, coastline was estimated to Corpus Christi and

Cape Cod (respectively). However, this range is often quoted from older records (often Carr 1952), and the actual range may not extend as far. A few records for Mexico (Smith & Smith 1980) and farther south (Allen & Neill 1959) exist but are unsubstantiated (Ernst & Lovich 2009).

Future of the Species

Although not a federally listed species, the terrapin is haphazardly protected in multiple states throughout its range by a variety of laws and policies in the form of general environmental protections, or harvest-related regulations. Some states have yet to implement of bycatch reduction device regulations for crab pots, while among those that do require BRDs there is a lack of uniform regulations on size, orientation, and other aspects of deployment. There is a lack of a uniform view on whether terrapins are "fish" or traditional "game" animals, as many state regulations found for terrapin were in handbooks for fishing regulations. Several federal laws exist that in theory, are designed to protect the necessary habitat, nonetheless the species is still declining in some areas.

The Terrapin as a Focal Species for Conservation Planning

Due to its specific habitat needs and life cycle, the diamondback could be considered as focal species candidate for the salt marsh ecosystem. Terrapin can be considered a dispersal-limited species. For example, in Kiawah Island, SC, a twenty year study of mark and recapture has found that individuals are most often recaptured in the same creeks and stretches of water (often within 100 meters) of previous captures (Gibbons et al. 2001) indicating little movement of adults. Diamondbacks could be considered a limited resource species, requiring estuarine habitats with marshes for foraging and nearby sandy dunes for nesting that are decreasing as human development increases. They are a process limited species, sensitive to the level, rate, spatial characteristics or timing of some ecological processes such as flooding, and predation (Carignan & Villard 2002). Terrapin nesting sites are susceptible to occasional flooding by high tides and predation by a multitude of avian and mammalian threats. Finally, they have the potential to be a focal species that can capture the public's interest. Campaigns initiated by grassroots groups and even the University of Maryland (the Fear the Turtle Fund donates to terrapin conservation) have influenced policy changes and conservation actions for terrapin. Carignan and Villard (2002) note that species that possess several of these mentioned characteristics are more desirable for research as the processes, resources and habitat features associated with such species will most likely coincide with the protection and requirements of other ecologically-similar species. Salt marshes provide a nursery for a variety of commercially important fish and crustaceans, and many barrier islands and coastal beaches offer nesting for both terrapin and water birds (Mitsch & Gosselink 2000). If the terrapin was used as a focal species, estuarine habitat loss would be slowed or in a best case scenario, stopped with increased public support. Habitat quality would increase due to tighter environmental scrutiny in diamondback areas and restoration efforts.

The focal species concept (e.g. umbrella, keystones and indicators) is often used to speed protection of a system. Past researchers have criticized the umbrella approach and other focal species types, stating that it is improbable that the requirements of one species could encompass those of all other species in the system (Roberge & Anglelstam

2004). This concept may require more research to ensure that the chosen focal species does in fact have enough life history traits and habitat requirements in common with other members of the community to benefit the system.

The Policy Hub Species

Instead of selecting one species on which to base conservation and management processes on, perhaps one species could be used to locate laws and legislation for the benefit of the system. By temporarily ignoring the creation of management plans for an umbrella species, funding could be secured for the system first. We propose the use of a new term to describe species like the diamondback terrapin that can aid in rallying political support for an ecosystem. Generally a hub refers to the center part of a wheel, supporting the spokes which connect to the actual rim of the wheel. A **political hub species** acts as a hub on a wheel, supporting policies and laws from various fields and connecting them to the overall goal (or rim) of protection for the hub species' specific ecosystem.

The diamondback terrapin presents an ideal example of the hub species. By funneling political support though the terrapin, an array of other species can be protected though overlapping laws. The terrapin could unite policies on estuaries, coastal stabilization and development, non-game species protection, fisheries and hunting, and recreational and commercial crabbing. By acting as a starting point, this hub species can influence public opinion and action, and radiate this movement through the spokes of various laws to protect the estuarine system. Efforts can be focused on enforcing existing laws and policies, instead of creating new ones. This approach has the potential to decrease time between the initiation of protection efforts and actual delivery of funding to field projects and habitat security.

Recommendations

I suggest a major coordination of effort across multiple jurisdictions throughout the terrapin's range. Multiple state laws and policies may be coordinated to protect the terrapin and shortcut any potential need for Federal listing under the Endangered Species Act. Furthermore, using the terrapin as a focal species for conservation planning may provide benefits to other species (e.g., shorebirds), and ecosystem processes. As there is no federal program for the diamondback terrapin specifically, and state programs rarely coordinate regional efforts in the absence of a federal mandate, there may be a profound role for private, non-profit groups to drive range-wide coordination. The Diamondback Terrapin Working Groups, Save the Bay, the Nature Conservancy and the Chesapeake Bay Foundation could combine efforts to work across the species' range to organize a blanket management plan that addresses individual regions' needs while still conforming to a uniform mission.

Increased enforcement of policies concerning the terrapin could lead to populations rebounding. Coastal developments need to be policed to ensure the safety of estuarine habitats. Crab pot BRDs need to be required on all commercial and recreational pots and a fine system needs to be in place for violations. A nation-wide standard size for crab pot BRDs also needs to be established. Restrictions can placed on waterways where a high risk of boat strikes has been documented. However, funding has to be secured for the addition of new enforcement agents.

Diamondback terrapin populations have declined over the last century due to many human- induced problems. Ending or greatly reducing the harvest of adults, reducing new construction of and possibly removing roadways in estuarine areas, and halting coastal development are the only solutions to ensuring the continuation of the species. Current legislation is in place that could further protect terrapin, but conservationists and politicians need to promote its use and application in a coordinated fashion, throughout the range of the species and across multiple jurisdictions. Importantly, range-wide population viability analyses would help to target and guide such coordinated action. If such coordinated action fails to take place, there may be little choice but for the regional working groups to petition the federal government for listing under the Endangered Species Act – a move that while effectively employed in many settings (Trombulak et al. 2006) is often politically divisive. With recent changes to the Endangered Species Act, by the time legislation progressed and listing occurred, the terrapin population may be in too critical a condition to save.

CHAPTER TWO

PREDICTING HOTSPOTS OF DIAMONDBACK TERRAPIN NEST PREDATION ON A VIRGINIA BARRIER ISLAND

Introduction

To successfully manage nesting habitat for at risk species, we need an understanding of how predator's efficiency of nest predation is affected by habitat features, which will lead to an understanding of how altering habitat will affect nest survival (Stephens et al. 2005). Predators vary in their foraging patterns, and landscape features may influence how and when a nest predator searches for prey (Phillips et al. 2003). Mutual attraction to edges can lead to the convergence of predator and prey abundances, resulting in heavy prey mortality near the edge and creating an "ecological trap" for prey (Leighton et al. 2008). Habitat characteristics may not be uniform along an edge and the structural complexity of vegetation may affect predation risk by altering the ability of predators to detect prey (Hampton 2004).

Turtle species are considered to be of particular conservation concern because their life history is characterized by low reproductive output, late maturity and habitat requirements of both wetland and terrestrial environments (Browne & Hecnar 2007). Worldwide populations of many turtles are declining (Gibbons et al. 2000), and when designing long-term management plans, all life stages should be considered to stabilize or restore declining populations (Marchand & Litvaitis 2004). Nest predation is a major cause of turtle egg mortality, and directly affects recruitments rates (Ernst & Lovich 2009). Higher predation rates can be especially problematic in human dominated landscapes, where populations of generalists predators can increase and limit the populations of some prey species (Marchand & Litvaitis 2004). Predators such as raccoons (*Procyon lotor*), corvids, and canids (*Vulpes vulpes* and *Canis latrans*) benefit from supplemental food sources associated with human developments and infrastructure (Marchand & Litvaitis 2004).

The diamondback terrapin (*Malaclemys terrapin*) is a turtle native to the estuarine environments of the United States. The species' broad range stretches from Cape Cod, Massachusetts to the Gulf Coast of Texas (Carr 1952). Terrapin became a popular menu item in the early 1800s, and overharvesting for both domestic and foreign markets have decimated populations (Brennessel 2006). In general, turtle nests are extensively exploited by predators and turtle eggs contribute a significant amount of nutrition to their ecosystem (Brennessel 2006; Moll & Moll 2004). Common predators of nests and hatchlings include ghost crabs (*Ocypode quadrata*), crows (*Corvus spp.*), shrikes (*Laius spp.*), gulls (*Larus spp.*), hogs (*Sus scrofa*), rats (*Rattus spp.*), muskrats (*Ondatra zibethicus*), foxes (*Vulpes spp.*), raccoons (*Procyon lotor*), skunks (*Mephitis spp.*), and mink (*Neovison vison*) (Ernst et al. 1994). In a Florida study, 81.9 to 86.5% of diamondback terrapin nests were depredated, most within 24 hours of oviposition (Butler et al. 2004).

The majority of conservation-oriented terrapin studies have focused on nesting success, road mortality, or incidental take in crab pots or other fishing gear. Articles have examined the preferred environments for nesting females (Feinburg & Burke 2003; Roosenburg 1994) rates of predation on nests (Butler et al. 2004; Burke et al. 2005;

Draud et al. 2004) and overall productivity (Burger 1977; Roosenburg 1990). I could not find an article that applied spatial modeling techniques to predict the distribution of predated terrapin nests. By examining the features common to depredated diamondback terrapin nests, I sought to determine where predators were likely to forage for terrapin eggs.

Opdam (et al 2002) viewed the landscape ecology field as having a knowledge pyramid with four layers: 1) empirical case studies, 2) modeling studies to extrapolate studies across space and time, 3) modeling studies to produce guidelines and general rules, 4) tools for integration into the landscape level. The higher levels (such as 3) modeling to produce guidelines and 4) making tools for integration) are poorly represented in landscape ecology articles (Opdam et al. 2002).

