

Status and conservation of the reptiles and amphibians of the Bermuda islands

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Abstract. Bermuda's herpetofauna includes three species of amphibians, one fossil tortoise, two species of freshwater turtles, five species of marine turtles, and four species of lizards. The amphibians *Eleutherodactylus johnstonei*, *E. gossei* and *Bufo marinus* were all introduced in the late 1880s. Amphibian population declines, including the possible extirpation of *E. gossei*, prompted the initiation in 1995 of an on-going investigation. Research into the high deformity rates in *B. marinus* has indicated that survival and development of larvae are affected by contaminants in a number of ponds and by the transgenerational transfer of accumulated contaminants. Of the two emydid turtles in Bermuda, *Malaclemys terrapin* may be native and its population characteristics are being studied; *Trachemys scripta elegans* is considered invasive and efforts are underway to remove its populations from the wild. The sizeable resident *Chelonia mydas* population has been the focus of a mark-recapture study since 1968. Results indicate that Bermuda is currently an important developmental habitat for green turtles originating from at least four different nesting beaches in the Caribbean. Immature *Eretmochelys imbricata* also reside on the Bermuda Platform and genetics studies suggest that multiple Caribbean genotypes are represented in Bermuda's hawksbill population. *Caretta caretta* do not appear to be regular inhabitants, but two known loggerhead nesting events have recently occurred (in 1990 and 2005) and post-hatchling loggerheads regularly strand after winter storms. *Dermochelys coriacea* are only occasionally seen and the last record for a live *Lepidochelys kempii* in Bermuda occurred in 1949. Three of the lizard species are introduced *Anolis*; *A. grahami grahami*, *A. leachii*, and *A. extremus*. Their populations appear stable and they are presently not being studied. The fourth lizard, the Bermuda skink *Eumeces longirostris*, is Bermuda's only endemic terrestrial vertebrate. It is classified as Critically Endangered on the IUCN Red List and is protected under the Protected Species Act (2003); much research has been undertaken recently to aid the development of effective conservation management plans for this species.

Key words: Bermuda; *Bufo marinus*; *Caretta caretta*; *Chelonia mydas*; chemical stressors; deformities; *Eleutherodactylus gossei*; *Eretmochelys imbricata*; *Eumeces longirostris*; *Malaclemys terrapin*.

Introduction

Bermuda is an isolated 5,560 ha chain of limestone islands on a 150,000 ha seamount located near 32°N and 64°W in the western North Atlantic. Situated some 960 km ESE of Cape Hatteras, North Carolina, Bermuda consists of a crescent-shaped chain of more than 360 low-lying islands that are closely linked. A shallow shelf consisting of coral reefs, shallow lagoons and seagrass meadows surrounds the islands and makes up the Bermuda Platform (fig. 1).

The Bermuda islands are positioned within the north-western sector of the Sargasso Sea, a vast area of weak and inconsistent currents whose surface is dotted with mats of Sargassum algae. The Sargasso Sea offers a unique refuge to a host of open ocean species, including sea turtles. Driven by the Gulf Stream Current from the northwest and the Canaries Counter Current from the southeast, the Sargasso Sea turns slowly clockwise. The Gulf Stream passes Bermuda to the west with great influence as eddies and gyres reach Bermuda's shores and deliver warm water along with elements of the fauna and flora from the Caribbean and the east coast of North America.

While ocean surface temperatures range from 18°C in January to 28°C in August, the water mass surrounding Bermuda between the depths of 200 and 500 m is consistently about 18°C. Inshore temperatures may vary from 15°C to 30°C. Rainfall is not highly seasonal with a mean actual accumulation of approximately 150 cm being distributed throughout the year. October is the wettest month with an average of 16 cm, and April the driest at 10 cm. Temperatures show marked seasonality with mean monthly air temperatures ranging from 18.5°C in February to 29.6°C in August.

Seven of Bermuda's largest islands are connected by bridges and comprise what is considered to be 'mainland Bermuda'. The available land area (4,650 ha) is divided into nine parishes (fig. 1). Bermuda's topography is dominated by low rolling hills of poorly fused limestone and fertile depressions.

A number of ponds are scattered throughout Bermuda, but the majority are either fully marine or brackish and many are man-made. The island's few freshwater wetlands, estimated at 127 ha in the early 1600s, totaled only 58 ha in 1980 due to drainage for agriculture or mosquito control and through being used as landfill sites for waste disposal (Thomas, 2004). Presently, these freshwater habitats (some of which temporarily turn slightly brackish in the summer or fall) include one swamp forest, two marshes, two natural ponds and eight excavated ponds, some of which are located in former landfill sites. Additionally, there are a number of lined golf course ponds which provide fresh water habitats for terrapins and toads.

Currently, more than 50% of Bermuda's land area is used for housing and over 75% of Bermuda is considered developed (Thomas, 2004). With a population of over 61,000 and a population density of 1,145 people per km², Bermuda is one of the most densely populated oceanic islands in the world (Anderson et al., 2001). As a result, Bermuda's natural environment is at risk from chemical contamination caused by a variety of sources including illegal dumping, emissions from vehicles,

Islands of Bermuda and Surrounding Reef Platform

Bermuda Parishes

1. Town of St. Georges
2. St. Georges
3. Hamilton
4. Smith's
5. Devonshire
6. Pembroke
7. City of Hamilton
8. Paget
9. Warwick
10. Southampton
11. Sandys

