Recovery Plan for the Diamondback Terrapin, *Malaclemys terrapin*, in Bermuda

Government of Bermuda
Ministry of Environment and Planning
Department of Conservation Services

Recovery Plan for the Diamondback Terrapin, *Malaclemys terrapin*, in Bermuda

Prepared in Accordance with the Bermuda Protected Species Act 2003

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Cover photo: Wild mature male diamondback terrapin, *Malaclemys terrapin*.
Photo by Mark Outerbridge
All photos throughout this document were taken by Mark Outerbridge
Maps were prepared by Mark Outerbridge

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"To conserve and restore Bermuda's natural heritage"

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DISCLAIMER

Recovery plans delineate reasonable actions that are believed to be required to recover and/or protect listed species. We, the Department of Conservation Services, publish recovery plans, sometimes preparing them with the assistance of field scientists, other government departments, as well as other affected and interested parties, acting as independent advisors to us. Plans are submitted to additional peer review before they are adopted by us, and formulated with the approval of interested parties mentioned in Parts II and III of the plan. Objectives of the recovery plan will be attained and necessary funds made available subject to budgetary and other constraints affecting the parties involved. Recovery plans may not represent the views nor the official positions or approval of any individuals or agencies involved in the recovery plan formulation, other than our own. They represent our official position only after they have been signed by the Director of Conservation Services as approved. Approved recovery plans are subject to modifications as dictated by new findings, changes in species status, and the completion of recovery actions.

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An electronic version of this recovery plan will also be made available at www.conservation.bm

Andrew Pettit

Director
Department of Conservation Services
Government of Bermuda

16th October 2013

Date

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EXECUTIVE SUMMARY

Current Species Status:
This recovery plan addresses the need for actions to conserve a native species of terrapin, *Malaclemys terrapin*, in Bermuda. This species is listed as Vulnerable (EN, B1a, biii) as per IUCN criteria, under the Protected Species Act 2003. Diamondback terrapins represent Bermuda's second naturally occurring non-marine reptile that still survives on the island (the other being the endemic skink *Plestiodon* (formerly *Eumeces*) *longirostris.*) The current terrapin population is estimated to comprise approximately 100 individuals ≥81 mm straight carapace length (SCL).

Habitat Requirements and Threats:
Diamondback terrapins are an inhabitant of the land-locked, brackish water pond environment in Bermuda. The entire population of diamondback terrapins can only be found in four ponds on the Mid Ocean golf course located in the eastern parishes of the islands. These ponds are known as Mangrove Lake, South Pond, North Pond, and Trott's Pond and all four bodies of water have been incorporated into the golf course as water hazards. Neonate and small juvenile terrapins use adjacent mangrove swamps and grass-dominated marshes as developmental habitat; larger juveniles (≥81 mm SCL), sub-adult and adult terrapins are found within the aquatic pond environment. It is thought that the principle factor which has led to the limited distribution of diamondback terrapins is loss of habitat through fragmentation of the wetlands in Bermuda. This restriction in habitat is due to both human development and natural processes. Pollution of ponds has also contributed to the decline and degradation of available habitat, as ponds and marshes were historically used as garbage disposal sites, and continue to receive run-off from roads and the surrounding golf course. In addition to having a limited distribution and a small population, Bermuda's terrapin population also suffers from low recruitment and poor annual hatching success which lends further support to the belief that it is vulnerable to local extirpation.

Recovery Objective:
The main goal of this plan is to increase both the population level and the areas of residency for diamondback terrapins in Bermuda.

Recovery Criteria:
Down listing of diamondback terrapins in Bermuda will be considered when:

- The genetic diversity of Bermuda's extant population is fully understood.
- All current and potential habitats suitable for diamondback terrapin growth, reproduction and survival are identified, assessed, restored and protected under legislation.
- Diamondback terrapins are viable residents in at least two separate geographic locations on Bermuda.
- Population levels in Bermuda indicate that terrapins are successfully maintaining themselves on a long-term basis and showing adequate levels of recruitment.

Actions Needed:

1. Protect wetland habitats of extant terrapin population through legislation,
2. Restore protected wetland habitats of current extant population,
3. Identify, assess, protect and restore wetland habitats deemed suitable for diamondback terrapin introduction,
4. Increase population size through increased hatching success and recruitment to the adult population,
5. Expand area of residency through translocation of individuals raised in captivity,
6. Identify the full genetic composition of existing population,
7. Develop research programmes on understanding the effects that environmental contaminants have upon the reproductive biology and overall health of terrapins in Bermuda,
8. Promote conservation education programmes concerning Bermuda's terrapin population,
9. Continued population monitoring.

Recovery Costs: The total cost of recovery actions cannot be defined at this point. Funding needs to be secured through Non-Governmental Organizations (NGO's), overseas agencies, and other interested parties for implementing the necessary research and monitoring studies on the biology of the diamondback terrapin. Developing budgets for each action are the responsibility of the leading party as outlined in the work plan.

Date of Recovery: Meeting the recovery objectives in Bermuda will depend on the restoration and protection of available habitats. Down listing will be considered following 10 years of implementation (2023), once evaluation of conservation efforts is complete.

PART I: INTRODUCTION

A. Brief overview

Diamondback terrapins *Malaclemys terrapin* have been listed as a globally near threatened species by the International Union for Conservation of Natural Resources (IUCN). In 2013, diamondback terrapins were included in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) in an attempt to regulate international trade so that exports from the native range are not detrimental to the species' survival in the wild. Diamondback terrapins are endemic to the coastal wetland environments along the east coast of the United States from Cape Cod in Massachusetts to Corpus Christi in Texas. Their status, which varies from state to state, ranges from endangered to a species of special concern. Massive over-harvesting for food consumption in the late 19th and early 20th centuries lead to huge declines in the North American populations, which continue to be affected by habitat loss, predation, crab trapping activities and commercial harvest for pet-trade and human consumption (Roosenburg et al., 1997; Hart and Lee, 2006).

Historical accounts of Bermuda's diamondback terrapins first appear in writings that date back to the 1950s (D. Wingate, unpublished notes), however it was not until 2007 when their origin on these remote oceanic islands was tested using a combination of palaeontologic (fossil, radiometric and palaeoenvironmental) and genetic data. These lines of evidence supported the hypothesis that these terrapins are natural colonizers of Bermuda, having arrived between 3000 and 400 years ago (Parham et al., 2008), and represents the second naturally occurring non-marine reptile that still survives on one of the most densely populated and heavily developed oceanic islands in the world (the other is an endemic skink). Bermuda is situated in a part of the North Atlantic Ocean which regularly receives spin-off eddies from the Gulf Stream. These eddies have been implicated in the transport of a great diversity of plants and animals from the Caribbean and eastern seaboard of North America to Bermuda (Glasspool, 1994; Meylan and Sterrer, 2000; Grady et al., 2001; Sterrer et al., 2004), and are most likely responsible for transporting diamondbacks as well (Davenport et al., 2005).

It appears that this Bermudian population is the only wild breeding population outside of the North American range. There has been a dearth of information regarding the health and status of this isolated oceanic population. Knowledge of their life history is necessary to make informed management decisions and was deemed critical for a species recovery plan. Consequently, work on this species was initiated in 2008 by Mark Outerbridge of the Bermuda Zoological Society as part of a Ph.D. programme. All of the Bermuda data presented in this recovery plan is the result of this doctoral investigation.

This recovery plan discusses threats and conservation efforts for Bermuda's diamondback terrapins, summarizing new and previously unavailable information about their local habitat and dietary requirements, reproductive biology, and threats to survival. In order to ensure sustainability of the terrapin population within Bermuda, an increase in the area of occupancy as well as in population size is recommended and deemed possible through head-starting and translocations initiatives. The recovery of the population is heavily dependent on the availability of suitable habitats, hence the restoration of selected ponds is a priority in this plan. Should all of this be realized, it may be possible to down list diamondback terrapins to a lesser threatened status and/or remove it from the Protected Species list.

B. Current protection status

Bermuda's diamondback terrapins are classified as a level 2 protected species and declared to be Vulnerable under the Protected Species Act (2003). Diamondback terrapins are not harvested for food in Bermuda or caught as by-catch in commercial or recreational shellfish pots, and none of the ponds have boating traffic, however, the area in which the terrapins reside is currently, and has also historically been, heavily impacted upon by other anthropogenic activities. There have been few opportunities for range increase, due in great part to the restriction in habitat availability. The fragmentation of the wetland habitat in Bermuda, and the very limited distribution of the terrapins, makes this species very vulnerable to human impact.

Legal Protection

The Protected Species Amendment Act (2011) considers it an offence for an unauthorized person to willfully damage, destroy, injure, disturb, uproot, fell, kill, take, import, export, sell or purchase a level 2 protected species or any part of a level 2 protected species. Offenders are liable, on summary of conviction, to a fine of $15,000 or 1 year of imprisonment.

Habitat Protection

Mangrove Lake, Trott's Pond and North Pond have been designated as 'nature reserves' under the 2008 Bermuda Development Plan; however, South Pond is currently zoned as a 'recreational area' (Fig. I in Appendix).

C. Taxonomy and description of species

Class: Reptilia (reptiles)
Order: Testudines (turtles, terrapins & tortoises)
Family: Emydidae (pond turtles)
Genus: *Malaclemys*
Species: *terrapin*
Common name: Diamondback terrapin

Diamondback terrapins belong to the Family Emydidae, a large and diverse group of reptiles collectively known as 'pond turtles' that are naturally found throughout North America, much of Europe, and eastward into Russia, the Near East, and North Africa (Meylan, 2006). They are the only member of the genus *Malaclemys*. Seven subspecies of diamondback terrapin are currently recognized, which have been divided into northern (*M. t. terrapin, M. t. centrata*) and southern (*M. t. tequesta, M. t. rhizophorarum, M. t.*

macrospilota, M. t. pileata, M. t. littoralis) populations with Merritt Island, Florida, providing a break between the two; however, genetic studies do not fully agree with the existence of these subspecies (Lamb and Avise, 1992; Hart, 2005; Hauswaldt and Glen, 2005).