I began this project on the first layer of Opdam's knowledge pyramid by conducting an empirical case study of diamondback terrapin nest predation on Fisherman Island National Wildlife Refuge in Cape Charles, VA. I extensively studied one population and one threat vector (nest predation). I plan to achieve Opdam's second layer by projecting this model throughout the Virginia barrier island chain at a later date. Habitat suitability maps based upon digital land cover maps and or data developed through GIS have been used successfully in the past (Boulinier et al. 2001; Cam et al. 2000; Jensen et al. 2005; Nelson et al. 2003; Ritters et al. 1997; Toschik et al. 2006; Watts & Bradshaw 1994) in the Chesapeake Bay area.

I theorized that patches of upland habitat would facilitate cover for common terrapin nest predators (raccoon (*Procyon lotor*) and fish crows (*Corvus ossifragus*))

(ADH, personal obs.) on Virginia barrier islands and high rates of depredation on northern diamondback terrapin (*Malaclemys terrapin terrapin*) would be encountered near the edges of these patches or other habitat features utilized by these predators. I used GIS to identify all patches of possible nesting habitat (open sand) on the island and then extensively searched each of these patches for depredated nests. GIS analysis was then used to determine if there were any relationships between a depredated nest's location and habitat variables that we theorized could increase the likelihood of predation.

Methods

Study Area

The study area was Fisherman Island National Wildlife Refuge (FINWR) in Cape Charles, VA, located at the mouth of the Chesapeake Bay. Designated as a refuge in 1969, the island is approximately 749 ha, with recent large accretions of sand occurring on the northern and eastern beaches. As the southernmost island in the Virginia barrier island chain, FINWR shares the classification of a "Wetland of International Importance" with the rest of the chain. FINWR is an important nesting ground for several bird species and sustains a relatively unstudied population of northern diamondback terrapin (*Malaclemys terrapin terrapin).* A considerable human infrastructure exists on the island dating back to the 1890s, when it was used as an immigrant quarantine station. Both the U.S. Army and Navy have operated posts on the island as well, and several World War II era bunkers, ruins and equipment occur on the island. In 1964, the Chesapeake Bay Bridge Tunnel (CBBT) roadway was built across the island, permanently changing the landscape by stabilizing dunes and creating a large area of upland habitat, while introducing daily road traffic. In 2009, 1,083,672 vehicles crossed the CBBT from May to July (Chesapeake Bay Bridge Tunnel 2009), which are peak travel times across the bridge and coincides with nesting migrations for diamondback terrapin females on the island. Furthermore, predators, such as raccoons and crows, can easily cross the small inlet that separates the island from the mainland.

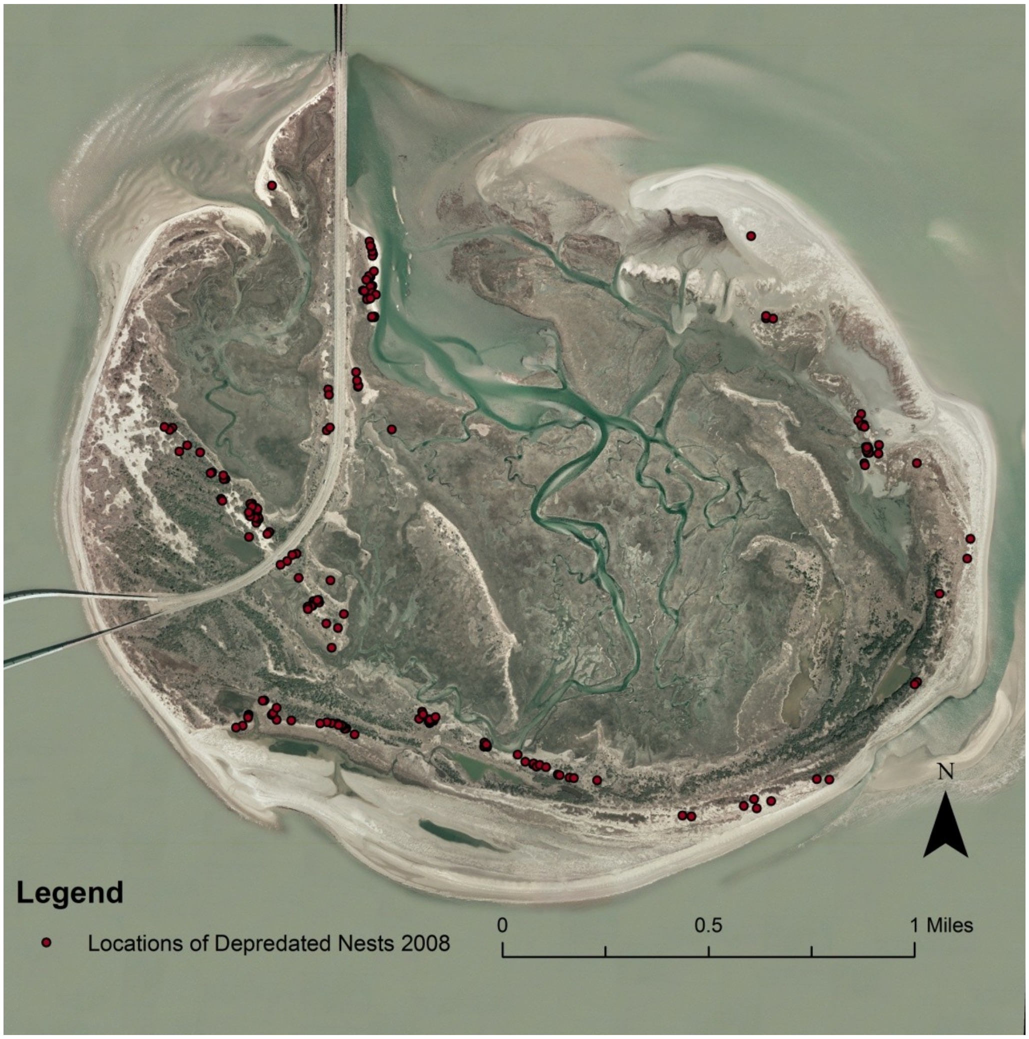
Ongoing monitoring from 2007- 2009 suggest that predators destroy a large percentage of terrapin nests each year, and prey upon hatchlings, juveniles and adults. Since 2006, refuge staff have noted heavy predation of terrapin nests on Fisherman Island, particularly in large patches of sparsely vegetated sand surrounded by maritime upland habitat (ADH, personal obs.) Diamondback females on Fisherman routinely return to these sand patches and nests can be found in dense clumps in these areas (Hackney & Denmon 2008). Groups of adult females staging roughly 2 to 10 m off the beach in areas along the eastern side of the island have also been noticed by refuge staff and these staging area locations remain the same each year.

Collection of Field Data

Using an aerial geo-referenced photo of Fisherman Island (2 m grid, USFWS), a supervised land cover classification was performed in Arc View (version 9.2). A basic habitat map was created, and divided into regions representing open water, marsh, upland forest/shrub, mud flat, roadway, sand and beach grass, all of which were separated into individual habitat-based polygon layers. All field sampling (see below) was conducted in the identified sand habitat polygon locations, preferred diamondback terrapin nesting habitat (Ernst & Lovich 2009). These seven individual habitat polygons were then converted into raster files.

Over the six weeks of the nesting season, each patch of sand habitat identified by the reclassification was surveyed for depredated nests by traveling to and walking the entire patch. Once a nest was identified, a GPS point was recorded (using a Trimble GeoXT; 2-5m accuracy) and time of day noted. Due to the difficulty in locating non depredated nests it was decided to only survey for depredated nests, and no information is available on the percentage of terrapin nests on the island that are depredated. If possible, the major predator of the nest was determined by tracks, the condition of the nest site or any remaining eggshells. Often predator tracks were found around destroyed nests and aided in identification. The size and shape of the hole dug by the predator was also used as an indicator (Burger 1977). Crows tended to leave smaller, triangular shaped holes, while raccoon excavations were larger and more crater-like. Nearly intact, whole shells were assumed to be left by crows and more mangled eggshells in small fragments were assumed to be predated by raccoon (Burger 1977). If it was unclear which species predated a nest, it was recorded as unknown. All eggshells were buried after analysis to prevent recounting.

FIGURE 2.1: Locations of depredated nests points collected in 2008 on Fisherman Island National Wildlife Refuge. (Sources: USGS; Projection: NAD 1983, Created by: Amanda Hackney 12.11.09)



Field data points representing found depredated nests (N= 198 (Figure 2.1)) were randomly divided in thirds. Two thirds of the available points were used to generate a spatial model that estimated the probability of nest predation in each raster cell (resolution 30 x 30 meters). The remaining third was reserved to later test the accuracy of the model predictions. I also generated 220 random points in the sand habitat polygons and these were divided into thirds for incorporation into the modeling process. In the field, GIS locations on abandoned human structures and staging areas for females preparing to nest were collected. Using the georeferenced photograph, shapefiles were created to represent the roadway and Fisherman Inlet representing the major crossing area for raccoon and crow.

Microhabitat model:

For each nest point and randomly generated point, the Euclidean Distance tool in ArcMap (version 9.2) was used to determine the distance to the nearest roadway, marsh habitat, water habitat, inlet bridge crossing, patch of upland habitat, abandoned infrastructure, and historical offshore staging areas for nesting females. The original shapefile of habitats on the island was divided into seven different polygon files (open water, marsh, upland forest/shrub, mud flat, roadway, sand, and beach grass.) I combined the open water and mud flat habitats into one category. As mud flats may be submerged at certain times of the day due to tidal movements, they were considered a representation of the water at high tide.