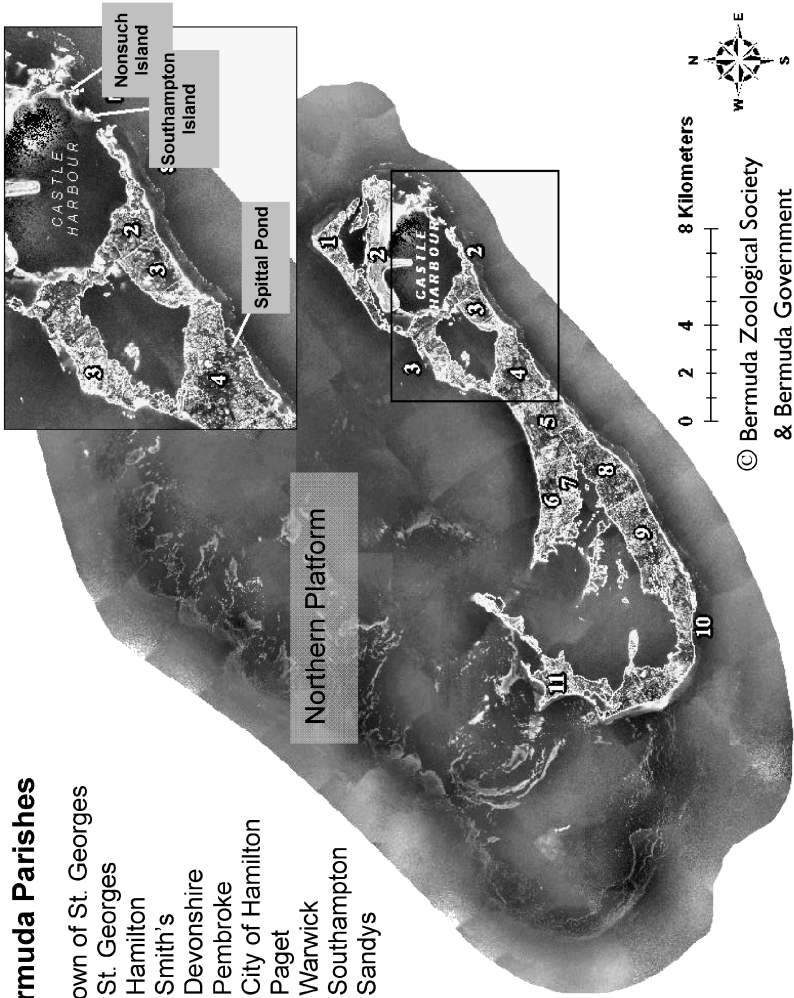


Figure 1. Map of Bermuda showing parishes, northern reef platform and key islands.

Bermuda's incinerator and electrical power plant, run-off from roadways and agricultural fields, and the leaching of contaminants from landfills, cesspits and deep-sealed bore holes.

The Amphibians

There are no native species of amphibians in Bermuda and this has been attributed to the archipelago's extreme isolation, recent geological origin and small size (Wingate, 1965). However, three species of West Indian anurans, all introduced in the late 1800s, did successfully become established on Bermuda's larger islands. These consist of the cane toad, *Bufo marinus*, and two species of whistling frogs, *Eleutherodactylus johnstonei* and *E. gossei* (table 1). As all three species were introduced to the island and their populations are not threatened globally, Bermuda's amphibian species are not protected under local conservation legislation.

B. marinus was deliberately introduced to Devonshire parish in 1885 in an effort to control garden insects (Wingate, 1965). In 1917, it was reported that *B. marinus* initially underwent a population 'explosion' which was followed by a decline to a stable level (Pope, 1917). When their status was reexamined by Wingate between 1956 and 1963, it was found that cane toads were 'common and universally distributed' on all of Bermuda's large inhabited islands (Wingate, 1965). Although the cane toad is recognized as a potentially damaging invasive species, there is currently no evidence to indicate that its presence poses an ecological threat in Bermuda.

The exact date of *E. johnstonei*'s introduction is unknown, but it was reported that they existed in very small numbers in Pembroke parish before 1880, when a pair from the Lesser Antilles was deliberately introduced in the same parish (Wingate, 1965). Based on the known range of *E. johnstonei* before 1880, it was hypothesized that the original population also arrived from the Lesser Antilles. By 1916, *E. johnstonei*'s range had expanded eastward through Hamilton parish and westward into Paget parish (Wingate, 1965). Its range continued to expand in subsequent years such that by 1963, it was considered very abundant on all the major islands excepting St. David's and even existed on some of Bermuda's smaller islets through man's introduction (Wingate, 1965).

It is believed that *E. gossei* was accidentally introduced into Pembroke, Paget, or Devonshire parish in vegetation imported from Jamaica in the 1890s (Wingate, 1965). By 1916, its range was still limited to Paget and Pembroke parishes (Wingate, 1965). Surveys in 1958 and 1963 revealed that its range, while including Warwick and Devonshire parishes, had become static, probably due to the fact that the more successful *E. johnstonei* had achieved an island-wide distribution (Wingate, 1965). Though there were also two separate colonies of *E. gossei* residing on large farms in Southampton, it was suggested that these populations were the result of individuals or eggs having been transported to these locations in manure (Wingate, 1965).

Table 1. Origin, distribution and conservation status of Bermuda's amphibian and reptile species.

Common name	Latin name	Ecological status	Date and origin	Distribution	Conservation status
Common whistling frog	<i>Eleutherodactylus johnstonei</i>	Introduced	L. 1800's Lesser Antilles	Island wide	Not evaluated
Whistling frog	<i>Eleutherodactylus gossei</i>	Introduced	L. 1800's Jamaica	Unknown	Locally extirpated
Cane toad	<i>Bufo marinus</i>	Introduced	1885 Guyana	Island wide	Not evaluated
Diamondback terrapin	<i>Malaclemys terrapin</i>	Native	N. America	In a few isolated ponds	Vulnerable (VU, D1)
Red-eared slider	<i>Trachemys scripta</i>	Introduced	L. 1900's N. America	Island wide in ponds	Invasive
Green turtle	<i>Chelonia mydas</i>	Native	–	Inner bays and harbours and north platform reefs	Endangered (EN, AI b,d)
Loggerhead turtle	<i>Caretta caretta</i>	Native	–	Sargassum rafts and occasionally near wrecks	Endangered (EN, AI a,b,d)
Hawksbill turtle	<i>Eretmochelys imbricata</i>	Native	–	Reefs island wide	Critically endangered (CR, AI b,d)
Atlantic Ridley turtle	<i>Lepidochelys kempii</i>	Rare visitor	–	–	Endangered (EN, AI b,d)
Leatherback turtle	<i>Dermochelys coriacea</i>	Migratory visitor	–	Offshore	Endangered (EN, AI b,d)
Bermuda skink	<i>Eumeces longirostris</i>	Endemic	Bermuda	Island wide in isolated pockets	Critically endangered (CR, B1, B2 b,c,d,e)
Jamaican anole	<i>Anolis grahami</i>	Introduced	1905 Jamaica	Island wide	Not evaluated
Antiguan anole	<i>Anolis leachii</i>	Introduced	1940 Antigua	Island wide	Not evaluated
Barbados anole	<i>Anolis extremus</i>	Introduced	1940 Barbados	Restricted mainly to the western parishes	Not evaluated

Despite the narrow range identified in the 1963 survey, there was no indication that *E. gossei* populations were in decline at that time.