Diamondback terrapins are small to medium sized turtles that show distinctive shell and soft tissue markings; however, these markings vary greatly throughout their range. The carapace is typically oblong in shape and possesses a mid-dorsal keel which is more visibly raised, or knobbed, in the southern subspecies. Carapace colour is highly variable but usually of earth tones ranging from light olive and brown to dark brown and black. The carapace is also marked with concentric growth rings that are most pronounced on younger individuals (Fig. 1 top), from which this species gets its common name, but disappear with age. The circular depressions that these rings make extend below the veneer of each scute and are imprinted upon the dorsal surface of the underlying bones of the carapace. The plastron, in contrast to the carapace, is more brightly coloured with yellowish or orange hues and can be either plain in appearance or smudged with varying amounts of dark blotches. Sometimes, however, the plastral scutes can have a dark base colour with lighter colourful edges. The plastral scutes may also show growth rings. These rings, or annuli, have been used by some researchers to estimate the age of individuals (Seigel, 1984; Tucker et al., 1995; Gibbons et al., 2001); however this technique remains a contentious method of aging terrapins and many agree that it is not possible to use it on older individuals whose rings have disappeared with the passage of time (Morreale, 1992; Gibbons et al., 2001). Skin colour also varies throughout the range, but is generally shades of gray with dark spots, flecks or lines (the latter having not been observed in the Bermuda population) (Fig. 1 bottom).

Diamondback terrapins show sexual dimorphism; with males being considerably smaller than females and having proportionally smaller heads, but wider and longer tails with a cloaca situated posterior to the edge of the carapace when the tail is fully extended.

The diamondback terrapin carapace normally features 38 named scutes:- 1 nuchal, 5 vertebrals, 4 pairs of costals (also known as pleurals), 11 pairs of marginals, and 2 supracaudals. The plastron is normally composed of 12 named scutes; 1 pair of gulars, 1 pair of humerals, 1 pair of pectorals, 1 pair of abdominals, 1 pair of femorals, and 1 pair of anals. Both carapace and plastron are joined by a bridge. Variations in the number of vertebral, costal or marginal scutes are not uncommon, and may involve an extra, split, or distorted scute. These variations are believed to be caused by high incubation temperatures (Wood and Herlands, 1997; Herlands et al., 2004) and possibly embryological exposure to petroleum crude oil and polycyclic aromatic hydrocarbons (Van Meter et al., 2006).

Figure 1. Photographs of a typical diamondback terrapin from Bermuda

D. Current status

<u>Global distribution</u>

Diamondback terrapins are endemic to the Atlantic and Gulf Coasts of the United States of America, whose range extends across 16 states from Cape Cod, Massachusetts, in the north to Corpus Christi, Texas, in the south (Fig. 3). Their distribution across this range is not continuous, but rather consists of fragmented populations concentrated in a linear fashion along the coast. Five of the seven subspecies occur within Florida, of which three are considered to reside exclusively in that state. The northern diamondback terrapin, *Malaclemys terrapin terrapin*, ranges from Cape Cod in Massachusetts to Cape Hatteras in North Carolina. The Carolina diamondback, *M. t. centrata*, ranges from Cape Hatteras southwards to Volusia County in Florida. The Florida East Coast diamondback, *M. t. tequesta*, ranges from Volusia County to Miami-Dade County, as well as possibly into the upper Keys in Monroe County. The mangrove diamondback, *M. t. rhizophorarum*, occurs in Monroe County from Fort Myers to Florida Bay and throughout the Florida Keys and the Marquesas. The ornate diamondback, *M. t. macrospilota*, occurs from Florida Bay to the western part of the Florida Panhandle in Walton County. The Mississippi diamondback, *M. t. pileata*, ranges from western Choctawhatchee Bay in Okaloosa County, Florida, westwards through the state of Louisiana. The Texas diamondback, *M. t. littoralis*, is found from western Louisiana to Corpus Christi in Texas (Ernst et al., 1994; Butler et al., 2006). The only geographic region where diamondback terrapins appear to naturally reside outside of their North American range is in Bermuda.

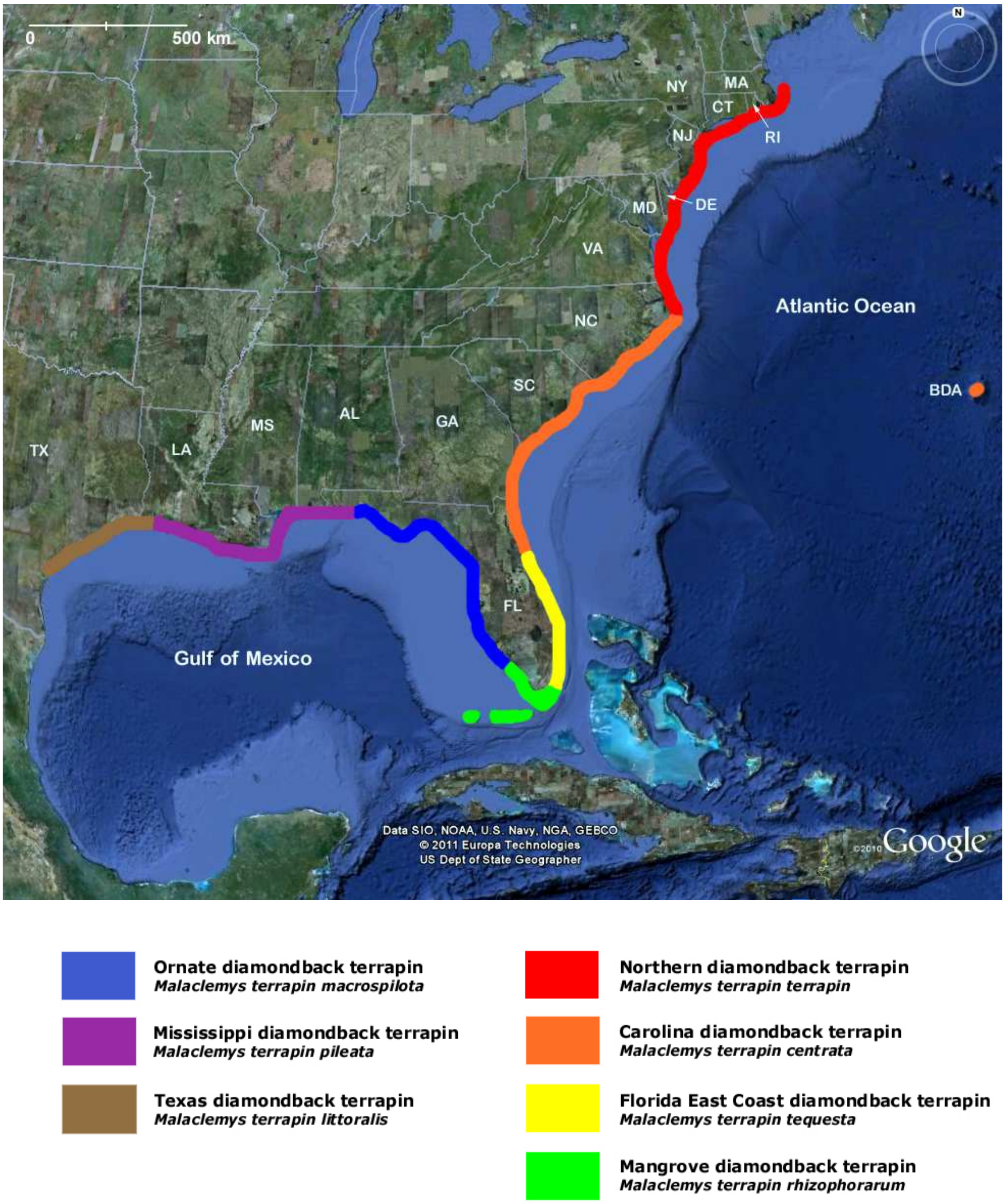

Figure 2. Map illustrating the range-wide distribution of the seven recognized diamondback terrapin subspecies (adapted from Butler et al., 2006; Lee and Chew, 2008).

Local distribution

The entire Bermuda population of diamondback terrapins is found only in four brackish water ponds named Mangrove Lake, South Pond, North Pond, and Trott's Pond. All four bodies of water are situated upon a single square kilometer of Bermuda and are only separated from each other by, at most, 380 meters of land. These ponds are located on a private golf course, the Mid Ocean Club, located in Smith's Parish at the eastern end of the islands (Figs. 3 and 4). Mangrove Lake and Trott's Pond are the largest of these ponds (approximately 10 ha and 3 ha respectively in area) and both are simple basins fringed by red mangrove trees *Rhizophora mangle* and characterized by shallow depths (averaging 1.4 m and 2.7 m respectively) with bottoms comprised of deep deposits of highly organic sediment (Thomas et al., 1991). North Pond and South Pond are considerably smaller in area (both approximately 0.4 ha) and lack mangrove vegetation; however both have small marshes in their centers dominated by grasses. Mangrove Lake, South Pond, North Pond, and Trott's Pond have been incorporated into the golf course as water hazards found between the 5^{th} and 12^{th} holes. No diamondback terrapins have been discovered in any other bodies of water on Bermuda despite a series of extensive wetland community surveys conducted between 2004 and 2007 (Outerbridge et al., 2007a; Outerbridge, 2008).