Roadways were not used in the analysis as roadway areas did not directly represent nesting habitat. Each of the five remaining habitat polygon files were converted into rasters with ones representing that individual habitat type and zeros for all other types. Statistics were calculated on the percentage of each individual habitat type in a 120 m radius buffer around each nest and random point. This radius was chosen after examining a summary of terrestrial migration distances for reptiles and was documented as the mode distance for migration in diamondback terrapin studied in New

Jersey (Semlitsch & Bodie 2003). The count of habitat cells in each buffer circle were used to represent the percentages of habitat.

Macrohabitat model:

A more general model using geographic proxies for habitat (digital data derived from remotely sensed sources) might be more applicable to management because it may be replicated for more extensive geographic areas. Such coarse scale models sacrifice specificity but are useful for illustrating patterns that may be followed up with field study (Miller et al. 1989).

For each nest point and randomly generated point, distances were calculated for specific habitat parameters that could be identified on satellite images or easily mapped in the field including distance of each point to the roadway, nearest marsh habitat, inlet bridge crossing, and nearest abandoned infrastructure. The sand polygon file was converted into a raster with ones representing sand habitat and zeros for all other areas. All nest and random points were visually examined on the aerial photo to determine if they were actually in sand habitat or not. Those in sand were coded "1" and those in other habitat types were coded "0."

Statistical Analysis:

Data for both randomly selected and actual nest sites were analyzed to determine the best selected model from those tested to predict predated nest locations given our data (SAS version 9.2). A stepwise forward logistic regression was performed to determine the important variables in the microhabitat model that had the strongest influence on predation probability. A Pearson's correlation table was calculated for nest points to indicate pairs of variables that were strongly correlated to aid in creating model combinations. Logistic regression calculations were then run for each individual variable and various model combinations.

Microhabitat Model:

Various a priori models were tested and ranked using Akaike's Information Criteria (AIC) (Burnham and Anderson 2002). A total of 12 variables combined into 36 models were used: distance to nearest water, distance to roadway, distance to nearest marsh habitat, distance to the inlet bridge crossing, distance to nearest patch of upland habitat, distance to nearest abandoned infrastructure, distance to staging area, and percentage of the five habitat types (water, marsh, upland forest, sand and beach grass) in the 120m buffer. Models consisted of individual variables, combinations of variables (32 models, Table 2.1), and the global model. AIC value was calculated with the following formula: $AIC = -2 \ln L(\theta) + 2k$ where $L(\theta)$ is the maximized likelihood value and k is the number of estimable parameters in the model (Burnham & Anderson 2002). I did not adjust AIC values for small sample size as our sample sizes were large enough relative to the number of parameters used (12: 198) All models were rescaled so that the minimum AIC value was 0 (Burnham & Anderson 2002).

TABLE 2.1: Relative difference in AIC model weights in microhabitat models obtained by logistic regression

DISMAR = Distance to nearest marsh habitat
DISWA = Distance to nearest water habitat
ROADWAY = distance to nearest roadway
INLET = Distance to the inlet bridge crossing
UPLAND = Distance to nearest patch of upland habitat
INFAST= Distance to nearest abandoned infrastructure
STAGE = Distance to nearest staging area
120 GR = Percentage of grass habitat within 120 m radius
120 SA = Percentage of sand habitat within 120 m radius
120 UP = Percentage of upland habitat within 120 m radius
120 MA = Percentage of marsh habitat within 120 m radius
120 WET = Percentage of water/ tidal flat habitat within 120 m radius

#	Model	df	AIC Value	AIC Delta	Exponent Of AIC Delta	AIC Weight
1	DISMAR, 120GR, 120SA, 120UP, 120MA	5	227.89	0	1	0.293231
2	DISMAR, 120SA, 120GR, 120UP	4	228.777	0.887	0.64178623	0.188192
3	DISMAR, 120 GR, 120 SA, 120 UP, 120 MA, 120 WET	6	229.686	1.796	0.40738361	0.119458
4	DISMAR, 120GR, 120SA	3	230.512	2.622	0.26955037	0.079041
5	DISMAR, DISWA, 120GR, 120SA, 120UP, 120MA	5	230.686	2.796	0.24709065	0.072455
6	DISMAR, DISWA, 120 GR, 120 SA, 120 UP, 120 MA, 120 WET	7	231.054	3.164	0.20556356	0.060278
7	DISMAR, 120GR, 120MA,120SA	4	231.809	3.919	0.14092887	0.041325
8	Global (DISMAR, DISWA, ROADWAY, INLET, UPLAND, INFAST, STAGE, 120 GR, 120 SA, 120 UP, 120 MA, 120 WET)	1 2	231.904	4.014	0.13439124	0.039408

Parameters of the top seven models were averaged by multiplying the AIC weight by parameter values (those with a lower AIC value than the global model) and these values were used to construct a logistic regression equation (habitat was determined by a count of each type in a 120 m radius around each nest point). This formula was then entered into the Multiple Output Map Algebra tool in ArcMap to construct a raster that represented the probability of a depredated nest occurring in each raster cell. The reserved set of nest points were then added to the map and values from the predation probability raster were extracted to points and then averaged to determine the effectiveness of the model in predicting the locations of predated nests.

Macrohabitat Model:

Akaike's Information Criteria (AIC) (Burnham and Anderson 2002) was also used to rank the macrohabitat models. Five variables were combined into 9 models were used: distance to roadway, distance to nearest marsh habitat, distance to the inlet bridge crossing, distance to nearest abandoned infrastructure and presence or absence of sand. Models consisted of individual variables, combinations of variables (9 models, Table 2.2), and the global model. I did not adjust AIC values for small sample size as the sample sizes were large enough with the number of parameters used (5: 198). I rescaled all models so that the minimum AIC value was 0.

Parameters of the top seven models were averaged and these average values were used to construct an logistic regression equation. The Multiple Output Map Algebra tool in ArcMap was used to construct a broader- based raster that represented the probability of a depredated nest occurring in each raster cell. The reserved set of nest points were added, then the extract values to points tool was used to extract predation probabilities to each point. These predation probabilities were averaged to determine the accuracy of the predation predictions.

TABLE 2.2: Relative difference in AIC model weights in macrohabitat models obtained by logistic regression

Sand = Presence or absence of sand in aerial photograph
Marsh = Distance to nearest marsh polygon
Road = Distance to roadway
Infast = Distance to nearest human infrastructure
Inlet = Distance to inlet crossing

#	Model	df	AIC Value	AIC Delta	Exponent Of AIC Delta	AIC Weight
1	Sand, Marsh, Road	3	242.917	0	1	0.97973
2	Marsh, Sand, Infast, Road	4	250.728	7.811	0.02013089	0.019723
3	Marsh, Sand, Infast, Inlet, Road	5	257.896	14.979	0.00055892	0.000548
4	Marsh, Sand	2	292.906	49.989	1.3965E-11	1.37E-11
5	Marsh	1	302.002	59.085	1.4786E-13	1.45E-13
6	Road	1	332.338	89.421	3.8236E-20	3.75E-20
7	Infast	1	332.356	89.439	3.7894E-20	3.71E-20
8	Inlet	1	364.768	121.851	3.4705E-27	3.4E-27
9	Sand	1	367.084	124.167	1.0901E-27	1.07E-27

Results

Microhabitat model:

For the summer of 2008, an exhaustive search of sand nesting habitats on Fisherman's Island National Wildlife refuge yielded 198 depredated diamondback terrapin nests. (Non-depredated nests were not counted.) Regression analysis and AIC model selection suggested that depredated nests were most likely to be found in sand habitats closest to marsh and near forested uplands. The best model with an AIC weight of 0.2932 was comprised of distance to marsh, % sand, % grass, % upland and % marsh. The second best model had an AIC weight of 0.1882 and included distance to marsh, % sand, % grass, and % upland. The third model had a weight of 0.1195 and had distance to marsh and all five of the habitat percentages (% sand, % grass, % upland, % marsh and % water). After extracting the predation probability raster values to our reserved nest points, all 67 points had a 100% probability of being depredated. When viewing the predation probability raster, nearly the entire island (with the exception of a small patch in the south west corner) had a 100% probability of having depredated nests present.

Distance from depredated nests to marsh habitat was negatively correlated in all models and percentages of beach grass, marsh and upland habitat were positively correlated in all models containing those parameters. Percentage of water habitat was positively correlated in two of the three models where it was used, and negatively in one. Percent sand habitat was negatively correlated in eight models tested. Distance to nearest patch of marsh habitat was negatively correlated with predation risk in all eight models, and distance to nearest patch of water habitat was negatively correlated with predation risk in the three models that included this variable.