By the mid 1990s, however, it became apparent that the population of *E. gossei* was declining, and indeed might have been extirpated from Bermuda since no specimens of this species had been observed since 1994. At about this time, there was also concern that the populations of *E. johnstonei* and *B. marinus* were declining (Royal Gazette, 1993). In response to these concerns, the Bermuda Amphibian Project was initiated in 1995.

Local residents and scientists suggested that habitat destruction and chemical pollution had contributed to the apparent declines in the island's amphibian populations (Wingate, pers. comm.; Linzey et al., 2003). Therefore, many of the initial investigations focused on identifying the environmental stressors potentially affecting Bermuda's amphibians. To do this, soil samples, water samples, and amphibian tissue samples were collected from 15 study sites between 1995 and 1999 and analysed for pesticides and heavy metals. The analyses revealed that p,p'-dichlorodiphenyldichloro-ethylene (DDE) was found in soil in concentrations ranging from <0.1 ppm to 1.2 ppm at the 10 sites where soil was sampled. DDE was also found in the livers and fat bodies of toads and whistling frogs from all six sites where specimens were collected as well as in invertebrate prey items from the one site where invertebrates were collected indicating possible transport through the food chain (Linzey et al., 2003). Although use of dichlorodiphenyltrichloroethylene (DDT) in Bermuda ceased in 1972, its metabolite, DDE, is apparently still ubiquitous across the main islands. Additionally, pesticide residues in soil samples included DDT at eight sites, kelthane at eight sites, dieldrin at five sites, and polychlorinated biphenyls (PCBs) as Arochlor 1254 and Arochlor 1260 at seven sites (Linzey et al., 2003). Furthermore, the data suggested that heavy metals from the environment were another potential stressor since analyses of toad livers revealed significant concentrations of cadmium, chromium, copper and zinc (Linzey et al., 2003).

Further studies strongly suggested that Bermuda's whistling frogs and toads were exhibiting effects caused by exposure to environmental stressors. Both species were found to harbour heavy parasite loads and both were infected with multiple species of nematodes and trematodes (Linzey et al., 1998a; Linzey et al., 1998b). In addition, histopathological and lymphocyte proliferation studies indicated that immune function was being suppressed in both species (Linzey et al., 2003). However, the sample sizes used in the immune function studies were small and this is being investigated further.

More recent investigations have focused on the disturbingly high incidence of abnormalities in Bermuda's cane toad populations (table 2) and the possible implications for environmental health. Surveys of adults and juvenile toads and metamorphic toads have shown that the problem is persistent and widespread. Abnormal toads were found in a variety of habitats in all nine parishes (Bacon et al., 2006). While most abnormalities in both age classes involved skeletal malformations of the

Table 2. Overall field abnormality frequencies in adult/juvenile and newly metamorphosed *Biffo marinus*. This table is updated from table 1 of Bacon et al. (2006) by addition of data for 2004 and 2005.

Adult/juvenile <i>B. marinus</i> ¹						Newly metamorphosed <i>B. marinus</i>					
Year	Number of sites ²	<i>n</i>	Abnormal (%)	Range per survey ³		Year	Number of sites ²	<i>n</i>	Abnormal (%)	Range per cohort ³	
1999-2000	27	726	19.1	0-29%		2000	18	2,223	15.9	0-47%	
2001	10	545	26.4	12-38%		2001	17	3,687	19.4	0-61%	
2002	11	521	30.1	6-43%		2002	24	3,520	21.4	0-81%	
2003	11	682	27.9	15-55%		2003	18	1,952	24.0	0-64%	
2004	13	894	30.2	13-48%		2004	16	2,204	20.4	0-46%	
2005	10	718	28.6	18-49%		2005	16	1,888	20.5	2-49%	

¹ Includes reproductively mature adults and juvenile specimens.

² Number of sites surveyed per year.

³ Range of abnormality frequencies found during the given survey year.

hind limbs, a variety of spinal, pelvic, and facial (predominantly eye) abnormalities were also observed (Bacon et al., 2006). In addition, annual metamorph abnormality rates at particular ponds were as high as 58% ($n = 71$ from four collections) and abnormality rates for particular cohorts were as high as 81% ($n = 26$ for this cohort; mean cohort size c. 67 individuals) (Bacon et al., 2006). Data from 2000-2003 revealed that breeding sites in public areas (natural or excavated ponds in parks and nature reserves, some of which were former landfill sites, or lined ponds on golf courses) had significantly higher abnormality frequencies than sites (lined or cement ponds) in backyard settings (Bacon et al., 2006).

The possibility that parasites were causing the *B. marinus* abnormalities was investigated in 2001 and 2002. However, no encysted *Ribeiroia* metacercariae were found in 80 malformed metamorphs collected from four sites with high abnormality rates, indicating that these parasites were not responsible for the abnormalities observed (Bacon et al., 2006). Subsequently, investigations were conducted to ascertain if chemicals were responsible for the abnormalities observed. To accomplish this, a number of water and sediment samples and embryos were collected beginning in 2002 from five ponds with high abnormality rates and two reference ponds for use in frog embryo-larval teratogenesis assays. Results from these assays revealed that water and sediment extracts from each of the five affected ponds induced severe abnormalities in the developing larvae of three amphibian species including *B. marinus* (Bacon et al., 2006; Fort et al., 2006a). Further studies showed that developmentally toxic sediment samples contained elevated levels of petroleum hydrocarbons, metals (aluminum, arsenic, tin, cadmium, chromium, copper, iron, lead, mercury, manganese, nickel, and zinc) and ammonia (Fort et al., 2006a).