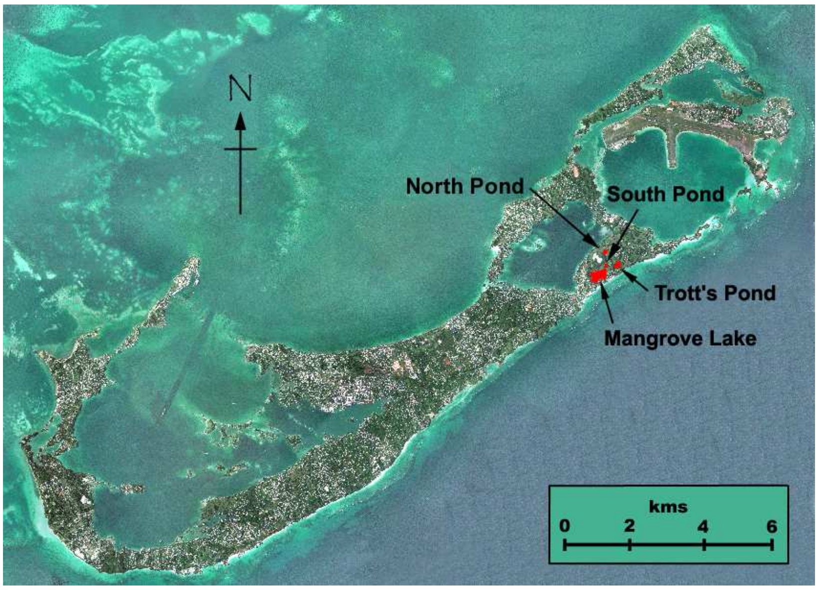

Figure 3. Aerial photograph of Bermuda showing the location of the diamondback terrapin ponds.

Figure 4. Aerial photograph from 2003 showing the diamondback terrapin ponds situated on the Mid Ocean golf course (A=Mangrove Lake, B=Trott's Pond, C=South Pond, D=North Pond)

Mangrove Lake

Mangrove Lake is currently the largest of Bermuda's brackish water ponds and is believed to have formed during the last 11,000 years through the action of dissolution of calcium carbonate from either rock or sand, thereby creating a depression that gradually filled with salt water as the seas rose (Watts and Hansen, 1986; Thomas, 2002). It is a simple basin approximately 10 ha, in area fringed almost exclusively by red mangrove trees *Rhizophora mangle* and characterized by shallow depths, averaging only 140 cm, fairly even contours and a gently sloping shoreline. The pond bottom comprises deep deposits of highly organic sediments, from which widgeon grass *Ruppia maritima* grows in dense clumps. Mangrove Lake is often subject to considerable changes in dissolved oxygen, temperature, salinity and nutrient levels (Thomas et al., 1991). A few small subterranean fissures ensure that ocean water still enters this pond from the south shore; however, it has a small tidal range of 1.4 cm (Thomas et al., 1992). Average mid-water temperatures ranged between 15.6°C (February) and 30.3°C (July); surface salinities between 26 psu (January) and 35.7 psu (August) (Outerbridge, unpublished data). Mangrove Lake and the surrounding land are owned by a variety of private individuals and organizations. The pond is mostly owned by the Tucker's Point Club, but the surrounding land is owned by the Mid Ocean Club, the Bermuda National Trust, and a number of private individuals who live adjacent to the pond.

Trott's Pond

Trott's Pond is also partially situated on the Mid Ocean golf course. It is approximately 3 ha in area and formed between low Pleistocene sand dunes that were inundated by postglacial seas. Over time fresh water slowly eroded away the depression creating fissures through which salt water enters from the south shore as the sea level rose around Bermuda. Trott's Pond is currently a simple basin characterized by fairly shallow depths, with the deepest part at its centre. It has fairly even contours and a gently sloping shoreline (Thomas et al., 1992). The connection to the ocean is small and located at the surface, giving Trott's Pond a very small tidal range of 1.5 cm. Rainfall and surface run-off from the surrounding area usually doesn't mix with the salt water below, but instead floats as a distinct layer on top, eventually draining off through the surface connection (Thomas, 2002). The pond bottom comprises deep deposits of highly organic sediments. The mean depth in Trott's Pond is 269 cm; the maximum was 320 cm. Average annual surface water temperatures range from 16-31° C (+/- 4°.8 C) and salinities vary from 24-34 psu (+/- 2.6 psu) (Thomas *et al*., 1991). Trott's Pond shares many species in common with neighbouring Mangrove Lake including the mangrove oyster *Isognomon alatus*, the Bermuda killifish *Fundulus bermudae* and the coffee bean snail *Melampus coffeus*. The shoreline of Trott's Pond is fringed almost entirely by red mangrove trees.

South Pond

South Pond is much smaller than Mangrove Lake and Trott's Pond and was deliberately dredged to create a golf course water hazard in the 1990s. A land bridge separates this pond into two distinct bodies of water; the moat-like pond to the north and a smaller pond to the south. These two bodies of water are collectively known as South Pond and comprise a combined area of approximately 0.4 ha. Mangrove trees are not present at this site, but there is a small 0.3 ha marsh located in the centre of the larger pond, made up predominantly of saw grass *Cladium jamaicense,* and to a lesser extent cattail *Typha angustifolia*. The emergent vegetation that grows around the perimeter of South Pond is exclusively sheathed paspalum *Paspalum vaginatum* which is periodically trimmed by the agronomy staff of the Mid Ocean Club. Widgeon grass *Ruppia maritima* grows seasonally within South Pond, and the pond bottom is comprised of highly organic sediment. The mean depth in the larger pond is 35 cm, while the smaller pond averages 81 cm. Average annual mid-water temperatures in 2011 ranged between 15.7 °C (Feb) and 29.8°C (August). The salinity of South Pond is much lower than in neighboring Mangrove Lake and Trott's Pond. Salinities in the larger pond ranged between 4.8 psu (March) and 16.8 psu (July) while in the smaller pond they ranged between 7.8 psu (April) and 18.7 psu (June) (Outerbridge, unpublished data). The water levels vary considerably according to the amounts received through rainfall, and in periods of drought it is not uncommon for some areas to dry up completely.

North Pond

North Pond is approximately the same size as South Pond (ca. 0.4 ha), is a naturally occurring pond, and has also been incorporated into the golf course. Mangrove trees are also not present at this site; however, there is a narrow band of marshland located in the pond which is dominated by sheathed paspalum *P. vaginatum*. As with all of the other diamondback terrapin ponds, North Pond's bottom is comprised of highly organic sediment. Mean depth of water is 30 cm. Mean mid-water temperatures are only available for a 6 month period in 2010, and ranged between 15.6°C (February) and 31.1°C (July). The salinity in this pond is slightly lower than in neighboring Mangrove Lake and Trott's Pond, but higher than South Pond. The mean mid-water salinities in 2010 ranged between 7.8 psu (April) and 18.7 psu (June) (Outerbridge, unpublished data). The water levels in North Pond vary considerably according to the amounts received through rainfall, and in periods of drought it is not uncommon for large areas of the pond to dry up completely.

E. Ecology

Habitat requirements

Diamondback terrapins have a life cycle comprised of distinct phases that have different habitat requirements. Adult and sub-adult terrapins have need of brackish bodies of water in which they feed, mate and, for populations residing in cooler regions, brumate (the reptilian equivalent of hibernation); mature female terrapins require sandy substrate for egg laying; hatchlings and small juveniles require dense vegetation which grows adjacent to the adult aquatic environment to forage, grow and hide from predators. Examples of this vegetation include salt marsh grasses (*Spartina spp.* in North America and *Paspalum vaginatum* and *Cladium jamaicense* in Bermuda) and red mangroves (*Rhizophora mangle*).

Diamondback terrapins are the only species of turtle that have specialized to inhabit the tidal salt marsh and estuarine environment along the Atlantic and Gulf coasts of North America (e.g. coastal marshes, mudflats, river estuaries, tidal creeks, brackish lagoons, and mangrove swamps). They exhibit unique physiological and behavioral adaptations that enable them to live within these habitats (Cowan, 1971; Gilles-Baillien, 1973; Cowan, 1990; Davenport and Macedo, 1990; Hart and Lee, 2006). Bermuda's extant terrapin population, however, is restricted to the brackish water pond environment. The present day saline pools and ponds in Bermuda vary both in size and in structure. Nearly all date back in formation to the Holocene era (approximately 10,000 years ago.) The sporadic addition of fresh water into these ponds, either directly in the form of rainfall or indirectly as surface run-off, means that salinities vary throughout the year. They are generally slightly lower than that of pure seawater, but do show predictable seasonal patterns. The primary factor influencing salinity is the size and location of the underground connections each pond has with the ocean. Pond size, depth and volume, the size and nature of the connections to the ocean, the rate of fresh water inflow, and the tidal exchange of seawater all influence the hydrographic characteristics of each pond. Bermuda's marine ponds generally have a rich biota. Species richness increases with increasing physical stability and diversity of habitat. Thus ponds having submerged rock substrata, an abundant submerged mangrove root community along the periphery of the pond, and bottom sediment show greater diversity than ponds that feature sedimentary substrata only (Thomas et al., 1992).

Physical factors

The most important factor influencing physical stability in the saline ponds is the amount of tidal exchange (Thomas et al., 1992). Temperature and salinity are dependent upon the amount of sea water that enters from the ocean, thus ponds close to the sea with relatively large connections have a higher flushing rate, narrower ranges of salinity and temperature and therefore provide a more stable environment than those of ponds further from the sea. The mean ocean tidal range in Bermuda is only 75 cm, but is greatly reduced in the ponds where there are more restrictions to tidal flow. While proximity to the ocean and the nature of the connections influence salinity level, the locations and sizes of these salt water inlets in relation to the tide level also affect the flushing rate. Salinity stratification can occur in poorly mixed ponds, or where the connection to the sea is in the deepest part, due to the different densities of fresh and salt water, although this phenomenon is unlikely to occur in very shallow ponds. Thomas et al. (1991) described the physical characteristics of the six largest saline ponds, including Mangrove Lake and Trott's Pond. Surface salinities ranged from 6.5 to 42.5 practical salinity units (psu) and the temperatures varied from 15.0º to 37.5ºC. More limited data exists for Bermuda's fresh water ponds; however, it appears that salinity and temperature also follow predictable seasonal patterns. Evaporation, coupled with the sporadic addition of fresh water either directly as rainfall or indirectly as surface run-off, typically via storm drains from neighboring roads, means that surface salinities can range from 0 (totally fresh water) to 12 psu (brackish water.) The small and shallow nature of most of these ponds means that temperatures can also vary greatly from 10.6°C to 34.6°C (Outerbridge, unpublished data). A shallow pond will show greater temperature range because it can exchange heat more rapidly with the atmosphere (e.g. North Pond).