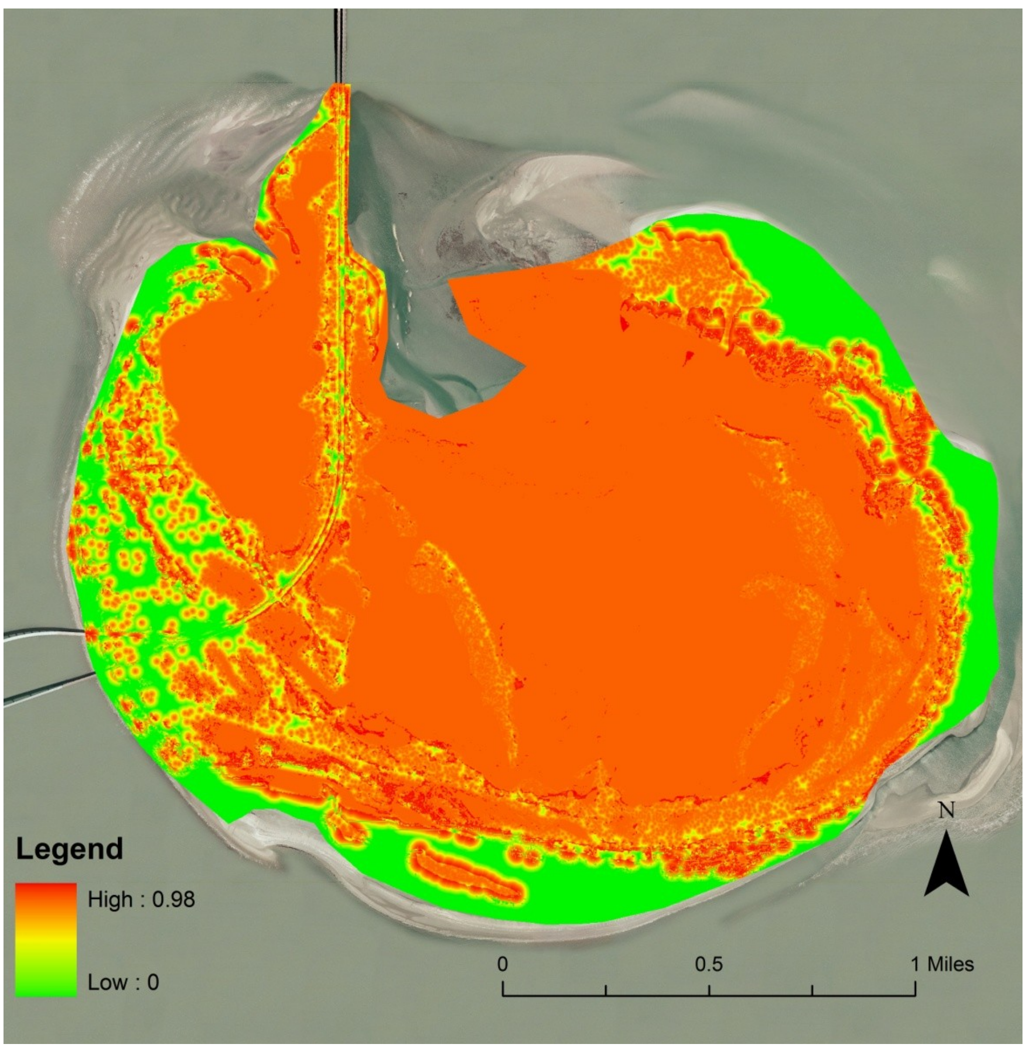
Macrohabitat model:

The best model with an AIC weight of 0.979 was comprised of presence or absence of sand, distance to marsh, and distance to road. The second best model (AIC weight of 0.019723) included distance to marsh, presence or absence of sand, distance to infrastructure and distance to road. The third (global) model (weight of 0.000548) had all four of the habitat distances and the presence or absence of sand. After averaging the top three models, a raster representing predation risk for the entire island was created (Figure 2.2). Model validation using the reserved nest points had an average predation value as

84.14% (range from 26.17 to 97.38%, first quartile 77.53%, median 88.07%, third quartile 95.08%).

Distance to marsh was negatively correlated in all three top models. Distances to the road and infrastructure were negatively correlated in the models containing them. Presence or absence of sand and distance to inlet were positively correlated in the models containing them.

FIGURE 2.2: Nest predation probability raster based on macrohabitat parameters in a logistic regression equation. Red areas indicate a high predation possibility (highest 98%) and the scale fades to green representing the lowest predation probability (0%). (Sources: USGS; Projection: NAD 1983, Created by: Amanda Hackney 12.11.09)



Discussion

Our results suggest that diamondback terrapin may be seeking out edge habitats with less open sand for nesting and that these areas in turn may be predisposing the nests to predation. In the microhabitat model, percentages of grass, marsh and upland habitat were all positively correlated with nest presence, while sand was not. Depredated nests were often located in close proximity to clumps of grass (often the empty nest chamber was "tucked up under" the base) or immediately under the overhang of a myrica bush (*Myrica cerifera*). Our macrohabitat models based on analysis of geographic proxies for habitat also support the theory of more depredated nests in edge habitat. On Fisherman Island, there are many variously sized patches of sand visible on digital orthophotos, creating sandy "islands" of prime nesting substrate dispersed throughout larger patches of marsh, upland or grass habitat. Presence or absence of sand proved to be a strong variable in the macrohabitat models. Yet when combined with other distance variables in our models, large open expanses of sand located farther away from more diverse habitat patchworks have a lower predation probability. Smaller sand patches with a greater percentage of edge surrounded by other habitat types often had a higher predation risk.

Predators such as raccoons and crows may also utilize edge habitat, and forage more often on edges, resulting in more depredated nests occurring in non-open sand. As we did not focus on locating non-depredated nests on Fisherman Island, I can't assume that all nests are along the edges of habitat patches, just those that are experiencing high depredation rates. However, because field observations by refuge personnel over the past decade have reported very few successful diamondback terrapin nests, it may be assumed that these spatial models apply to diamondback terrapin nests generally, and not only depredated ones. This assumption should be tested with further field study.

Terrapin are relatively small, slow moving animals and seem to have some difficulty traveling over land (Ernst & Lovich 2009), so the distance to marsh variable being negatively correlated was not surprising. Water habitat percentage only appeared in three top ranked models, with 2 being positively and one negatively correlated suggesting an inconclusive effect. It can be assumed that females are trying to find suitable nesting habitat with a minimal output of energy and time, and by choosing locations near the areas they forage and use most often (marsh and water habitat) they may be nesting in some optimal combination of suitable nesting areas that are still within easy travel of the salt marsh (Ernst & Lovich 2009). Another possibility for these areas being nest depredation hotspots is that raccoons could also be preferentially traversing the edges of salt marshes and waterways, perhaps for ease of travel. Refuge staff regularly find game trails and raccoon tracks along the marsh edge on Fisherman Island. Raccoons may be foraging in nesting habitat nearest to marshes to utilize both terrapin eggs and resources found in the marsh such as invertebrates, marsh bird nests, fish or carrion. In one edge effect study, a significantly higher nest predation rate for 22 turtle nests (representing three species) was found within 50 m of marsh or wooded edge habitat (Temple 1987). Kolbe and Janzen (2002) also found a higher probability of nest survival as distance from water or wooded edge increased in years with a significant edge effect in their study of painted turtle nests (*Chrysemys picta*) (Kolbe & Janzen 2002). A combination of the limited distance terrapin will travel on land and the regular use of marsh habitat by raccoons may be why these distance variables are important.

The three variables in our strongest macrohabitat model (with a 97.97% chance it was the best model) were presence/ absence of sand and distances to the nearest marsh and roadway. Presence or absence of sand proved to be a strongly correlated positive variable. Terrapin are documented as preferring to nest in sandy locations (Ernst & Lovich 2009). Generally, they prefer to nest above the high tide line in areas with minimal erosion (Burger 1977) and terrapins in Maryland tend to choose sunny locations and lay heavier eggs in sunny sites than more heavily vegetated sites (Roosenburg 1996). Ernst and Lovich (2009) state that nests are often located in areas with <20% vegetation cover. Female terrapin may be preferentially choosing these open areas to nest in on Fisherman Island, and the absence of heavy vegetation cover may make detection of a recently laid nest easier for predators. The macrohabitat model was developed after several microhabitat models using the same field data proved to be poor predictors of predation risk. A simpler, broader scale model produced more accurate results and the process and variables used would be very simple to recreate for other terrapin nesting areas in the Chesapeake bay region.

Distance to nearest marsh was also an important macrohabitat variable; the closer a location was to known marsh areas, the higher the probability of nest depredation. Instead of using the habitat raster generated by the supervised classification in the microhabitat model, it was decided to hand draw very basic polygons that represented the large known estuarine areas. In the macrohabitat model, distance was based on these large polygons. The habitat raster created by supervised classification was a poor quality output, and had issues with scale, habitat class accuracy and habitat class resolution. Due to spectral band color similarities in the five habitat types, individual grids square were often mislabeled as incorrect habitat. While it may not have had as much detail as a polygon layer generated from the classified raster, this hand drawn layer was more accurate and did not result in misclassification of habitat as marsh. Incidentally, the final map representing predation probability ranks the entire marsh as a high risk area. It's very possible that there are small patches of sand on raised areas that may be terrapin nesting locations, but are too small to be classified using a digital orthophoto. When walking through raised areas in the marsh on Fisherman Island, game trails and predator signs (tracks and scat) are very evident (AH, personal obs.). Predators seem to utilize this higher elevation areas for travel and any terrapin nests laid there will be more susceptible to detection. Most high use game trails on the island are loose sand, and terrapin will readily nest in these narrow mammalian "highways" (ADH, personal obs.).

Modeling is the process of building a simple, abstract representation of a complex system to gain insights into how the system works, to predict its future behavior, to guide future research and to make management decisions (Akcakaya et al. 2004). In the summarization of complex distributional patterns using a reduced set of predictor variables, inevitably some degree of mismatch occurs between the predictions and the actual distributional patterns they describe (Barry & Elith 2006). This degree of mismatch can only increase when poor quality GIS (Geographic Information Systems) input data are used to create the statistics that build a model. The adequacy of a model depends on the interplay of the ecological processes driving the true distribution and the process used to observe and model it (Barry & Elith 2006). I expected to find a more specific model that specified finer-scale areas of the islands for high predation risks. It's very likely that the poor microhabitat model fit was due to a poor quality habitat raster that was used to define habitat statistics for each nest point location. In order to create a model as accurate as possible, researchers need be aware of the possibility that base GIS data can introduce uncertainty (when the difference between produced information and reality is unknown) and error (when there is a measurable known difference between the produced information and reality) (Rae et al. 2007) to GIS outputs.