More recent investigations have indicated that the levels of petroleum hydrocarbons and metals in sediments from the affected ponds were capable of inducing developmental malformations in *B. marinus* independently of each other (Fort et al., 2006a). However, joint mixture interaction studies also suggested that the two classes of pollutants act synergistically when both are present, and these findings have significant environmental health implications as all five of the ponds tested contained both classes of pollutants (Fort et al., 2006a). Larval exposure to the identified contaminants was confirmed through tissue residue analyses (Fort et al., 2006a), and chronic exposure studies have also indicated an association between the amounts of contaminants absorbed and the frequencies of developmental malformations observed in *B. marinus* metamorphs (Fort et al., 2006a). More recently, cross-over exposure studies, in which *B. marinus* embryos from contaminated sites were raised in reference site media and vice versa, showed that there was also a marked maternal effect on larval development and survival. These studies suggested that metals and petroleum hydrocarbons were being transferred from the mother to her eggs during oogenesis and oocyte maturation, and that this transfer of contaminants had a marked impact on larval development and survival (Fort et al., 2006b). In summary, investigations to date indicate that survival and development of *B. mar-*

inus larvae in Bermuda are being affected both by contaminants found in a number of its ponds and by transgenerational transfer of accumulated contaminants.

The focus of current research is to complete the investigations and analyses required in order to determine and communicate the probable risks that the identified environmental contaminants pose to Bermuda's amphibians and potentially other species including humans. These data will be presented to Bermuda's government and environmental NGOs for use in the development of management plans for amphibians and affected sites and, if appropriate, remediation plans for affected sites.

The Turtles

Records for members of the Testudines in Bermuda exist for one fossil land tortoise, two freshwater turtles and five marine turtle species (table 1). The land tortoise, *Hesperotestudo bermudae*, was described from the Pleistocene of Bermuda. This single fossil was discovered in 1991 during the excavation of a fossilized sand dune and is thought to be some 300,000 years old (Meylan and Sterrer, 2000). *Hesperotestudo* has a long record in North America and these authors hypothesized that it rafted to Bermuda, perhaps using the Gulf Stream.

The brackish and freshwater ponds of Bermuda support populations of two emydid turtles; the diamondback terrapin, *Malaclemys terrapin*, and red-eared slider, *Trachemys scripta elegans*. There is a single record of *Malaclemys* from a cave in Bermuda (Thomas, 2004), but the bone does not appear to be fossilized and was found in association with pig bones (*Sus scrofa*). Pigs were likely introduced to Bermuda by Spanish sailors prior to 1535. Presently, two natural brackish water ponds and a few small adjacent golf course ponds support a population of this species. In these ponds, *Malaclemys* has been observed to forage among the submerged roots of red mangroves, *Rhizophora mangle* (Thomas, 2004). They are also known to lay their eggs in the sand bunkers of a local golf course in Hamilton Parish (Davenport et al., 2005). Preliminary study indicates a small but stable population and ecologists for the Bermuda Biodiversity Project are currently assessing the population characteristics, which will include total estimated population, density, ecological role, and genetic identity. There is no recorded evidence that *Malaclemys* were ever imported into Bermuda and the fact that they are well suited to long distance travel at sea raises the possibility that the species could be native (Davenport et al., 2005). If further study suggests that *Malaclemys* is native, this species would likely be given serious consideration as an addition to the Protected Species Act 2003.

The red-eared slider (*Trachemys scripta elegans*) is considered an invasive species in Bermuda, having been introduced to the island through the pet trade. The full extent of its impact on freshwater ecosystems in Bermuda has not been extensively studied but this species is now known to be established in numerous countries around the world. Recent research provides evidence that introduced *T. s. elegans*

negatively impacts at least some native species in Europe (e.g., Cadi and Joly, 2003, 2004). Recent surveys in Bermuda have found it in almost every freshwater and wetland ecosystem and even a few brackish water ponds. Efforts are now underway to remove populations from the wild and raise awareness in the community regarding their potential impact.

Five species of marine turtles have been recorded from Bermuda with two, the green turtle, *Chelonia mydas*, and the loggerhead turtle, *Caretta caretta*, being the only species recorded nesting. The large breeding population of green turtle that was described in early histories of Bermuda was quickly decimated, through overharvest, by the first colonists and New World explorers, leading to one of the earliest pieces of conservation legislation, written in 1620, to protect young sea turtles (Garman, 1884). This early attempt at green turtle conservation was unsuccessful in maintaining the nesting population and there has been no reproduction of green turtles on the islands of Bermuda since the early 1900s (Babcock, 1937; Gray, unpublished data). However, in an effort to re-establish a breeding population of *C. mydas*, more than 25,000 green turtle eggs were collected from beaches in Costa Rica and Surinam and reburied on local beaches between 1967 and 1977. Approximately 16,000 hatchlings were produced during this restocking experiment (Department of Agriculture and Fisheries Monthly Bulletin, 1972). Due to the late incubation period and cool sand temperatures it is likely that these hatchlings had a male-biased sex ratio. No green turtle nesting has been recorded in Bermuda since the restocking project was carried out.

At the present time significant numbers of juvenile green turtles and a smaller number of hawksbill turtles from nesting populations in the Caribbean region forage and reside in Bermuda. The shallow reefs and seagrass meadows of the northern Bermuda Platform (fig. 1) provide excellent grazing areas for the large numbers of resident green turtles. These animals are the focus of a mark and recapture study, initiated in 1968, by the Bermuda Turtle Project (BTP) (Meylan et al., 1994; Gray et al., 1998). Turtles are captured for study using a 2000 ft entrapment net set at 40 sites around the island (fig. 2, c & d). Data are collected from all turtles captured by the BTP using a standardized protocol (Meylan et al., 1992-2003). As of December 2005, data from approximately 2,500 green turtles have been collected and more than eight hundred recaptures have been made. These observations provide extensive data on population structure and trends, genetic identity, sex ratios, growth rates, site fidelity and migratory patterns.