Biological factors

Bermuda's brackish and marine ponds all have deep benthic deposits of highly organic sediments and are subject to large changes in dissolved oxygen, temperature, salinity and nutrient levels. Surface run-off from surrounding land transports particulate matter and plant nutrients into the ponds. Fringing mangrove trees are a common feature of these saline ponds. These trees constantly drop leaves that slowly decompose, forming a highly organic layer on the pond bottom that enhances the base of the food web. Due to their small physical size and accumulated sediments, the saline ponds are usually quite shallow. Because of this, ambient light levels at the bottom can be high, despite the fact that these ponds are typically very turbid due to the high levels of suspended organic material. Plants, however, do not usually grow on the deeper bottoms of the ponds due to the unstable, anoxic environment created by the decomposition of the organic matter. The levels of dissolved oxygen also vary considerably between ponds as well as diurnally and seasonally. Daytime photosynthesis can supersaturate pond water with oxygen while the consumption of oxygen at night from fishes and microbial life on the sediment can reduce oxygen levels to zero, at least in patches, resulting in transitory nighttime anoxia. Anoxic events are routine in some of the poorly flushed anchialine ponds in summer and are partly responsible for their low species diversity, which is typically much reduced below that of open water marine habitats (Thomas and Logan, 1992). The biotic characteristics of Bermuda's ponds are highly variable. Pond size, volume, and physical stability, as well as the stochastic nature of species' colonization and the ability of these species to adapt and survive in the ponds are all factors responsible for this biological variability. One of the curious features of the ponds is that there is great variability of biota amongst the ponds. Quite often a species is found in only one or a few ponds and few species occur in all ponds.

General biology

The annual activity cycle of adult diamondback terrapins from northern populations is one that generally begins with emergence from winter-induced brumation during the spring. Emergence is quickly followed by a period of courtship and mating. Nesting soon follows and often lasts for many months during which females can deposit multiple clutches of eggs (Seigel, 1980b; Goodwin, 1994; Roosenburg and Dunham, 1997). Diamondback terrapins are believed to have a very small home range (Lovich and Gibbons, 1990; Gibbons et al., 2001; Baldwin et al., 2005) and some mature females are known to return to the same nesting beaches annually (Jeyasuria et al., 1994). The incubation period and the gender of the developing embryos are determined by the incubation temperatures; cooler temperatures produce male offspring while warmer temperatures produce female. Hatchlings will, upon emergence, typically seek refuge within the closest vegetation and show avoidance of open water (Burger, 1977; Lovich et al., 1991). Very little exists in the literature about the life history of hatchlings and juveniles from the time they depart the nest to the time that they recruit to the sub-adult population. Growth is most rapid during the first few years after hatching, but then slows down considerably after sexual maturity has been attained (Tucker et al., 1995; Roosenburg and Kelley, 1996). Diamondback terrapins usually enter brumation in November and December and remain in that state either buried in sediment or beneath undercut banks through February or March the following year (Yearicks et al., 1981; Seigel, 1984); however, some populations in Florida were observed to be active on warm days during the winter (Hart, 2005). The lifespan of diamondback terrapins in the wild has been estimated to be approximately 20 years (Seigel, 1984), but may last as long as 40 years in captivity (Hildebrand, 1932).

Population biology

The results of a three year mark and recapture survey (2008-2010) suggest that the adult and sub-adult population of diamondback terrapins presently living on Bermuda comprises approximately 100 individuals. The recapture rate in this population was relatively high over the census period (60.6%), and coupled with the fact that 99 individuals were captured and marked (64 mature females, 22 mature males, 13 juveniles) suggests that the estimate may be very accurate. The Bermuda population is dominated by females (3:1), which ranged in size 116-196 mm straight carapace length (SCL notch-to-notch) (mean 158 mm; SD 22.6 mm) and 270-1340 grams (mean 720 g; SD 285.8 g). Males ranged in size from 109-134 mm SCL (mean 122.7 mm; SD 8.2 mm) and 200-350 grams (mean 281.4 g; SD 47.1 g); and juveniles ranged in size from 81-108 mm SCL (mean 98 mm; SD 9.5 mm) and 95-215 grams (mean 168 g; SD 42.6 g). Thirty four out of 99 individuals (34.3%) showed carapace scute anomalies. The most common anomalies were extra vertebral scutes (15.2% frequency of occurrence), extra costal scutes (15.2% frequency of occurrence), and extra marginal scutes (18.2% frequency of occurrence). The mean annual recruitment rate to the adult population throughout the three year census period was 2 terrapins; 1 new recruit was encountered in 2008, 5 in 2009 and none in 2010. The density of diamondback terrapins in Bermuda is estimated to be 6.0 terrapins/ha (Outerbridge, unpublished data.)

Information on the population biology of diamondback terrapins in their North American range shows variation in relative body sizes, sex ratios, estimates of population size and density. Roosenburg et al. (1997) reported a population estimate of 2778-3730 individuals in the Patuxent River Estuary of Chesapeake Bay; Seigel (1984) estimated populations of 213 and 404 at two sites in east central Florida; Hurd et al. (1979) suggested that as many as 1655 terrapins inhabited the Canary Creek salt marsh in Delaware; Butler (2002) reported a population of 3147 terrapins were found to be using a northeastern Florida nesting beach; and Hart (2005) estimated the Big Sable Creek population within the Everglades National Park in southwest Florida to be 1545 individuals. It is believed that the total number of diamondback terrapins in North America may exceed 100,000 individuals (van Dijk, 2011). Density estimates of terrapins in North America are less available in the literature, but were reported to range from 53-72 terrapins/ha in central Florida (Seigel, 1984). Sex ratios in terrapin populations vary from being strongly female biased (Seigel, 1984; Roosenburg et al., 1997) to being male biased (Lovich and Gibbons, 1990). Hart (2005) reported that the sex ratio in the Big Sable Creek population was 1:1. Female terrapins can reach carapace lengths of 238 mm range wide in North America; males 140 mm (Ernst et al., 1994).

Reproduction

Bermuda's population of diamondback terrapins typically commences mating in February-March and begins egg laying in late March or early April, with peak egg laying observed in May and June. Nesting is known to occur through the summer until late August. The average clutch size is five eggs (range 0-10) and incubation (length of time between egg deposition and first hatching) takes 49-83 days (mean 61.8 days). Bermuda's terrapins exhibit delayed emergence, with as many as 44% of the hatchlings remaining buried in their natal nests during the winter months. The majority of nesting appears to occur within the sand bunkers on the 5^{th}, 6^{th} and 7^{th} holes of the Mid Ocean golf course (most notably the 5^{th} and 7^{th}), although some nesting has been observed in the bunkers on the 8^{th}, 9^{th} and 11^{th} holes as well. Additionally, residents along the shoreline of Mangrove Lake have reported terrapins nesting occasionally in the soil of flower beds and vegetable gardens on their properties (Fig. 6). Nest densities in Bermuda are higher than those reported in the literature, reaching as many as 2,784 nests/ha (bunker on the 7^{th} hole, 2011). The overall nest density in the bunkers on the Mid Ocean Golf course for

2010 and 2011 was calculated to be 347/ha and 443/ha respectively (Outerbridge, unpublished data.) The reason for these high densities is believed to be primarily due to limitations in suitable nesting habitat. The mean depth of nest chambers was 13.7 cm (range 11-16 cm), the mean width was 6.7 cm (range 5-9 cm), and the mean depth of sand over the top most eggs was 9.6 cm (range 7-13 cm). Terrapin eggs in Bermuda range in length from 29.6-46.5 mm (mean 35.6 mm, SD 2.1 mm); width from 18.0-25.5 mm (mean 21.8 mm, SD 1.4 mm); and mass from 7-16 mm (mean 10.7 mm; SD 1.5 mm). These biometrics fall well within the published mean egg dimensions throughout the North American range (Butler et al., 2006). As a general rule of thumb, the northern subspecies of terrapins exhibit smaller eggs sizes but larger clutches than those subspecies found in the south.

The overall annual hatching success of Bermuda's terrapin eggs from 2009-2011 was 19%, despite the complete absence of nest and egg predators. A pilot study initiated in 2009 revealed a very low hatching success rate (18%). Of the eggs that did not hatch, 35 (70%) appeared to show no evidence of embryonic development and 6 (12%) contained dead embryos in various stages of development. The overall hatching success for 57 monitored nests (collectively containing 268 eggs) during the 2010 nesting season was 21%. A total of 61 hatchlings emerged, 165 eggs (61.6%) appeared to show no evidence of embryonic development, 33 (12.3%) contained dead embryos in various stages of development, and 9 (3.4%) contained fully formed dead hatchlings - many of which had managed to break through the shell, but all failed to successfully emerge from their nest chambers. Twenty six of the 57 nests (45.6%) produced at least one hatchling; however 31 nests (54.4%) did not produce any hatchlings (i.e. experienced total failure). In 2011, the overall hatching success for 69 monitored nests (collectively containing 356 eggs) was 17.6%. A total of 64 hatchlings emerged, 277 eggs (77.8%) appeared to show no evidence of embryonic development, 6 (1.7%) contained dead embryos, and 9 (2.5%) contained fully formed dead hatchlings. 30.4% of the monitored nests produced at least one hatchling; however 69.6% nests did not produce any hatchlings (i.e. experienced total failure) (Outerbridge, unpublished data).

Hatchling emergence was also studied to quantify the post-hatching nest residency periods. Emergence periods (defined as the time between hatching and full emergence from the nest) ranged from 1-219 days. Two distinct emergence patterns were documented; July-October (during which the mean emergence time was 31.4 days), and January-March (during which the mean emergence time was 188.1 days). No emergence was observed in November and December. A similar pattern was observed in 2011 and 2012.

The observed annual hatching rates in Bermuda are low in comparison to regions which experienced no mammalian depredation within the North American range; Feinburg and Burke (2003) reported 93% hatching success during the 1980s when raccoons were absent within the Jamaica Bay Wildlife Refuge and Roosenburg et al. (2003) reported a mean hatching success rate of 92.7% at a study site devoid of mammalian predators in Maryland. Nest depredation by small mammals has been identified as a significant source of egg mortality in North America (Burger, 1977; Feinberg and Burke, 2003) however, none of the Bermuda nests monitored in 2009, 2010 or 2011 experienced any nest depredation.