Land use/ land cover data has been used extensively in the environmental field for a variety of applications. This data is often the result of an unsupervised (purely computer generated based on image spectral bands) or supervised (human assisted) classification of a satellite image into a raster containing values that represent certain predetermined habitat types. Errors can occur in the simple creation of land use and land cover raster layers, may be difficult to detect, and assumed by most users to be an accurate representation of reality. Class accuracy is a measure of how closely the land-cover classes in classified data represent the actual land cover at a specific time and place (Bolstad 2008). Class resolution refers to the specificity of the land cover class (a broad evergreen class vs. a more specific spruce/ fir class) and the ability to distinguish among classes (Bolstad 2008). Increases in class resolution can result in a decrease in class accuracy because of the method's reliance on accurately detecting and identifying differences in spectral bands to determine differences in similar vegetation types

(Fleming et al. 2004). Due to the coarse spatial scale of available National Land Use Land Cover data maps (30m grid) we decided to create a more precise habitat map by running a supervised classification on an existing digital orthophoto (USDA NAIP MrSID Mosaic) from 2006 (2m grid).

When changing between vector and raster formats of spatial data, conversion quality and boundary representational accuracy depends highly on the cell size of the resulting digital raster map (Congalton 1997). If the cell size used is too large, some narrow features such as roads or streams may be "lost" and not appear in the final raster (Rae et al. 2007). In Rae's (et al. 2007) demonstration of the effects of error on the creation of a protected area network, the cell size used when vector maps were transformed to raster maps had the largest effect on the results. The square grid nature of a raster cannot perfectly represent the curved boundary of a polygon, and during transformation, considerable information can be lost or altered (Bolstad 2008). Polygon files were converted often to raster format in this project (i.e. the habitat buffers around each nest point) and error introduced in these steps may have negatively affected the model.

After the poor fit of the microhabitat model, the broader based macrohabitat model produced a more accurate equation for predicting nest predation that can be adapted to other sites in the terrapin's range. Field observations will often be superior to GIS modeling outputs, but when budgets are decreased and manpower is reduced a model can help to pinpoint vital areas for management efforts. Although remote modeling is an excellent tool for wildlife managers, it should not be the only basis for management of a species. Models, such as these predation models, combined with knowledge gained from the field will allow wildlife professionals to optimize resources and effectively plan future management practices.

CHAPTER THREE

CHALLENGES TO MANAGING AN ISLAND POPULATION OF NORTHERN DIAMONDBACK TERRAPIN (*Malaclemys terrapin terrapin*)

Introduction

Coastal regions comprise only 17% of the contiguous land area of the United States, but 53% of the nation's human population inhabits these areas, with population densities reaching their highest on the east coast (Wilke et al. 2007). The Chesapeake Bay is the largest estuary in the United States and includes extensive tidal wetlands that cover 123,100 ha (Wilson et al. 2007). It's watershed has lost a significant number of marshes over the last 200 years as a result of urban, industrial and agricultural development (Wilson et al. 2007). Much of the low lying shoreline is extremely vulnerable to sea level changes (Kearney et al. 2002). Furthermore, researchers have documented declines in numbers of colonial birds and colonies and a consistent increase in numbers of mammalian predators on the Virginia and Maryland barrier islands over the past 20 years (Wilke et al. 2007). Increases in populations of avian predators such as fish crows (*Corvus ossifragus*), American crows (*Corvus brachyrhynchos*) and great horned owls (*Bubo virginianus*), have seriously reduced reproductive success at several seabird colonies in Maryland (Brinker et al. 2007). Increases in subsidized predators such as crows and raccoon (*Procyon lotor*) are a problem for several coastal species that breed on the barrier islands of the Mid-Atlantic.

One of these species, the diamondback terrapin (*Malaclemys terrapin*), is native to estuarine environments of the Atlantic seaboard and Gulf Coast of the United States

(Carr 1952). The diamondback is the lone American turtle adapted to brackish water, and its seven subspecies are distinguished by varying morphological features, reflecting diversification across its vast range (Ernst et al. 1994). Identified threats to terrapin populations include mortality from motor boat strikes, predation, alteration or destruction of nesting and other habitat, pollution, drowning in crab traps, shoreline development, harvesting for food and the pet trade, and road mortality (Ernst & Lovich 2009). Terrapin are found throughout the barrier islands of Virginia and a seemingly dense population can be found on Fisherman Island at the tip of the Delmarva peninsula.

Study Goals

Fisherman Island represents a unique environment in which habitat is protected under the National Wildlife Refuge system, yet modern threats such as subsidized predators, automobiles, boats and crab pots continue to influence the diamondback terrapin population. Continued research on the island will allow better management of this population, but will also add much needed information on terrapin in the rarely studied Virginia area, which may in turn be generalized to similar geographic locations throughout the diamondback terrapin's range.

As a case study of terrapin management in an island marsh system, I will summarize three years (2007-2009) of field research on the diamondback terrapin population of Fisherman Island National Wildlife Refuge in Cape Charles, VA. Objectives of the study were to analyze the demographics and estimate the total population of nesting females through a mark recapture program, determine "hotspots" along the CBBT road where terrapin females were most likely to cross and to test different materials and methods for drift fences along the highway.

Study Site

Terrapin research has been conducted on Fisherman Island National Wildlife Refuge (FINWR) since 2007. Established as a national wildlife refuge in 1969, the island is approximately 749 ha, with recent accretion of sand occurring on the northern and eastern beaches. As the southernmost island in the Virginia barrier island chain, FINWR shares the classification of a "Wetland of International Importance" with the rest of the chain. FINWR is an important nesting ground for several bird species and sustains a relatively unstudied population of northern diamondback terrapin (*Malaclemys terrapin terrapin).* In 1964, the Chesapeake Bay Bridge Tunnel (CBBT) roadway was built across the island, permanently changing the landscape by stabilizing dunes and creating a large area of upland habitat and introducing daily automobile traffic. Predators, such as raccoons and crows, can easily cross the small inlet that separates the island from the mainland. In the case of raccoons, several road killed carcasses have been found in the middle of the bridge that connects the island, indicating that the roadway serves to connect the mainland raccoon population with Fisherman Island.

The Eastern Shore of Virginia is a major travel route and destination for tourists in the summer months and sees high volumes of traffic from Memorial Day to Labor Day. In 2009, 1,083,672 vehicles crossed the CBBT from May to July (Chesapeake Bay Bridge Tunnel 2009). Diamondback terrapin inhabit salt marshes alongside some of these major roads and are often struck by passing vehicles. Highway 13 (as part of the

Chesapeake Bay Bridge Tunnel (CBBT)) crosses Fisherman Island NWR. Hwy 13 bisects a large expanse of salt marsh habitat, creating a barrier between the estuaries terrapins use year round and the patches of open sand the females travel to for nesting. This toll road is four lanes, with a grassy median and a 55mph speed limit. Guard rails run along the entire expanse of highway and a shoulder wide enough to drive on is present on both sides. In 2006, GPS locations were taken of terrapin carcasses found on the CBBT highway to pinpoint high mortality areas of the road. A drift fence (approx. 2500 feet long) to prevent terrapin mortality has been erected and maintained by the US Fish and Wildlife Service each year beginning in 2007; however, lack of funds has prevented the agency from building a proposed northern section, and females continue to be struck north of the fence and near the ends as they go around the edges.

Methods

Live Female and Nest Data Collection

Since 2007, the refuge staff and volunteers have captured and marked females that are traveling on land during the nesting season. Any females that were encountered had their carapace and plastron measurements taken, were weighed, palpated for eggs and marked by shell notching. If already present, shell notches were identified and remarked. Digital photographs were taken of the top view of the carapace, the plastron and a view of the head/ shell notches. Any shell irregularities, scars, wounds or barnacles were also recorded. A GPS location was recorded (using a Garmin GPS 76, 5-10 m accuracy), time and date recorded, and a quick description of the habitat noted. All animal handling was brief to minimize stress and females were released as quickly as possible.

A population estimate was calculated using the three years of mark-recapture data using Schnabel's binomial model. This method was chosen due to its simple calculations and flexibility over a wide range of capture conditions (Chapman & Overton 1966).

All non-depredated nest locations were recorded and later mapped in Arc View 9Version 9.2). Any nests not depredated were covered with a 24"x 24" piece of hardware cloth and secured with tent stakes. Covers were removed from nests after 50 days to allow hatchlings to emerge, as the best estimates for terrapin incubation ranges from 60-100 days (Brennessel 2006), with shorter incubation periods occurring farther south. It was decided to remove covers at 50 days, to ensure that possible early emerging hatchlings would not be obstructed.

Chesapeake Bay Bridge Tunnel Roadway Fence:

In 2008, the refuge created a fence to prevent nesting terrapin females from entering the highway based on a design by the Wetlands Institute in New Jersey. Materials consisted of 36 inch high Tenax, wooden stakes and zip ties. A trenching machine was used to dig a 6 inch trench along the edge where the road shoulder met the shrub edge of the refuge. The Tenax was stretched out, with approx 6" laid down in the trench. Stakes were pounded in the ground, then the Tenax material was sandwiched between the stake and a short wooden slat. Plastic zip ties were then used to hold the stakes to the Tenax.

Monitoring of Terrapin Road Crossings:

In 2009, a volunteer was assigned the task of monitoring the CBBT highway daily to collect information on where nesting terrapin are crossing by obtaining locations on both live and dead animals. The drift fence was checked twice a day and the highway north of the Fisherman Island gate was monitored from May 28th until July 10th. Observations occurred from approximately 8:30 a.m. through 1:00 p.m. with additional monitoring (e.g., driving the road briefly and checking the drift fence) in the afternoon. Highway workers may have removed some carcasses before they were counted by refuge staff.