BTP studies indicate that the very small, pelagic size class and mature adults are absent from the Bermuda Platform. This supports the hypothesis that Bermuda is a developmental habitat for green turtles (Meylan et al., 1994; Meylan and Meylan, 1998). Green turtles captured by the BTP have varied in minimum straight carapace length at first observation from approximately 22 to 81 cm and in weight from 1 to 86 kg (Meylan et al., in prep.). Although a small number of the green turtles captured are larger than the minimum size at sexual maturity, laparoscopy of a sample of more than 125 individuals suggests that none are mature (Meylan et al., 1994; Meylan

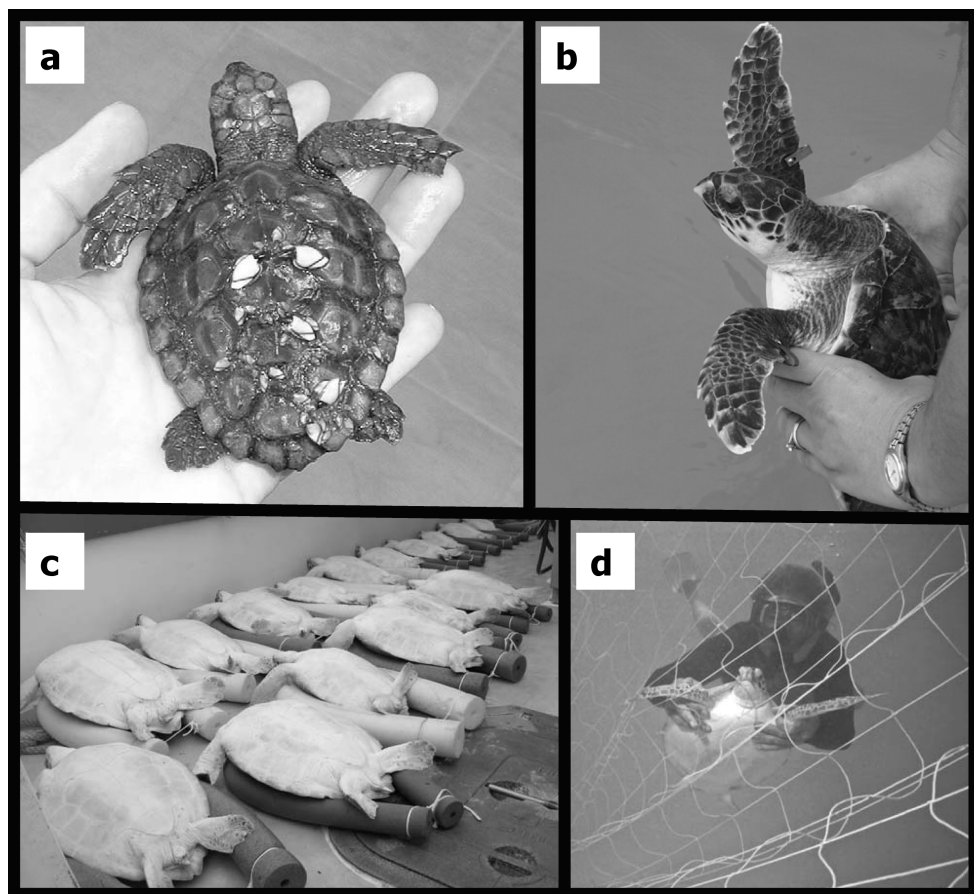


Figure 2. Sea turtles: (a) juvenile loggerhead; (b) juvenile hawksbill; (c) green turtles on research vessel; (d) green turtle capture in net.

et al., in prep.). Among the green turtles observed through the Bermuda Aquarium stranding network, 8.4% are smaller than the minimum size captured on the seagrass flats by the mark and recapture study. This would suggest that Bermuda receives a small number of pelagic phase green turtles that become sick or injured in the oceanic environment.

Bermuda's green turtles have been found to maintain grazing plots on seagrass beds (Vierros et al., 2002). Furthermore, the capture of green turtles during every month of the year suggests that they are year-round residents of the platform, staying in Bermuda's waters as long as 14 years or more (Meylan et al., in prep.).

Blood samples are taken from each captured turtle to determine gender and genetic affinities through sequencing of the mitochondrial control region. Data indicate that at least four different nesting beach populations contribute to the group of green turtles that forage on the Bermuda Platform (Engstrom et al., 1998; Vierros et al., 2002).

Upon reaching a shell length of approximately 65-70 cm, green turtles depart from Bermuda and migrate to distant foraging grounds where they complete their development and become sexually mature (Meylan et al., in prep.). External tags allow researchers to determine the locations of these distant foraging grounds. To date, over 90 green turtles and one hawksbill tagged by the BTP in Bermuda have been recaptured in other countries bordering the Caribbean. Most green turtle recaptures have been made in Nicaragua, reflecting travel of about 2500 km straight-line distance. The tag return data suggest that the turtles take up residence on the extensive shallow grass beds off the coast of this country. This region is the primary feeding ground for mature adult green turtles in the western Caribbean. From this area, mature turtles undertake reproductive migrations to the nesting beach where they were born, completing a long and complex life cycle (Carr et al., 1978).

Hawkbills (*Eretmochelys imbricata*) are found on the reefs from the NW to NE of the islands and occasionally on the south shore reefs. They are only very rarely caught in the entrapment net used to capture green turtles, but a small sample has been collected by a variety of methods (Meylan et al., 2004). Since 2000, the BTP has dedicated annual sampling effort to swimming transects of suitable habitat with teams of snorkelers, capturing hawkbills by hand. This has proven to be a successful technique, but the apparent low density of the species precludes a large sample size for study. The majority of the hawkbill data from Bermuda have been collected from stranded animals reported to the Bermuda Aquarium Wildlife Rehabilitation Centre and through animals captured by cooperating recreational divers licensed to take lobsters. A data set for 136 hawkbills (caught by hand or in nets, or observed as strandings) shows a straight carapace length range from 5.3 cm to 75.7 cm with the smallest individuals being from the stranding network (fig. 2b).

Three of the hawkbills examined approached the minimum size at maturity for hawkbills in the Atlantic. However, necropsies of stranded animals have yet to reveal any sexually mature individuals. Furthermore, no nesting by hawkbills has been documented in Bermuda. Thus, the hawkbills known from Bermuda appear to represent residents from a developmental habitat on the Bermuda Platform and stranded individuals from the pelagic life history stage (Meylan et al., 2004).

The mitochondrial control region has been sequenced for a sample of Bermuda hawkbills, and multiple Caribbean genotypes have been detected. These include haplotypes known in 2002 from nesting beaches on Cuba, U.S. Virgin Islands, Mexico and Costa Rica (Meylan et al., 2004). However, reanalysis of the growing Bermuda data set in light of the increasing knowledge of hawkbill genetics will be required to corroborate these sites as source populations for the hawkbills in Bermuda.