Nesting ecology in North America shows variability throughout the terrapin range. Females mature at ages of 4-13 years (Seigel, 1984; Lovich and Gibbons, 1990; Roosenburg, 1991a), with those in the northern parts of the range taking longer to reach sexual maturity than those in the southern range. Males mature at much younger ages of 2-7 years (Cagle, 1952; Seigel, 1984; Lovich and Gibbons, 1990; Lovich et al., 1991; Roosenburg, 1991a; Gibbons et al., 2001). The nesting season typically begins in late April and ends in late July for terrapins in Florida (Seigel, 1980b; Butler et al., 2004), while the nesting seasons in the extreme northern range are restricted to only June and July (Burger and Montevecchi, 1975; Lazell and Auger, 1981; Goodwin, 1994; Jeyasuria et al., 1994; Feinberg and Burke, 2003). In Louisiana, egg laying may occur as late as September (Burns and Williams, 1972).

Terrapins are reported to nest on sand dunes, beaches and along the sandy margins of marshes and islands (Burger and Montevecchi, 1975; Burger, 1977; Seigel, 1980b; Roosenburg, 1994). Sand is the preferred nesting medium as it allows for sufficient gas exchange to occur between the developing embryo and the environment (Roosenburg, 1994). Nest sites are generally flat (which facilitates the postures that females assume during digging and egg deposition) with low vegetative cover (which minimizes the destruction of the nests via mammalian and plant root predation.) Diurnal nesting appears to be the standard for most terrapin populations (Burger and Montevecchi, 1975; Seigel, 1980b; Goodwin, 1994), however nocturnal nesting has been documented in some populations (Auger and Giovannone, 1979; Roosenburg, 1992). Clutch size ranges from 4-22 eggs; northern subspecies have the greatest mean clutch sizes of approx. 16 in Rhode Island (Goodwin, 1994) and 13 in Maryland (Roosenburg and Dunham, 1997), while those in Florida have mean clutch sizes of approx. 7 (Seigel, 1980b; Butler, 2000). Estimated nesting densities range from 0.52/ha in Massachusetts (Auger and Giovannone, 1979) to 157.1/ha in New Jersey (Burger and Montevecchi, 1975), to 1125/ha in Maryland (Roosenburg, 1994).

Terrapins exhibit temperature-dependent sex determination (TSD) whereby the ambient temperature of the nest medium affects the gender of the developing embryos. The thermo-sensitive period (the most critical period for sexual development) has been identified as the middle third of the incubation period, and eggs that have been artificially incubated at constant temperatures between 24-27°C produced male hatchlings while those incubated at 30-32°C produced all females (Ewert and Nelson, 1991; Jeyasuria et al., 1994; Roosenburg and Kelley, 1996). The temperatures that produce mixed sex ratios in a nest are believed to be 28.5-29.5°C (Jeyasuria et al., 1994; Roosenburg and Place, 1994), however eggs that are incubated at constant temperatures of 35°C or higher fail to hatch entirely (Cunningham, 1939). TSD has been suggested as being a factor in biased sex ratios observed in some terrapin populations (Lovich and Gibbons, 1990; Ewert and Nelson, 1991). Incubation periods (the time it takes for eggs to develop and hatch) vary from 50-120 days; in New Jersey the mean incubation period was reported to be 76.2 days (Burger, 1977), while terrapins on the east Florida coast had a mean period of 65.6 days (Seigel, 1980c). Hatching occurs from early August through to mid-October in northern terrapin populations (Burger, 1977; Roosenburg, 1991b), and from early July to early October in some Florida populations (Butler et al., 2004). Emergence periods (the time hatchlings spend in the nest prior to leaving it) show tremendous variability throughout the range; hatchlings may depart hours after hatching (Roosenburg and

Kelley, 1996) or they may spend months over-wintering in the nest chamber and emerge the following spring (Lazell and Auger, 1981; Roosenburg and Kelley, 1996; Baker et al., 2006).

Figure 5. Map illustrating diamondback terrapin nesting activity encountered during the 2010 and 2011 surveys. Red dots represent nests with egg clutches; yellow dots represent nesting attempts. (A=Mangrove Lake, B=Trott's Pond, C=South Pond, D=North Pond).

Diet and feeding

Diamondback terrapins are carnivorous and selectively feed upon a variety of marine mollusks and crustaceans (namely periwinkles, crabs, mussels and clams) within the salt marsh and mangrove ecosystems throughout their North American range (see reviews in (Butler et al., 2006; Ernst and Lovich, 2009). They also show resource partioning whereby individuals with wider heads (the largest females) consume larger snails and crabs than those terrapins that possess smaller heads (Tucker et al., 1995). Terrapins have been identified as an important component of the trophic dynamics of the salt marsh ecosystem (Silliman and Bertness, 2002; Davenport, 2011).

The foraging ecology of Bermuda's terrapins was examined using a variety of methods (direct observation, necropsy and faecal analyses). Faecal analyses, and to a limited extent necropsies, revealed that Bermuda's terrapins are consuming a wide variety of marine and terrestrial food items, but show preference towards pond gastropods. The frequency of occurrence of each food item is as follows; aquatic gastropods (*Heleobops bermudensis, Melanoides tuberculata, Melampus coffeus*) occurred in 66.7% of the faecal samples, while plant material (primarily mowed grass but also saw-grass seeds *Cladium jamaicense*) occurred in 33.3% of the samples. Terrestrial arthropods (e.g. bees, beetles, isopods, millipedes, caterpillars, ants) occurred in 14.3%, fish bones and fish scales occurred in 11.9%, and cane toad bones (*Rhinella* (formerly *Bufo*) *marinus*) occurred in 4.8%. Reptile bones (*Malaclemys terrapin*), bivalves (*Isognomon alatus*) and polychaete worms (*Arenicola cristata*) occurred in 2.4% of the faecal samples respectively. Additionally, 73.8% of the terrapins in this study excreted sediment, supporting the observation that many terrapins are ingesting the sediment found on the bottom of the ponds (Outerbridge, unpublished data.) Some of the plant material (especially the mowed grass) may have been ingested inadvertently while grazing upon invertebrates and the animal prey is believed to have been consumed as carrion. Carrion eating has been reported in a New Jersey population of terrapins (Ehret and Werner, 2004). The sediment consumption is also believed to be inadvertent since the targeted food items, *M. tuberculata* and *H. bermudensis*, are benthic gastropods that inhabit areas rich in detritus and silt (Dundee and Paine, 1977; Roessler et al., 1977). The occurrence of terrestrial arthropods is believed to be from terrapins encountering and ingesting arthropods that have fallen into the ponds rather than as a result of terrapins actively foraging within the terrestrial environment.

Habitat usage

Adult and sub-adult terrapins in Bermuda appear to spend most of the time within the aquatic environment; however their abundance varies seasonally. Monthly head count surveys were conducted at South Pond (following the methods described in Butler, 2002) for a 5 minute period each visit. The results show that the number of observed terrapins dropped during the winter months (Fig. II in Appendix). Brumation occurs within the benthic sediment of Mangrove Lake and under the embankment of South Pond (Outerbridge unpublished data). Direct observation and the results from the mark-recapture surveys indicate that Bermuda's terrapins move freely between the various ponds, traversing overland.

Radio-telemetry was used in August 2010 and April 2011 to investigate the survival rate, post hatching movement and habitat usage of hatchling diamondback terrapins in Bermuda. Ten transmitters (BD-2 model from Holohil Systems Ltd.) were attached to the carapaces of ten newly emerged hatchlings in both years following the method described by Draud et al (2004). The hatchlings were released in sand bunkers on the 5th and 7th holes and tracked on a daily basis for a 4-5 week period. The results from the August 2010 session revealed that upon release all of the hatchlings moved immediately to the edge of the bunkers and either buried into the sand or crawled under the grass growing at the edge of the bunkers. Eight of the ten hatchlings remained concealed in these locations throughout the survey period; however two made major moves over the open fairways into the mangrove and saw-grass marshes bordering the ponds. The results from the April 2011 tracking session, in contrast, revealed that virtually all of the hatchlings quickly moved away from the sand bunkers and headed towards the mangrove trees and marsh grasses. These areas appear to be critical for the development of Bermuda's hatchling and juvenile terrapins. The high level of spring-time activity, however, also makes hatchlings vulnerable to avian predation, especially by yellow crowned night herons, *Nyctanassa violacea*.

Young terrapins in the U.S.A. have been reported to seek refuge within dense mats of vegetation and debris above mean high water levels in salt marshes and tidal mudflats (Pilter, 1985; Lovich et al., 1991; Roosenburg, 1991a).

F. Current threats

Diamondback terrapins have been listed as a globally near threatened species by the International Union for the Conservation of Natural Resources (IUCN). Their status, which varies from US state to state, ranges from 'endangered' to 'a species of special concern' (Hart and Lee, 2006; Lee and Chew, 2008). Massive over-harvesting for food consumption in the late 19th and early 20th centuries led to huge declines in the North American populations, which continue to be affected by habitat loss, predation, crab trapping activities and commercial harvest for pet trade and human consumption (Roosenburg et al., 1997; Hart and Lee, 2006; Ernst and Lovich, 2009). The incidental capture and drowning of terrapins in commercial and recreational traps designed to catch blue crabs along the Atlantic and Gulf coasts continues to threaten some terrapin populations (Roosenburg, 1992; Hoyle and Gibbons, 2000), and has prompted some states to require the use of by-catch reduction devices (BRDs) on crab traps in order to minimize terrapin by-catch (Wood, 1997; Hart and Lee, 2006). Road associated mortality of nesting females has also been identified as a significant threat in some terrapin populations (Wood and Herlands, 1997). Diamondback terrapins are presently not harvested for food in Bermuda, nor are they caught as by-catch in commercial or recreational crab traps; however they are threatened with habitat fragmentation, pollution, predation, and to a limited extent, motorized vehicles and human collection.