Each day a volunteer monitored various locations along the roadside and watched for moving terrapins. When located, females were captured, assigned an ID number, measured, marked and photographed. Time of the crossing or discovery time of carcasses and date were recorded for all terrapins. GPS locations were taken of all terrapins (live and dead) encountered to determine where they may have entered the road area and in what direction.

Results

Live Female and Nest Data Collection

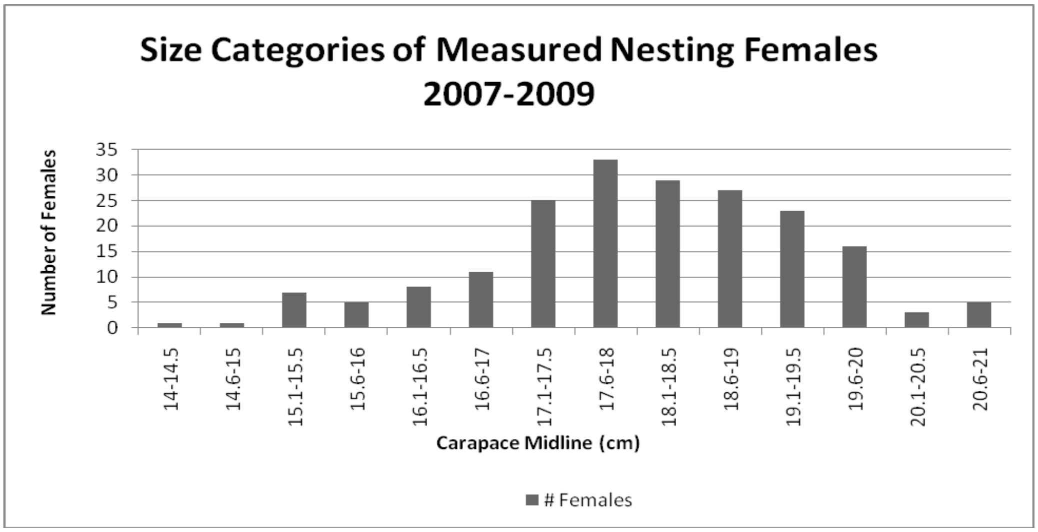
During the 2007, 2008 and 2009 nesting seasons, 220 individual adult female diamondback terrapin were shell notched with a unique identification number on the Fisherman Island NWR and the Eastern Shore of Virginia NWR. Using Schnabel's model, there are estimated to be 349.24 (roughly 350) breeding age females on Fisherman Island. Only 13 terrapin (16.05%) were captured outside of the access road area in 2009, with most of these captures occurring along the water's edge on the northeastern side.

In 2007, 65 females were marked and there were 13 subsequent recaptures of this group. Preliminary analysis showed that the majority of females we located in 2007 are large, older individuals (Hackney & Denmon 2007). Sampling efforts were increased in 2008 with the addition of a refuge intern and more volunteer help. However, capture and recapture numbers remained about the same, with 53 new captures and 15 recaps. Of these recaptures, 9 animals were originally marked in 2007 for the first time and 6 were first marked in 2008.

A total of 102 individuals were marked in 2009. Of these, 81 were marked on Fisherman Island and 21 were marked at the Eastern Shore of Virginia NWR boat ramp. Females marked on Fisherman Island or the Eastern Shore refuge were not encountered at the other site. There were 46 recaptures of females marked on Fisherman Island in 2009; 19 were first marked in 2007, 7 in 2008 and 14 were notched in 2009.

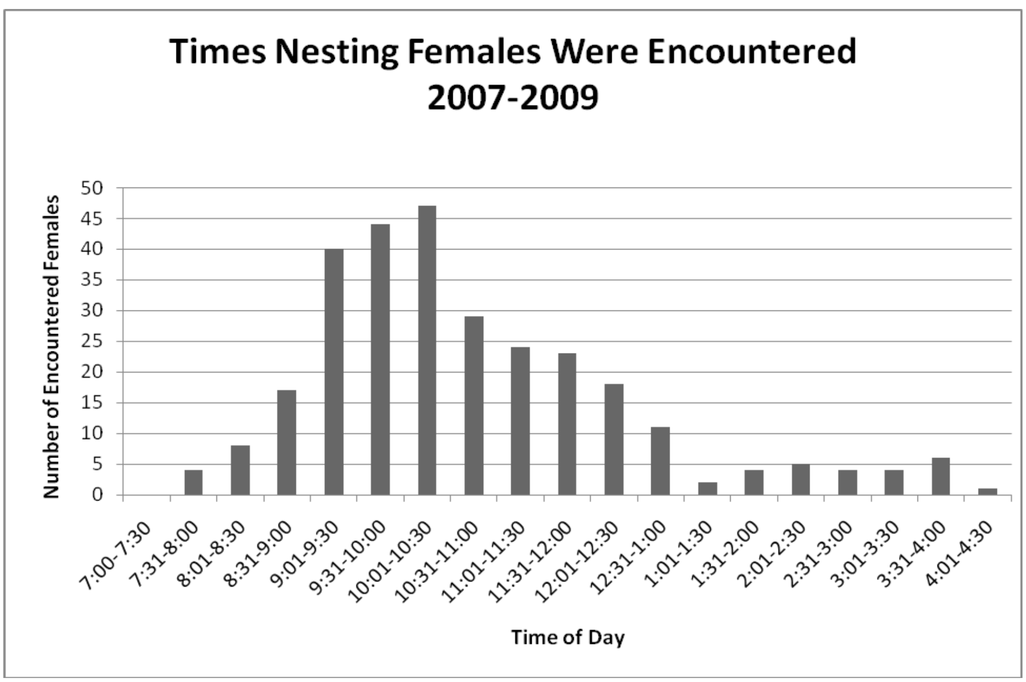
Of the 220 individuals captured from 2007-2009, 194 had data collected on shell measurements. Average carapace midline measurement was 18.45 cm. Average plastron midline measurement was 16.62 cm. The majority (78.9%) of females captured over the last three years has a carapace midline measurement greater than 17 cm, and less than 20 cm (see Figure 3.1).

Figure 3.1: Size categories (based on carapace midline measurements in cm) of diamondback terrapin females marked on Fisherman Island NWR 2007-2009



Most terrapin (89.7%) are encountered between the hours of 8:00a.m. and 1:00 p.m. (Figure 3.2).

Figure 3.2: Diurnal migration timing as indicated by capture time for nesting diamondback terrapin females 2007-2009



Three naturally laid nests and one artificially dug nest were protected in 2009. On June 23, a female was struck by a car and had to be euthanized. Upon dissection, 7 viable eggs were recovered and placed in a hand dug nest on Fisherman Island. All three naturally laid nests were located in the sand access road. These nests were uncovered after 50 days and at least one was depredated by a raccoon shortly before hatching or as the hatchlings were emerging.

Chesapeake Bay Bridge Tunnel Roadway Fence:

In 2009, examination of the fence in early spring revealed extensive damage. The 2008 drift fence constructed with grey Tenax was less UV resistant and has not performed as well in field trials in New Jersey (The Wetlands Institute 2008). The grey material was extremely brittle and was easily broken, had numerous holes and few sections were salvageable. The 2008 fence remnants were patched with the aid of volunteers using black Tenax and staff continued to closely examine and repair the fence daily through the 2009 nesting season.

Monitoring of Terrapin Road Crossings

A total of 78 crossings (successful and nonsuccessful) were noted, over 34 observation days (Table 2). Females ranged from 15 to 21 cm (carapace midline measurement). It was not always possible to get to a terrapin before it crossed the road successfully or was struck by a passing vehicle. Some carcasses were too crushed to collect data, so 27 (42.2%) were not measured. Juveniles were found along the road as well, with carapace midline measurements between 1.5 and 4 cm. Of the 78 crossings, 31 of these individuals were captured and prevented from completely crossing the highway. Some individuals managed to successfully cross without human assistance (14) and 33 were found dead. If calculating the success rate from these attempted crossings without human interference, 14 of 47 (29.8%) animals did not die on the roadway.

Table 3.2: Results of CBBT highway monitoring in 2009

End Status of Crossing	**Number of Individuals**
Alive (crossed without human assistance)	14
Alive (captured, marked and assisted across)	31
Dead	33
Age Class of Individuals	**Number of Individuals**
Breeding Adult Female	64
Juvenile	14

Numerous incidences were also recorded of females attempting to nest in the grassy, mowed slopes of the road and many unfinished nests were found. Females even attempted to dig nest holes along or under the edge of the asphalt of the highway. This behavior was previously unknown, and it is curious that these animals are choosing vegetated mowed slopes over nearby sand clearings.

Discussion

Fisherman Island is a unique ecosystem that harbors a seemingly robust population of diamondback terrapin. However, there are many gaps in knowledge of the species' age distributions, sex ratios and preferred habitat on this refuge. The high number of terrapin marked in 2009 was unexpected and was due to USFWS volunteers marking animals on the roadway (an area not previously patrolled). It was unknown how many animals were traveling across the highway to reach nesting habitat. Without information on other age and sex classes, and no monitoring of the highway outside of nesting season, I cannot predict the impact of road mortality on the population. 61.4 % of all terrapin encountered in 2009 were located on the highway (78 of 127 animals (81 new captures and 46 recaptures)). The CBBT roadway is a major influence on the island's overall ecosystem though upland habitat stabilization, acting as a predator corridor and crossing the route that many terrapin are travelling to access needed habitat.

Capture of nesting females continued to be focused on the sand access road and adjacent clearings. The majority of the data is most likely a representative of the terrapin population living to the west of the CBBT highway, in the large salt marsh bordered on the south side by the USFWS access road. Time of day estimates may be a true indication of when the animals are moving or, alternately may be when staff are most likely to be traveling through terrapin nesting areas. The population estimate of 350 females may only be an accurate for those females living in the north-west marsh of Fisherman Island, as few individuals (17 total from 2007-2009) have been captured outside of the stretch of nesting habitat bordering the marsh.