The loggerhead, *Caretta caretta*, is not known to regularly inhabit the waters of the Bermuda Platform nor is it the main target of research. However, during winter months, juvenile, post-hatchling *Caretta* strand on Bermuda shores, typically washed in by winter storms (fig. 2a). They vary in size from 6.26 cm to 74.5 cm straight carapace length with more than 75% being less than 20 cm. Live, stranded

loggerheads are cared for in the Bermuda Aquarium Museum and Zoo's Wildlife Rehabilitation Center and then tagged with BTP tags before release. There are anecdotal reports of large *Caretta* on or near the outer reefs and wrecks, but such records have not been confirmed with size or species verification (BTP sighting log). In 1990, the first nesting by *Caretta* in Bermuda was recorded (Gray, 1990) and this was followed by a second loggerhead nesting event in 2005 (Gray, in prep.). While sea turtle nesting in Bermuda is extremely rare, with only two nests recorded in nearly two decades, there is nonetheless a recognized need to protect Bermuda's remaining habitat for any returning breeders.

Leatherback turtles, *Dermochelys coriacea*, are only occasionally seen offshore and there are only five records of strandings since 1967. Three of these were a result of entanglement in fish or lobster trap lines. Large leatherbacks are seen off the edge of the Bermuda Platform and very occasionally within the reef system, presumably passing the islands on their migration to or from other regions in the North Atlantic.

Two museum records from the 1940s exist for Kemp's Ridley turtle, *Lepidochelys kempii*, in Bermuda. It was also presumed that this species had visited the island on rare occasions previously (Babcock, 1937). Other than anecdotal records, however, there is only one live *Lepidochelys kempii* account on record for Bermuda of a specimen caught in 1949 and held by the Bermuda Aquarium (Mowbray and Caldwell, 1958). More recently, in April of 2006 an additional dead specimen of *Lepidochelys kempii* was collected by the Wildlife Rehabilitation Centre at the Bermuda Aquarium Museum and Zoo.

The degree of protective legislation for turtles in Bermuda has been progressive. The earliest known legislation protecting marine turtles was passed by the First Assembly in 1620, only eleven years after Bermuda was colonized. The act prohibited the taking of young turtles, protecting all turtles less than 18" breadth or diameter. In 1937, there was a prohibition of taking turtles under 20 lbs. The Board of Trade (Fisheries) regulations (1947) enforced a restriction on the take of any turtle of a weight smaller than forty pounds. An order made under the Fisheries Act (1972) implemented a moratorium on the take of all turtles for a five year period. This moratorium was never lifted but rather was replaced with the Fisheries Protected Species Order of 1978. To this end, all sea turtles in Bermuda have been completely protected from direct take since this act commenced on April 1, 1973. Sea turtles are further protected today under the Protected Species Act of 2003.

Sea turtles in Bermuda are a shared regional resource and as such are threatened by factors in other parts of the region that are not possible for us to track. Such threats may include, but are not limited to, harvest by humans, incidental catch, loss of habitat and natural predation. Threats to sea turtles on the Bermuda Platform are monitored by the stranding network which reports that 43% of local strandings are directly attributable to anthropogenic causes (Gray et al., 2006). Incidental catch and entanglements (entanglements in nets, fishing line or kite string; ingestion of fishing hooks) caused 22% of strandings in which a probable cause of death could be determined. An additional 18% of strandings appeared to involve boat

collisions or propeller injuries, although some boat interactions may have occurred post mortem and may not have been the cause of the stranding. Death due to ingestion of plastic contributed to 3% of strandings. Necropsy results also reveal the presence of ingested plastics in the stomach contents and intestinal tracts of animals where death was caused by another factor. The negative effect of these contributing factors is likely to be underestimated, as partially dismembered carcasses that are too decomposed to necropsy may also be the result of human impacts. In addition to the threats of entanglement, boat collision, and ingestion of plastics, mortality of sea turtles stranded in Bermuda can be attributed to but not limited to gut impaction, drowning, toxæmia, foreign body ingestion, parasite burden, septicaemia, lung infection, clostridium burden, degenerative tissue disease and emaciation (Gray et al., 2006). A solution to the problems of incidental catch, ingestion of marine debris and entanglement will require international cooperation because in many cases the entangling and ingested materials do not have their origin in Bermuda.

Habitat loss as a result of a 30% decline in seagrass beds locally is an issue of great concern in Bermuda today. The potential effects to Bermuda turtles of the loss of nearly 500 hectares of critical marine habitat are of extreme concern, as is the lack of data that could aid in explaining this dramatic decline (Murdoch et al., in prep.).

The Skinks and Anolis Lizards

There are four species of extant terrestrial reptiles in Bermuda and all of them are lizards (table 1). Only one species, the endemic Bermuda skink, *Eumeces longirostris*, is native to the island while the other three, all *Anolis* species, are introduced.

The Jamaican anole, *Anolis grahami grahami*, is the most common of the three species of introduced lizards. It was introduced intentionally in 1905 to control the Mediterranean fruit fly, *Ceratitidis capitata*. This lizard successfully colonised the mainland and most of the offshore islands. *A. grahami* is usually found on walls, trees and shrubs. It preys on a variety of insects including those introduced as biological pest controls, most notably a ladybird beetle, *Rhyzobius lophanthæ*, that was introduced to combat infestations of the scale insect, *Carulaspis minima* on endemic cedar and palmetto trees (Thomas, 2004). This anole is also known to consume juvenile Bermuda skinks (Giffith and Wingate, 1994) and eggs of the native Eastern bluebird, *Sialia sialis* (Thomas, 2004). A bird from Trinidad, the Great Kiskadee, *Pitangus sulphuratus*, was introduced in 1957 in an unsuccessful attempt to control *A. grahami*. However, these birds also became predators of the Bermuda skink (Wingate, 1965; Thomas, 2004).

A second anole, *Anolis leachii*, native to Antigua and Barbuda, was accidentally introduced and first spotted in 1940 at the north end of Warwick parish. It is locally known as “the Warwick lizard” although the distribution of this species is now island wide. It is the largest lizard species in Bermuda (males reach up to 35 cm) and

is dominant over the other anole species. *A. leachii* eats a wide variety of insects (Thomas, 2004) and Wingate (pers. comm.) hypothesizes that these anoles may also eat bluebird eggs and bluebird hatchlings from the nest because they are often found in vacant bluebird boxes and there are instances of egg and chick disappearances from boxes where this species is seen in the vicinity.

The third anole, *Anolis extremus* native to Barbados, was also accidentally introduced via ships at the west end of the island (the naval dockyard) around the same time as the introduction of *A. leachii*. This species is less common than the other two anoles and is largely restricted to the western parishes. It eats insects, spiders and woodlice (Thomas, 2004).