<u>Lack of suitable habitat</u>

Perhaps the greatest constraint to increasing the range of Bermuda's terrapin population is a lack of suitable wetland habitat. Human activities have caused nearly all of Bermuda's wetlands to fragment and decline through deleterious habitat modification. Since the island's colonization humans have filled, dredged, drained, denuded, and polluted the ponds, marshes, and mangrove swamps in an effort to create more arable land, residential and commercial building sites, as well as waste disposal sites. During the period of marsh reclamation by garbage disposal (1920-1970), five ponds totaling 1.6 hectares were completely filled in. Widespread drainage of marshes was employed as part of the mosquito control methods in the first half of the 20th century as health officials attempted to prevent the spread of malaria. Records indicate that in the 17th century approximately 127.5 hectares of fresh water ponds, marshes and swamps existed, representing 2.4% of the total land area of Bermuda. It has been estimated that during the 1970's 100 tons of garbage was dumped daily into the Pembroke parish marsh complex (Sterrer and Wingate, 1981). By 1980 Bermuda's total fresh water wetland area had been reduced by 65% to only 58.9 hectares (Thomas, 2004). It has been suggested that the most concentrated destruction of Bermuda's wetland communities occurred between 1941 and 1943 when 32% of the island's total mangrove acreage was destroyed on Longbird and St. David's Islands by the construction of the American-operated Kindley Air Force Base (Sterrer and Wingate, 1981). Historical writings about Bermuda's natural history fail to mention diamondback terrapins as part of the herpetological fauna (Jones, 1859; Jones and Goode, 1884; Agassiz, 1895; Hurdis, 1897; Verrill, 1902, 1903; Verrill et al., 1903), thus preventing an estimate of the former population size and also making the former distribution of the Bermuda population unclear.

A lack of suitable nesting habitat has also been identified as a current constraint to the long term growth of the population. Presently there are a few high-density nesting areas on the 5th, 6th and 7th holes of the Mid Ocean golf course that are frequented by avian predators (most notably the yellow crowned night heron *Nyctanassa violacea*) and offer little in the way of shading to the incubating eggs. Roosenburg and Place (1994) suggested that preserving only high-density nesting areas which favour the production of one gender over the other may not adequately maintain a viable terrapin population. Instead the authors recommended that a wide variety of nesting micro-habitats is necessary to maintain balanced sex ratios.

Pollution

Pollution is considered to be a relatively new threat to diamondback terrapins. Recent investigations into the health status of the pond environment in Bermuda suggest that there is a suite of contaminants of concern that are having detrimental effects on the resident fauna (Fort et al., 2006a; Fort et al., 2006b; Bacon, 2010; Bacon et al., 2012). These contaminants include petroleum hydrocarbons - namely gasoline-range organics (TPH-GRO) and diesel-range organics (TPH-DRO), polycyclic aromatic hydrocarbons (PAH) and heavy metals. Entry into the wetlands comes through storm-water run-off from adjacent roadways, aerial deposition and leachate from nearby landfills and ground-water sources. Ponds located within and adjacent to golf courses are among the most toxic wetlands in Bermuda (J. Bacon personal communication). Water and sediment from three of the four diamondback ponds (Trott's Pond, Mangrove Lake, and South Pond) were collected and analyzed in 2009 by Fort Environmental Laboratories. Results showed that all three ponds had highly contaminated sediment (Bacon and Fort, 2010). Tissue residue analyses from cane toads (*Rhinella marinus*), mosquitofish *Gambusia holbrooki*, killifish *Fundulus* spp., and red-eared sliders *Trachemys scripta elegans* collected from a variety of contaminated wetlands across Bermuda have showed that petroleum hydrocarbons, polycyclic aromatic hydrocarbons and heavy metals are being accumulated and inducing developmental malformations, endocrine disruption, liver and gonad abnormalities, and immunological stress (Bacon, 2010; Bacon et al., 2012). Diamondback terrapins are known molluscivores throughout their North American range (Tucker et al., 1995), and investigations into the feeding ecology of Bermuda's diamondback terrapins have shown that they are also consuming small gastropods, which are known bio-accumulators of toxic compounds along with large quantities of benthic sediment (Outerbridge, unpublished data). Terrapins in the U.S.A. accumulate heavy metals in liver and muscle tissue (Burger, 2002), accumulate PAHs in eggs (Holliday et al., 2008), and have been used as bio-indicators of environmental contaminants in salt marsh ecosystems (Blanvillain et al., 2007; Basile et al., 2011), however the long-term effects of such exposure are unknown. Evidence indicates that total petroleum hydrocarbons (particularly the diesel-range organics) as well as polycyclic aromatic hydrocarbons (most notably fluorene, pyrene, chrysene and benzo(a)anthracene) and heavy metals (including lead, cadmium, zinc and mercury) are being accumulated by aquatic gastropods and diamondback terrapins in Bermuda (Outerbridge unpublished data).

Predation

Terrapin nests and hatchlings are preyed upon by a wide variety of predators throughout the North American range. Predators include small mammals (raccoons, skunks, foxes, rats) and birds (gulls, crows, herons), as well as ghost crabs, ants, and plant roots (most notably dune grass) (see review in Ernst and Lovich, 2009). Adult terrapins (particularly nesting females) are also occasionally preyed upon by raccoons (Seigel, 1980a; Feinberg and Burke, 2003). Draud et al (2004) reported that the Norway rat *Rattus norvegicus* was a major predator on hatchlings and juveniles (25-41 mm SCL) in a New York population, but perhaps the greatest terrapin predator is the raccoon which has been responsible for destroying 87-99% of nests in various regions in North America (Roosenburg, 1992; Feinberg and Burke, 2003; Butler et al., 2004).

Yellow crowned night herons have been identified as a significant predator to hatchling and juvenile terrapins in Bermuda. This species was observed preying upon ten neonate terrapins among the emergent pond vegetation in South Pond over a 4-week period between 8:00 and 18:00 hrs in the spring of 2010. Subsequent radio-telemetry investigations suggested that yellow crowned night herons may be responsible for at least 40%, and possibly up to 70%, of the mortality of hatchlings within one month of emerging from hibernacula. Furthermore, this species of heron may remain a predator to neonate terrapins for three years following hatching (Outerbridge, unpublished data).

Motorized vehicles

Observations made between 2009 and 2012 indicated that hatchling terrapins are occasionally run over by motorized vehicles (golf carts, law mowers, trucks, etc.) operating on the Mid Ocean golf course. This source of mortality is thought to be low, but each year during the survey period at least one hatchling was discovered crushed upon the cart paths between Mangrove Lake and South Pond. It is believed that they are accidentally killed by motorists unaware of their presence on the road as they wander in search of the wetland vegetation that borders the ponds. Road mortality has been identified as a major source of death among adult female terrapins in parts of their North American range. Adult females are killed every nesting season as they search for alternative nesting sites on highway embankments along the Atlantic coast of New Jersey. During a seven year period, over 4,000 terrapins were discovered as road kill during routine patrols at one study site (Wood and Herlands, 1997).

Human collection

Anecdotal evidence suggests that some diamondback terrapins in Bermuda have been removed from ponds as pets. The total number of terrapins currently kept in captivity by members of the general public is unknown. This activity is of concern as it removes valuable individuals from the local breeding population.

Commercial interest in diamondback terrapins remains high in the U.S.A. This interest is largely driven by the pet trade industry, and most specimens are exported to Asian markets where hatchlings can sell for US$ 50-100 (Anonymous, 2013).

G. Current conservation action

Artificial incubation of terrapin eggs collected from the wild was first attempted at the Bermuda Aquarium Museum and Zoo in 1994. The hatching success was very limited (only four eggs produced hatchlings out of 18 eggs collected from three different clutches) and three of the individuals (one died) were subsequently kept on display at BAMZ for a number of years (R. Marirea *pers. comm.*) Egg incubation was re-attempted in 2012 during which 74 eggs were collected from 10 nests located in the sand bunkers between the 5th and 7th holes on the Mid Ocean golf course. Thirty three eggs (44.6%) developed into hatchlings, of which 29 were subsequently released into the wild (four hatchlings died in captivity shortly after hatching).

Raising awareness about the vulnerable status of this fragile oceanic population is on-going, with organized public and private lectures occurring throughout the calendar year. Bermuda's terrapins have featured in several local newspaper articles, in local and international magazines as well as on a local television documentary. A representative from Bermuda has been actively participating in the triennial Diamondback Terrapin Working Group symposia since 2007 and maintains open dialogue with the south-eastern regional group (to which Bermuda is a member).

PART II: RECOVERY

A. Recovery goal

The principal aim of this Recovery Plan is to increase both the population level and the areas of residency for diamondback terrapins in Bermuda. The short term goal (5 years) is to continue to research the biology and ecology of Bermuda's diamondback terrapins, as well as assess the suitability of appropriate habitats and ensure their protection, in order to promote effective management. The long term goal (30 years) is to increase the population levels and range of Bermuda's terrapins, enhancing natural recruitment and restoring wetland habitats.

B. Recovery objectives and criteria

Favorable conservation status will be achieved when:

- The genetic diversity of Bermuda's extant population is fully understood.
- All current and potential habitats suitable for diamondback terrapin growth, reproduction and survival are identified, assessed, restored and protected under legislation.
- Diamondback terrapins are viable residents in at least three separate geographic locations throughout Bermuda.
- Population levels in Bermuda indicate that terrapins are successfully maintaining themselves on a long-term basis and showing adequate levels of recruitment.

These overall objectives translate into specific targets outlined below:

<u>Short-term target (5 years):</u> To ensure that by 2018 all studies necessary for development of effective management will be complete, and that both species and habitat will be protected under legislation. Habitats will be identified as "Critical Habitat" and designated as such under law, should they be considered crucial to the recovery of the species. This short-term goal includes examining the impact that environmental pollution has upon terrapin health and additional investigations to determine sources of threats to their survival. During this time, the identification and assessment of "health" status of current and potential habitats will be conducted.