The USFWS continues to explore new solutions for a more permanent drift fence along the CBBT highway. Extensive email contact with members of the Diamondback Terrapin Working Group have given staff several ideas with varying budgets and permanence. In addition to the traditional Tenax fencing, the refuge is examining the possibilities of low concrete fences or chain link fencing with a solid bottom barrier to protect smaller terrapin. In 2009, refuge staff erected sections of the fence made from commercial poultry curtain material. This material is designed to last at least five years on poultry houses and may prove to be a more UV resistant alternative to Tenax that would require less labor. Funding is currently being sought for the construction and possible extension of drift fences on Fisherman Island. However, new nesting habitat may need to be constructed on the marsh sides of the fences so that females have an opportunity to nest despite the new barriers.

Until the 2009 road monitoring project, the refuge was unsure how many females were attempting to cross the highway and how many were successfully accomplishing the task. High mortality (approximately 70%) in diamondback terrapin that attempted crossings without human interference may be a serious problem for the sustainability of the island's population. Previous studies at the Jacques Cousteau National Estuarine Research Reserve reported that between 1999 and 2002, 71% of the 634 terrapins recovered on Great Bay Boulevard in New Jersey died because of automobile traffic (Szerlag & McRobert 2006). Fisherman Island figures are from terrapin that attempted to cross and were not interrupted by human intervention and this figure may represent higher mortality sections of the road that volunteers and staff were not able to patrol as well. Extension of the drift fence and addition of more volunteers may significantly reduce road mortality in nesting females. However, several juvenile carcasses were also located and a year-round solution needs to be found to protect the island's terrapin from highway mortality.

There is a high concentration of nest sites along the southern edge of the northwest marsh (the sand access road) and the level of predation on nests and hatchlings here is unknown. There was no monitoring of depredated nests in 2009 due to time constraints and the new road project. Nests continued to be dug up by crows and raccoons in traditionally high predation areas. However, extensive trapping of raccoon and shooting of crows seemed to have had an effect on the number of destroyed terrapin nests. Visits to several of the island's "hot spots" revealed fewer predator tracks and depredated nests, but data are anecdotal and cannot prove this observation. Live hatchlings are rarely encountered on the island. Several dried carcasses less than 5 cm in carapace length are found every year along the edge of the CBBT highway. Further studies could track juvenile terrapins to determine mortality and areas used by this age class on the island. The refuge also plans to continue marking and gathering data on live females to determine if the breeding population is truly aging, or if normal recruitment is occurring in females. Fisherman Island's terrapins may be headed for a population crash in the future. Further study is greatly needed to assess the FINWR population status.

The Eastern Shore of Virginia has and will likely continue to experience rapid growth through the construction of retirement, vacation and luxury homes. Recreational boaters and tourism are also on the rise. In 2008, a public boat ramp opened on the Eastern Shore of Virginia NWR, a half mile north of Fisherman Island. Increasing traffic to the boat ramp across the Chesapeake Bay Bridge Tunnel and more recreational boaters and crab pots will further deplete the nearby diamondback terrapin population.

Several challenges related to habitat loss are facing the Chesapeake Bay's diamondback terrapin populations. Since the mid 1970s, many of the small islands in the Delmarva peninsula system monitored as bird breeding sites have eroded away (Brinker et al. 2007). Sea levels are predicted to rise more than 40 cm in the 21st century and maybe at an accelerated rate along the Mid-Atlantic coast (Brinker et al. 2007). Increased wetland flooding and coastal island loss is expected in Dorchester, Somerset and Worcester counties in Maryland and in Accomack and Northampton counties in Virginia (Titus & Richman 2001). The Chesapeake Bay is estimated to have lost 50% of its wetland cover since European colonization began (Wilson et al. 2007). Studies within Virginia's coastal bays estimate annual rates of marsh loss due to sea level rise between 0.15% and 0.67% (Wilke et al. 2007). Canal dredging has disrupted sediment delivery and tidal flows and has increased the water's erosion energy (Wilson et al. 2007). Shoreline development has increased reinforced erosion control structures that limit terrapin access and destroy habitat; in Virginia 400 km (4.3%) of shoreline was newly armored between 1993 and 2004 (Wilson et al. 2007). Protective ownership and tight regulations near these delicate ecosystems is vital to the longevity of the estuarine environment. Federal, state and private non-governmental organization ownership of these barrier islands such as Fisherman will protect this fragile system from the threats accompanying development and extensive human recreational use.

Recommendations

Fisherman Island appears to have an extensive diamondback terrapin population, but so far the majority of animals studied have been located near the north-west marsh. Further study of other locations on the island is needed. Several terrapin females have been found coming straight out of the surf on the ocean side and it is unknown if they are simply traveling through these areas to nest or utilize them year-round. Recruitment success is unknown on the island. Possible future projects could search for terrapin in the juvenile age class or more extensively monitor the rates of nest depredation. Predator control is vital for the continuation of several species on the island. Extensive raccoon trapping and removal of crows may not only aid terrapin populations, but also those of American oystercatcher (*Haematopus palliates*), piping plover (*Charadrius melodus*), least terns (*Sternula antillarum*), brown pelicans (*Pelecanus occidentalis*), clapper rails (*Rallus longirostris*) and other beach and marsh nesting birds.

Road mortality problems need to be addressed soon. Increased tourism to the Delmarva peninsula and the Eastern Shore of Virginia is resulting in higher traffic, especially on the CBBT roadway. There is no other access route from the tip of the peninsula to the mainland, so increasing traffic is funneled south on this road, directly across Fisherman Island. Ideally, outside funding will be secured to build a permanent drift fence that with weather the elements well and require little maintenance. However, the possibility of new semi-permanent, lower cost construction materials still needs to be considered, not only for Fisherman but for locations throughout the terrapin's range. Further study is needed overall to truly assess the road mortality situation. More daily monitoring, continued collection of GPS points and possible spatial models will help to place fences in high risk areas and gather more data on the problem.

References

Akcakaya, H. R., M. A. Burgman, O. Kindvall, C. C. Wood, P. Sjogren-Gulve, J. S. Hatfield, and M. A. McCarthy, editors. 2004. Species conservation and management: case studies. Oxford University Press, Inc., New York, New York.

Allen, E. R., and W. T. Neill. 1959. Doubtful locality records in British Honduras. Herpetologica **15**:227-233.

Barry, S., and J. Elith. 2006. Error and uncertainty in habitat models. Journal of Applied Ecology **43**:413-423.

Bolstad, P. 2008. GIS fundamentals, a first text on geographic information systems. Eider Press Inc., White Bear Lake, MN.

Bortone, S. A. 2005. Using Waterbirds as Indicators in Estuarine Systems: Successes and Perils. Pages 409-422. Estuarine Indicators. CRC Press, Boca, Raton, FL.

Boulinier, T., J. D. Nichols, J. E. Hines, J. R. Sauer, C. H. Flather, and K. H. Pollock. 2001. Forest fragmentation and bird community dynamics: inference at regional scales. Ecological Society of America **82**:1159-1169.

Brennessel, B. 2006. Diamonds in the Marsh: A Natural History of the Diamondback Terrapin. University Press of New England, Lebanon, NH.

Brinker, D. F., J. M. McCann, B. Williams, and B. D. Watts. 2007. Colonial-nesting seabirds in the Chesapeake Bay region: where have we been and where are we going? Waterbirds **30**:93-104.

Browne, C. L., and S. J. Hecnar. 2007. Species loss and shifting population structure of freshwater turtles despite habitat protection. Biological Conservation **138**:421-429.

Burger, J. 1977. Determinants of hatchling success in diamondback terrapin, *Malaclemys terrapin*. American Midland Naturalist **97**:444-464.

Burke, V. J., and J. W. Gibbons. 1995. Terrestrial buffer zones and wetland conservation: a case study of freshwater turtles in a Carolina Bay. Conservation Biology **9**:1365-1369.

Burnham, K. P., and D. R. Anderson 2002. Model Selection and Multimodel Inference: a Practical Information-Theoretic Approach. Springer-Verlag, Inc., New York, NY.

Butler, J. A., C. Broadhurst, M. Green, and Z. Mullin. 2004. Nesting, Nest predation and hatchling emergence of the Carolina diamondback terrapin, Malaclemys terrapin centrata, in northeastern Florida. The American Midland Naturalist **152**:145-155.
Cam, E., J. D. Nichols, and C. H. Frather. 2000. Relative species richness and community completeness: Birds and urbanization in the Mid-Atlantic states. Ecological Applications **10**:1196-1210.
Carignan, V., and M.-A. Villard. 2002. Selecting indicator species to monitor ecological integrity: a review. Environmental Monitoring and Assessment **78**:45-61.
Carr, A. 1952. Handbook of Turtles. The Turtles of the United States, Canada and Baja California. Cornell University Press, Ithaca, NY.
Chapman, D. G., and W. S. Overton. 1966. Estimating and testing differences between population levels by the Schnabel estimation method. Journal of Wildlife Management **30**:173-180.
Chesapeake Bay Bridge Tunnel. 2009. Number of vehicles crossing the CBBT in 2009 in A. Hackney, editor, Cape Charles, VA.
Clark, T. W., A. R. Willard, and C. M. Cromley. 2000. Improving natural resources policy and management in T. W. Clark, A. R. Willard, and C. M. Cromley, editors. Foundations of Natural Resources Policy and Management. Yale University Press, New Haven, CT.
Congalton, R. G. 1997. Exploring and evaluating the consequences of vector-to raster and raster-to-vector conversion. Photogrammetric Engineering and Remote Sensing **63**:425-434.
Davis, D. W. 1992. Canals and the Southern Louisiana Landscape. Pages 375-379. Geographic Snapshots of North America:. Guilford Press, New York, NY.
Ernst, C. H., and J. E. Lovich 2009. Turtles of the United States and Canada. John Hopkins University Press, Baltimore, MD.
Ernst, C. H., J. E. Lovich, and R. W. Barbour 1994. Turtles of the United States and Canada. Smithsonian Institution Press, Washington D.C.
Feinburg, J. A., and R. L. Burke. 2003. Nesting ecology and predation of diamondback terrapins, Malaclemys terrapin, at Gateway National Recreation Area, New York. Journal of Herpetology **37**:517-526.
Fleming, K. K., K. A. Didier, B. R. Miranda, and W. F. Porter. 2004. Sensitivity of a white-tailed deer habitat-suitability index model to error in satellite land-cover data: implications for wildlife habitat suitability studies. Wildlife Society Bulletin **32**:158-168.
Friends of the Kiawah River. 2009. Friends of the Kiawah River webpage in S. Limehouse, editor, Pawleys Island, SC.
Gibbons, J. W. 1986. Movement patterns among turtle populations: applicability to management of the desert tortoise. Herpetologica **42**:104-113.
Gibbons, J. W., D. E. Scott, T. J. Ryan, K. A. Buhlmann, T. D. Tuberville, B. S. Metts, J. L. Greene, T. Mills, Y. Leiden, S. Poppy, and C. T. Winne. 2000. The global decline of reptiles, déjà vu amphibians. BioScience **50**:653- 666.
Gibbons, W. J., J. E. Lovich, A. D. Tucker, F. S. N.N., and J. L. Greene. 2001. Demographic and ecological factors affecting conservation and management of