The Bermuda skink, also locally known as a “rock lizard”, is the only endemic terrestrial vertebrate in Bermuda (fig. 3). Unless noted otherwise, information on this species is derived from a thesis by L. Kitson (in prep.). The Bermuda skink is a diurnal, ground-dwelling lizard that is thought to have evolved after an ancestral species colonised the islands via an oceanic journey (rafting) from the east coast of North America. The species differs widely from other members of the genus *Eumeces*. Heilprin (1889) suggested that the Bermuda skink’s closest relative was *Eumeces fasciatus*, the common five-lined skink, from the south-eastern United States. Preliminary genetics studies suggest, however, that *E. longirostris* is more closely related to the western skink, (*Eumeces skiltonianus*) (Richmond, pers. comm.). This skink is common to parts of the Western United States and does not inhabit the east coast. It is likely that there is no extant common ancestor to the Bermuda skink and that this species evolved very early on during the radiation of the *Eumeces* genus (Richmond, pers. comm.).

Jones (1859), stated that the Bermuda skink was observed island wide particularly on walls and stones in cedar groves. However, 43 years later Verill (1902) reported that Bermuda skinks were rarely seen on the mainland and were prevalent only on Castle Island around the forts and cliffs. The difference between these two reports suggests that there was a dramatic decline of Bermuda skinks within a short period. However, the virtual absence of skinks in early records preceding the report made by Jones (1859) may imply that the skink was never particularly conspicuous. Wingate (1965) suggested that skinks were more subtly abundant on the mainland than previously thought, although in more recent years local residents have noticed a dramatic decline in numbers (Bermuda Biodiversity Project, unpublished).

E. longirostris is classified as critically endangered on the IUCN Red List (Conyers and Wingate, 1996). This species is protected locally under the Protected Species Act (2003) (table 1). The most significant threat to this species has undoubtedly been habitat loss due to the expanding area taken up by homes and gardens (now 50% of the total land area) and agriculture (17% of the total land area). However, declining skink numbers are also evident in nature reserves with restored vegetation and this has been attributed to predation by introduced species (Davenport et al., 2001).



(a)



(b)

Figure 3. (a) Juvenile (1 year old) Bermuda skink *Eumeces longirostris*. (b) Adult (4 year old) Bermuda skink. (Colour originals — see www.ahailey.f9.co.uk/appliedherpetology/cariherp.htm).

Efforts to understand the ecology of this species have been undertaken recently in order to develop effective conservation management plans. These include studies on population health and size (Raine, 1998; Wingate, 1998; Davenport et al., 2001; Glasspool and Outerbridge, 2005) species distribution, genetic differentiation of populations, reproductive biology, seasonal activity and prey availability.

In 1998, the Bermuda Zoological Society sent out a public questionnaire to all households. The results showed that there were possibly many isolated populations spanning the entire mainland. These reports were followed up by surveys using baited traps in areas where skink sightings had been reported. Skinks are now known to inhabit many rocky coastal areas throughout the mainland of Bermuda. However, they appear to be absent from the islands of St. George's and St. David's. Verill (1902) documented that there was a plague of rats in the 17th century and, in an attempt to control the rat population, the vegetation on these islands was repeatedly burned and domestic cats were deliberately shipped to Bermuda and introduced onto these islands. It is possible that skinks were eliminated from these islands (where humans first settled) as a result of this dramatic episode.

The greatest known abundance of skinks on Bermuda's mainland can be found within the Spittal Pond Nature Reserve (fig. 1). Raine (1998) estimated there were at least 124 individuals there although the entire rocky coastal area of the nature reserve was not surveyed during this study.

There are also substantial populations of skinks on several offshore islands, the largest of which is Southampton Island (fig. 1). Mark and recapture surveys on Southampton Island in 1997 showed that the population was healthy with adequate recruitment, which may have reached carrying capacity at approximately 400 adult animals (Davenport et al., 2001). Glasspool and Outerbridge (2005) later adjusted this figure to 534 in order to account for an assumed absence of mature females. Females brood eggs in early summer (Kitson, unpublished), the period when the original survey took place. In 2004, this island was surveyed again and estimated to contain 582 skinks (Glasspool and Outerbridge, 2005). Southampton Island appears to have the highest density of skinks in Bermuda and is regarded as the only safe haven for *E. longirostris* (Davenport et al., 2001) because introduced predators and anthropogenic threats are largely absent. However, in 2004 Glasspool and Outerbridge (2005) noted that the mutilation rate had increased since 1997. They suggested that the most likely cause was storm-induced stress, however they could not rule out increased avian predation.

Nonsuch Island is a protected nature reserve that is being restored in order to achieve a true representation of the prehistoric "native" environment of Bermuda. Detailed observations and surveys of *E. longirostris* have been carried out on this island since the 1970s (Wingate, pers. comm.). In 1997, a survey of the island's skink population indicated that it was ageing and failing. It is suggested that this decline resulted from predation by kiskadees, Jamaican anoles, and possibly cane toads. More than 50% of this population showed mutilation (damaged tails or digit

loss). It is suspected that extinction of the Nonsuch Island population is inevitable without control of predators (Davenport et al., 2001).

Several studies have been carried out to investigate aspects of isolated skink populations. This work has added knowledge on environmental and genetic stress (Raine, 1998), population size, distribution and structuring (Davenport et al., 2001; Raine, 1998; Glasspool and Outerbridge, 2005). Raine (1998) found that skinks on Charles Island and Inner Pear Island and at Spittal Pond Nature Reserve were suffering from significant levels of environmental and genetic stress even though all three populations appeared healthy, with sufficient numbers of juveniles and adults.

Raine (1998) found significant morphological differentiation between geographically isolated populations and, in a study using microsatellite markers developed by Coughlan et al. (2004), significant genetic differences were found between skinks at Spittal Pond Nature Reserve and those on Southampton Island. In order to preserve the genetic diversity of *E. longirostris* and avoid outbreeding, it will be important not to mix the gene pools of geographically isolated populations in any future captive breeding and reintroduction attempts.

Recent research found that the skinks in Spittal Pond Nature Reserve are more genetically diverse than those on Southampton Island. Results from this study also suggest that the Spittal Pond population has suffered a dramatic decline recently or that there are barriers preventing intermixing within the population. Both populations have a healthy level of genetic variation compared to other species of island reptiles and endangered lizards.