<u>Long-term target (30 years):</u> Following the habitat assessments, restoration of habitats deemed suitable for diamondback terrapins will lead to the potential to increase both the area of occupancy and population within each pond. Artificial egg incubation and head-starting of hatchlings may be needed to achieve this long-term goal. Monitoring of efforts will be necessary to evaluate survival and growth of newly established populations, and determine their self-sustainability.

C. Recovery strategy

The species addressed in this recovery plan are currently restricted in both population size (approx. 100 individuals ≥81 mm SCL) and range (total area of residency is less than 1 km^2). Bermuda's wetlands are easily impacted upon by physical disturbances (e.g. development), chemical processes (e.g. fertilizer, pesticide, herbicide and road run-off from surrounding lands) and ecological processes (e.g. encroachment of invasive species). In the case of the ponds on the Mid Ocean golf course, these activities are primarily via course maintenance which results in disturbance and fragmentation of the various habitats required during each stage of the life cycle (e.g. nesting and juvenile developmental habitats.) The strategy for recovery revolves around the protection of wetland habitats, the assessment of their "health" status, namely sediment and water quality, their remediation in some cases, and in the active intervention required for increasing the species distribution to a greater range. The selection of ponds for translocation is critical as habitat quality appears poor in several areas, based on previous sediment analyses and toxicological examination of red-eared sliders (J. Bacon, *pers. comm*.). This further drives the need for habitat protection of "healthier" ponds, controlling as much as possible input from external sources. It is believed that contaminants appear to be entering some of the ponds through groundwater, atmospheric deposition and/or road run-off (Bacon et al., 2013). Predator control should be seasonally employed in order to reduce hatchling mortality and increase recruitment to the existing population, stock enhancement via artificial egg incubation and captive rearing of hatchlings should be considered as a tool for the establishment of populations in sites considered adequate, and success for growth and survival of the species further ensured via legislated habitat protection.

D. Tools available for strategy

One tool is to seek collaboration with partner institutions that already have experience in successful research and conservation activities. In 2011 Bermuda, through a regional representative (MO), became a life-time member of the Diamondback Terrapin Working Group, which is a body of people and organizations committed to research, conservation management and education efforts that benefit terrapin populations and their associated ecosystems. Terrapins are an ideal species for captive rearing as demonstrated by the Wetlands Institute in New Jersey which has a 20 year history of successfully incubating eggs and head-starting young diamondback terrapins (Wood and Herlands, 1997; Herlands et al., 2004). Additionally, there is information available on the levels of contaminants, such as heavy metals, pesticides, pharmaceuticals, total petroleum hydrocarbons (TPHs) and polycyclic aromatic hydrocarbons (PAHs) for some of Bermuda's ponds, including South Pond, Trott's Pond and Mangrove Lake. Sediment analyses and red-eared slider tissue analyses have been conducted, providing data on suitability of selected ponds and the health of their resident sliders. Necropsies on sliders from a number of ponds have also indicated abnormalities in reproductive tissue and should be taken into consideration when planning future translocation programmes. All of this data is documented by Drs Jamie Bacon (Bermuda Zoological Society) and Douglas Fort (Fort Environmental Laboratories Inc.)

E. Step-down narrative of work plan

Abbreviations used in sections E and F:
DCS – Department of Conservation Services
DPW – Department of Public Works
Parks – Department of Parks
Planning – Department of Planning
DEH - Department of Environmental Health
AG - Attorney General's Chambers
MOC – Mid Ocean Club
BZS – Bermuda Zoological Society
BNT – Bermuda National Trust
BAMZ – Bermuda Aquarium Museum and Zoo
USGS – United States Geological Survey
FEL – Fort Environmental Laboratories

The actions needed to achieve recovery are as follows:

1. Protect wetland habitats of extant terrapin population through legislation,
2. Restore protected wetland habitats of current extant population,
3. Identify, assess, protect and restore wetland habitats deemed suitable for diamondback terrapin introduction,
4. Increase population size through increased hatching success and recruitment to the adult population,
5. Expand area of residency through translocation of individuals raised in captivity,
6. Identify the full genetic composition of existing population,
7. Develop research programmes on understanding the effects that environmental contaminants have upon the reproductive biology and overall health of terrapins in Bermuda,
8. Promote conservation education programmes concerning Bermuda's terrapin population,
9. Continued population monitoring.

1. Protect wetland habitats of extant terrapin population through legislation.

   Actions proposed:
   - Designation of Mangrove Lake, South Pond, North Pond, and Trott's Pond as "critical habitat" for Bermuda's diamondback terrapins.

   Work team: DCS
   Team leader: DCS
   Assistance: AG
   Outputs: Legislation for habitat protection

   List of equipment required: GPS for boundary delineation, GIS mapping applications.

2. Restore protected wetland habitats of current extant population.

   Actions proposed:
   - Diversify and increase the area of nesting habitat,
   - Increase the area required for neonate and juvenile development (including the establishment of terrapin corridors between nest sites and wetlands),
   - Produce habitat management and landscaping guidelines for land owners bordering the ponds,
   - Create buffer zones between road drains and ponds,
   - Initiate remediation of select ponds where appropriate (e.g. use of diatomaceous earth to bind pollutants in sediment, cyclically plant and remove vegetation known to absorb pollutants and increase the activity of indigenous bacteria that are capable of metabolizing pollutants),
   - Monitor sediment and water quality in South Pond, North Pond, Mangrove Lake and Trott's Pond.

   Work team: DCS, MOC, DPW and collaborative institution for sample analyses
   Team leader: DCS
   Assistance: BZS, BNT and private land owners
   Outputs: Creation of a more terrapin-friendly environment that promotes long-term population stability.

   List of equipment required: Beach sand for creation of nesting habitat, funding required for laboratory analyses of sediment and water samples.

3. Identify, assess, protect and restore wetland habitats deemed suitable for diamondback terrapin introduction.

   Actions proposed:
   - Survey all of Bermuda's wetlands for suitable expansion habitats,
   - Designate identified wetlands as "critical habitat" for diamondback terrapins,
   - Produce habitat management guidelines for terrapins,
   - Remove red-eared sliders from wetlands identified as suitable for terrapin introduction,
   - Initiate remediation of select ponds where appropriate (e.g. use of diatomaceous earth to bind pollutants in sediment, cyclically plant and remove vegetation known to absorb pollutants and increase the activity of indigenous bacteria that are capable of metabolizing pollutants).

   Work team: DCS, Parks, DPW, Planning and AG
   Team leader: DCS
   Assistance: BNT, DEH and private land owners
   Outputs: Creation of a greater diversity of terrapin-friendly wetlands that promotes long-term population stability.

   List of equipment required: Boat, traps and bait for the capture of feral red-eared sliders.

4. Increase population size through increased hatching success and recruitment to the adult population.

   Actions proposed:
   - Reduce and control predators (e.g. yellow-crowned night herons and rats), especially during periods of hatchling emerge, in areas where hatchlings and small juvenile terrapins reside,
   - Increase ground cover between nest sites and wetlands by establishing terrapin corridors using natural vegetation,
   - Relocate terrapin nests from areas subjected to frequent disturbance (i.e. sand bunkers on golf course) to areas subjected to less disturbance,
   - Initiate an artificial egg incubation and head-starting programme.

   Work team: DCS, MOC
   Team leader: DCS
   Assistance: BZS, members of the public
   Outputs: Enhancing population size of natural stocks and engaging community in preservation of threatened native species.

   List of equipment required: Egg incubator, head-starting tanks, rat poison.

5. Expand area of residency through translocation of individuals raised in captivity.

   Actions proposed:
   - Assess requirements for most favorable transfers of captive raised individuals to suitable wetlands,
   - Introduce juvenile terrapins into suitable wetlands in equal sex ratio,
   - Monitor populations via a mark-recapture programme.

   Work team: DCS
   Team leader: DCS
   Assistance: Members of the public
   Outputs: Assessment of terrapin populations following translocation, increasing range of occupancy and optimizing survival of the species, data on terrapin requirements for optimal growth and survival.

   List of equipment required: Boat, traps and bait for capture of diamondback terrapins.

6. Identify the full genetic composition of existing population.

Actions proposed:
- Continued collection of tissue samples,
- Analysis of collected samples

Work team: DCS and USGS
Team leader: DCS
Assistance: Dr. Kristen Hart (USGS)
Outputs: Determination of genetic diversity of extant population in Bermuda and a population level genetic scientific publication.

List of equipment required: Boat, traps and bait for capture of diamondback terrapins and funding required for laboratory fees.

7. Develop research programmes on understanding the effects that environmental contaminants have upon the reproductive biology and overall health of terrapins in Bermuda.

   Actions proposed:
   - Collect terrapin blood samples for hormone and heavy metal analyses,
   - Monitor red-eared sliders at select locations via necropsy and tissue analyses for metals, total petroleum hydrocarbons (TPHs) and polycyclic aromatic hydrocarbons (PAHs).

Work team: DCS and collaborative institution for necropsies, tissue and blood sample analyses (FEL)
Team leader: DCS
Assistance: Graduate student for research studies
Outputs: Determination of eco-toxicological effects on terrapins in Bermuda and a scientific publication.

List of equipment required: Boat, traps and bait for capture of sliders and terrapins, funding required for laboratory fees.

8. Promote conservation education programmes concerning Bermuda's terrapin population.

   Actions proposed:
   - Create and post cautionary and interpretive signage at relevant locations on the Mid Ocean golf course that explains the natural history of terrapins as well as the threats facing the species (e.g. turtle crossing signs at locations on the cart paths adjacent to Mangrove Lake and South Pond),
   - Perform periodic presentations to public on the ecology and conservation of Bermuda's terrapin population,
   - Publish scientific papers based upon research findings in addition to annual management plan progress reports.

   Work team: DCS, MOC
   Team leader: DCS
   Assistance: BZS
   Outputs: Engaging community in preservation of native terrapins.

   List of equipment required: Text and image materials for signage

9. Continued population monitoring.

   Actions proposed:
   - Monitor all terrapin populations via a mark-recapture programme.

   Work team: DCS
   Team leader: DCS
   Assistance: Volunteer interns
   Outputs: Comprehensive assessment of existing and re-established populations.