the diamondback terrapin (Malaclemys terrapin) in South Carolina. Chelonian Conservation and Biology **4**:66-74.

Green, A. A. 2007. O'Malley signs environmental bills: governor praises bipartisan consensus. Baltimore Sun, Baltimore, MD, April 25, 2007.

Hackney, A. D., and P. Denmon. 2007. 2007 Diamondback terrapin nesting project. Pages 1-4. USFWS, Cape Charles, VA.

Hackney, A. D., and P. Denmon. 2008. Monitoring of northern diamondback terrapin (*Malaclemys terrapin terrapin*) on Fisherman Island National Wildlife Refuge in Cape Charles, VA. USFWS, Cape Charles, VA.

Hampton, S. E. 2004. Habitat overlap of enemies: temporal patterns and the role of spatial complexity. Oecologia **138**:475-484.

Hoyle, M. E., and J. W. Gibbons. 2000. Use of a marked population of diamondback terrapins (Malaclemys terrapin) to determine impacts of recreational crab pots. Chelonian Conservation and Biology **3**:735-737.

Hunter, M. L., and J. P. Gibbs 2007. Fundamentals of Conservation Biology. Blackwell Publishing, Oxford, UK.

Jensen, O. P., R. Seppelt, T. J. Miller, and L. J. Bauer. 2005. Winter distribution of blue crab Callinectes sapidus in Chesapeake Bay: application and cross-validation of a two stage generalized additive model. Marine Ecology Progress Series **299**:239-255.

Kearney, M. S., A. S. Rogers, J. R. G. Townshend, J. C. Stevenson, J. Stevens, E. Rizzo, and K. Sundberg. 2002. Landsat imagery shows decline of coastal marshes in Chesapeake and Delaware Bays. Transactions American Geophysical Union **83**:177-178.

Kolbe, J., and F. Janzen. 2002. Spatial and temporal dynamics of turtle nest predation: edge effects. Oikos **99**:538-544.

Leighton, P. A., J. A. Horrocks, B. H. Krueger, J. A. Beggs, and D. L. Kramer. 2008. Predicting species interactions from edge responses: mongoose predation on hawksbill sea turtle nests in fragmented beach habitat. Proceedings of the Royal Society Biological Sciences **275**:2465-2472.

Marchand, M. N., and J. A. Litvaitis. 2004. Effects of landscape composition, habitat features, and nest distribution on predation rates of simulated turtle nests. Biological Conservation **117**:243-251.

McFaden, F. 2008. New recreational crab pot requirements. Maryland Department of Natural Resources.

Miller, R. I., S. N. Stuart, and K. M. Howell. 1989. A methodology for analyzing rare species distribution patterns utilizing GIS technology: the rare birds of Tanzania. Landscape Ecology **2**:173-189.

Mitsch, W. J., and J. G. Gosselink 2000. Wetlands. John Wiley and Sons, Inc., New York, NY.

Moll, D., and E. O. Moll. 2004. River turtle exploitation: past and present. The ecology, exploitation and conservation of river turtles. Oxford University Press, New York, NY USA.

Nelson, R., M. A. Valenti, A. Short, and C. Keller. 2003. A multiple resource inventory of Delaware using airborne laser data. BioScience **53**:981-992.

New Mexico Center for Wildlife Law. 2009. Chapter 4 statute summaries. Federal wildlife and related laws handbook University of New Mexico School of Law, Albuquerque, NM.

Opdam, P., R. Foppen, and C. Vos. 2002. Bridging the gap between ecology and spatial planning in landscape ecology. Landscape Ecology **16**:767-779.

Park, C. 2007. Clean Water Act (1972). A Dictionary of Environment and Conservation. Oxford University Press.

Phillips, M. L., W. R. Clark, M. A. Sovada, D. J. Horn, R. R. Koford, and R. J. Greenwood. 2003. Predator selection of prairie landscape features and its relation to duck nest success. Journal of Wildlife Management **67**:104-114.

Rae, C., K. Rothley, and S. Dragicevic. 2007. Implications of error and uncertainty for an environmental planning scenario: a sensitivity analysis of GIS- based variables in a reserve design exercise. Landscape and Urban Planning **79**:210-217.

Ritters, K. H., R. V. O'Neil, and K. B. Jones. 1997. Assessing habitat suitability at multiple scales: a landscape approach. Biological Conservation **81**:191-202.

Roberge, J., and A. P. Anglelstam. 2004. Usefulness of the umbrella species concept as a conservation tool. Conservation Biology **18**:76-85.

Roosenburg, W. M. 1990. The Diamondback terrapin: population dynamics, habitat requirements and opportunities for conservation. Pages 227-234. New Perspectives in the Chesapeake System: a Research and Management Partnership. Chesapeake Research Consortium, Baltimore, MD.

Roosenburg, W. M. 1994. Nesting habitat requirements of the diamondback terrapin: a geographic comparison. Wetlands Journal **6**:9-12.

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

Roosenburg, W. M., W. Cresko, M. Modesitte, and M. B. Robbins. 1997. Diamondback terrapin (Malaclemys terrapin) mortality in crab pots. Conservation Biology **11**:1166-1172.

Semlitsch, R. D., and J. R. Bodie. 2003. Biological criteria for buffer zones around wetlands and riparian habitats for amphibians and reptiles. Conservation Biology **17**:1219-1228.

Smith, H. M., and R. B. Smith 1980. Synopsis of the herpetofauna of Mexico, volume 6: guide to Mexican turtles. John Johnson, North Bennington, VT.

Speir, H. 2008. Fisheries Service Draft Regulations. Maryland Department of Natural Resources.

Steen, D. A., and J. P. Gibbs. 2004. Effects of roads on the structure of freshwater turtle populations. Conservation Biology **18**:1143-1148.

Stephens, S. E., J. J. Rotella, M. S. Lindberg, M. L. Taper, and J. K. Ringelman. 2005. Duck nest survival in the Missouri coteau of North Dakota: landscape effects at multiple spatial scales. Ecological Applications **15**:2137-2149.

Szerlag, S., and S. P. McRobert. 2006. Road occurrence and mortality of the northern diamondback terrapin. Applied Herpetology **3**:27-37.

Temple, S. A. 1987. Predation on turtle nests increases near ecological edges. Copeia **1987**:250-252.

The Wetlands Institute. 2008. Comments on diamondback terrapin fencing in P. Denmon, editor.

Titus, J. G., and C. Richman. 2001. Maps of lands vulnerable to sea level rise: modeled elevations along the US Atlantic and Gulf coasts. Climatic Research **18**:205-228.

Toschik, P. C., M. C. Christman, B. A. Rattner, and M. A. Ottinger. 2006. Evaluation of Osprey habitat suitability and interaction with contaminant exposure. Journal of Wildlife Management **70**:977-988.

Trombulak, S. C., D. S. Wilcove, and T. D. Male. 2006. Science as smoke screen. Science **312**:973.

USFWS. Digest of Federal Resource Laws of Interest to the U.S. Fish and Wildlife Service.

USFWS. 2009a. Digest of Federal Resource Laws of Interest to the U.S. Fish and Wildlife Service. Resource Laws. USFWS Division of Congressional and Legislative Affairs, Arlington, VA.

USFWS. 2009b. Federal Register: July 13, 2009. Pages 33460-33464 in Department of the Interior, editor. Conference of the Parties to the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES); Fifteenth Regular Meeting: Proposed Resolutions, Decisions, and Agenda Items Being Considered; Taxa Being Considered for Amendments to the CITES Appendices; Observer Information.

Watts, B. D., and D. S. Bradshaw. 1994. The influence of human disturbance on the location of Great Blue Heron colonies in the lower Chesapeake Bay. Colonial Waterbirds **17**:184-186.

Wilke, A. L., D. F. Brinker, B. D. Watts, A. H. Traut, R. Boettcher, J. M. McCann, B. R. Truitt, and P. P. Denmon. 2007. American oystercatchers in Maryland and Virginia, USA: status and distribution. Waterbirds **30**:152-162.

Wilson, M. D., B. D. Watts, and D. F. Brinker. 2007. Status review of Chesapeake Bay marsh lands and breeding marsh birds. Waterbirds **30**:122-137.