Deliberate and accidental introductions are thought to have had dramatic effects on *E. longirostris* (Davenport et al., 2001; Raine, 1998; Wingate, 1998). The black rat, *Rattus rattus*, brown rat, *Rattus norvegicus* and domestic cat, *Felis domesticus*, have been resident on the island since the early human settlers. These species are considered threats to *E. longirostris*. There are currently thousands of feral cats in Bermuda (Glasspool, pers. comm.) and cases of domestic cats catching and killing skinks are frequently reported by their owners.

The kiskadee flycatcher, *Pitangus sulphuratus*, is an adept skink predator (Samuel, 1975) and is presently perceived to be the only bird that creates a major threat to the remaining skink population (Raine, 1998; Davenport et al., 2001). Yellow crown night herons, *Nyctanassa violacea*, were introduced between 1976-78 to replace an extinct native heron. Night herons are also known to eat skinks although their diet mostly consists of crabs (Davenport et al., 2001).

Griffith and Wingate (1994) observed a Jamaican anole eating a juvenile skink on Castle Island. Wingate (1998) suggested that, although *A. grahami* occupies a separate niche by being primarily arboreal, it could be a major predator of *E. longirostris* and the reason why skinks are more abundant on islands where these anoles are absent. Juvenile Jamaican anoles can frequently be observed foraging on the ground in skink habitats, and therefore almost certainly compete directly at times with hatchling and juvenile skinks (Edgar, pers. comm.). Cane toads, *Bufo marinus*, are considered a potential predator of Bermuda skinks (Davenport et al.,

2001). They could also compete with skinks for prey although they are nocturnal and not usually found in the same habitat.

Heilprin (1889) originally suggested that skinks were primarily insectivorous, in addition to preying upon isopods and amphipods. Wingate (pers. comm.) later observed that skinks also consumed carrion opportunistically and eggs from tropic bird, *Phaethon lepturus*, and cahow, *Pterodroma cahow*, nests. Davenport et al. (2001) discovered that skinks also eat prickly pear fruit, *Opuntia dillenii*. More recent studies, which examined fecal samples and gut contents from dissected specimens (incidental death), indicate that skinks prey upon a wide variety of arthropods including small crustaceans (isopods and amphipods), crickets, spiders, cockroaches, beetles and flies. Studies carried out in captivity show that skinks will eat the majority of terrestrial arthropods offered to them.

Prey availability surveys carried out in several sites show that out of all the arthropod species consumed by skinks, the most abundant are amphipods and isopods. These surveys were carried out in areas inhabited by skinks and in areas where they appeared to be absent (after pitfall surveys). It was revealed that isopods and amphipods were more available in rocky coastal areas where skinks were found compared to an upland hillside area where they appeared to be absent. It is suggested that this is one of the reasons why skinks are found mainly in rocky coastal areas.

It was found that *E. longirostris* has a life history similar to skinks of the same genus in North America. Adults court and mate in late April/early May and lay one clutch of eggs in late May/early June with hatchlings appearing in late July/early August. In captivity females brood their eggs for the entire incubation period. Studies in captivity show that Bermuda skinks have a mean clutch size of 4.5 ($n = 9$) and can lay up to 6 eggs. Incubation (in captivity) lasts an average of 36.3 days ($n = 6$). Captive skinks may reach reproductive maturity at two years of age and adult size after three years.

Bermuda skinks were originally thought to hibernate during the cooler winter months. However, recent studies now show that they remain active throughout the year although they are found (using baited traps) in greater abundance during the summer months.

Litter is considered to be a threat to the survival of this species (Davenport et al., 2001). Glass bottles are potentially lethal traps for skinks since they are unable to climb up steep smooth surfaces. Remains confirmed to be those of *E. longirostris* have been found inside bottles on the mainland (including in nature reserves) and on islets (Wingate, 1998; Wingate, pers. comm.).

Hurricanes occasionally affect Bermuda and cause the destruction of skink habitat. In 2004, Glasspool and Outerbridge (2005) noted that the 2003 cohort was virtually missing from Southampton Island. This cohort would have hatched shortly before Hurricane Fabian (direct hit, category 3) and it is suggested that this hurricane was primarily responsible for the lack of individuals in this size class. Pesticides and other chemicals in manicured areas may also threaten skinks. In one reported

instance a dead skink was found in a flowerbed shortly after a pesticide had been used.

A Species Action Plan has been drawn up for the Bermuda skink with the help of the Herpetological Conservation Trust (U.K.) in order to ensure that this species is effectively managed (Edgar et al., 2006). Habitat restoration is currently the top priority for the conservation of this species and the replanting of native and endemic plants is an ongoing island-wide government initiative.

Acknowledgements. The Bermuda Turtle Project (BTP) was founded “to promote the conservation of marine turtles through research and education”. Entering its 38th year in 2006, this is one of the longest-running projects of its kind in the world. We acknowledge the Bermuda Government Department of Conservation Services, the Bermuda Zoological Society and the Caribbean Conservation Corporation with Drs. Anne and Peter Meylan as scientific directors for the project. The Bermuda Amphibian Project, initiated in 1995, is a long-term investigation of the status and health of Bermuda’s amphibian populations, the potential causes for their decline, and the implications for environmental health. The authors wish to thank the Bermuda Zoological Society (BZS) which hosts this project, The Bermuda Government Ministry of the Environment for its continued support, and the numerous charities, schools and businesses that have supported this project. Research was conducted in compliance with the Animal Welfare Act and other Federal statutes and regulations relating to animals and experiments involving animals and adheres to principles stated in the Guide for Care and Use of Laboratory Animals (NRC, 1996). All of the recent research done on the Bermuda skink (Kitson in prep.) has been part of a Ph.D. program undertaken in cooperation with University College Cork, Ireland, under the supervision of Professor John Davenport. None of the research would have been possible had it not been for Professor Davenport and the generous assistance of the Bermuda Biodiversity Project, the Bermuda Zoological Society, the Bermuda Aquarium Museum and Zoo and Friends of the Bermuda Aquarium. L.K. would also like to thank Professor Tom Cross and Dr. Jamie Coughlan at University College Cork for their assistance with the genetics part of the research. This is Contribution No. 110 of the Bermuda Biodiversity Project (BBP), BAMZ.

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