   List of equipment required: Materials for population surveys (boat, traps, bait, calipers, spring scales.)

F. Estimated date of down listing

It is anticipated that it will take at least five years to identify and restore key habitats for Bermuda's terrapins, and one year to complete the first head-starting and translocation initiative. Diamondback terrapins are a slow growing, long-lived species therefore programmes developed to aide in their recovery need to recognize that there may be long delays before favorable responses can be detected. It is only once implemented actions are evaluated that down listing (or removal) of this species will be considered, following assessments of population distribution and habitat quality monitoring. Re-assessment of this species should be done every ten years.

PART III: IMPLEMENTATION

<u>Priority 1</u>: An action that must be taken to prevent extinction or to prevent the species from declining irreversibly.
<u>Priority 2</u>: An action that must be taken to prevent a significant decline in the species population/habitat quality, or some other significant negative impact short of extinction.
<u>Priority 3</u>: All other action necessary to provide for full recovery of the species.

Priority #	Task #	Task description	Task Duration	Responsible Party
1		**Protection of wetland habitats of extant population**		
	1	Designation of current sites as 'critical habitat'	12 months	DCS, AG
1		**Restoration of wetland habitats of extant population**		
	2	Diversify and increase the area of nesting habitat	3 months	DCS, MOC
	3	Increase the area required for hatchling and juvenile development	24 months	DCS, MOC
	4	Produce habitat management guidelines	3 months	DCS
	5	Create buffer zones between road drains and ponds	12 months	DPW
	6	Initiate remediation of select ponds where appropriate	24 months	DCS
	7	Monitor sediment and water quality	indefinite	DCS
2		**Identification and assessment of additional wetland habitats for translocation**		
	1	Survey for suitable expansion habitats	100 man hours	DCS
	2	Designate identified wetlands as 'critical habitat'	12 months	DCS, AG
	3	Produce habitat management guidelines	3 months	DCS
	4	Remove red-eared sliders	indefinite	DCS
	5	Initiate remediation of select ponds where appropriate	24 months	DCS, DPW
2		**Enhance population numbers**		
	6	Control predators	indefinite	DCS, MOC
	7	Increase ground cover between nest sites and wetlands	12 months	MOC
	8	Relocate terrapin nests	indefinite	DCS

	9	Initiate an artificial egg incubation and head-starting programme	12 months	DCS, BAMZ
2		**Expand area of occupancy through translocations**		
	10	Assess requirements for successful transfers	6 months	DCS
	11	Introduce captive raised juvenile terrapins	1 month	DCS, BAMZ
	12	Monitor populations	indefinite	DCS
3		**Research genetic composition**		
	1	Collection of tissue samples	12 months	DCS
	2	Analyses of collected samples	6 months	DCS, USGS
3		**Research into effects of contaminants**		
	3	Collect terrapin blood samples	12 months	DCS
	4	Monitor red-eared sliders at select locations	indefinite	DCS, FEL
3		**Promote conservation education**		
	5	Create and post cautionary and interpretive signage	3 months	DCS, MOC
	6	Continue public presentations	indefinite	DCS
	7	Publish scientific papers and annual reports	indefinite	DCS
3		**Continued population monitoring**		
	8	Monitor all terrapin populations	indefinite	DCS

APPENDIX

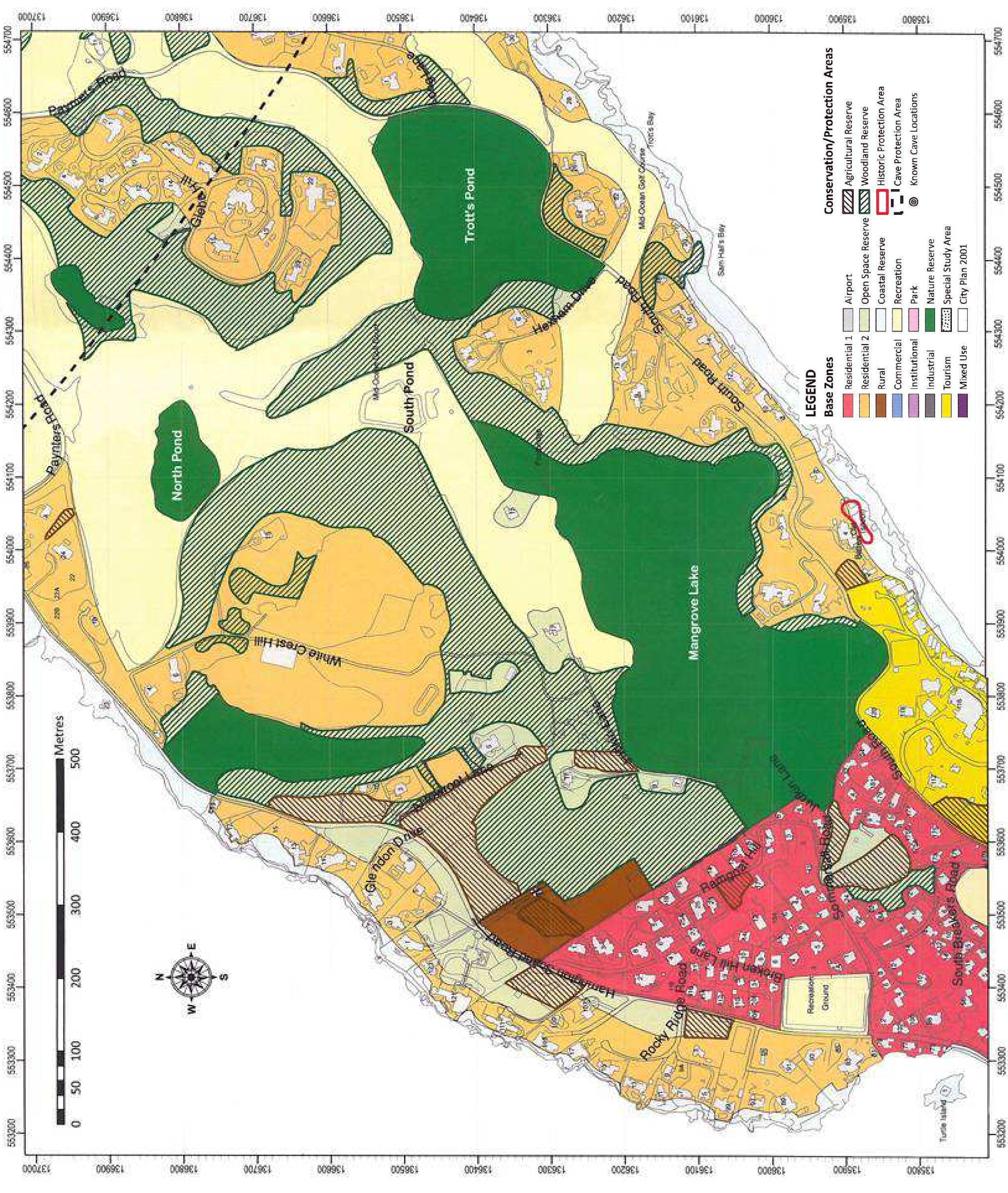

Figure I. Development base zones for the area inhabited by Bermuda's population of diamondback terrapins (adapted from the 2008 Bermuda Plan)

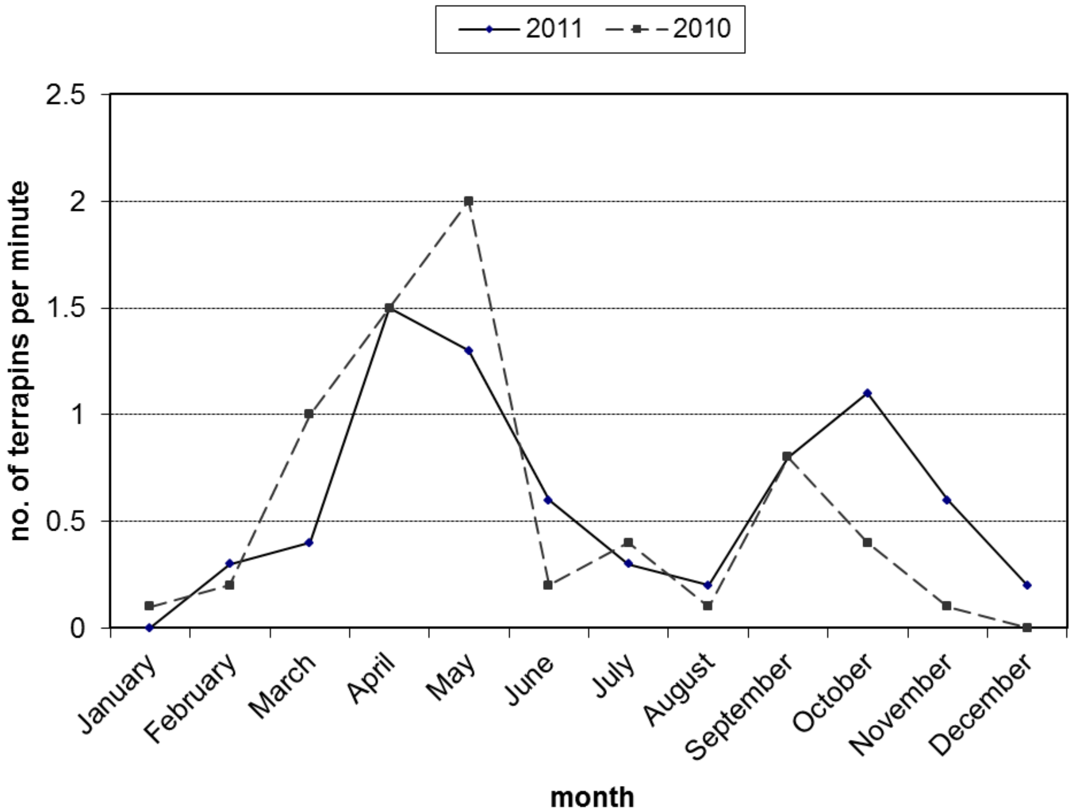

Figure II. Diamondback terrapin head count surveys in 2010 and 2011 at South Pond.

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