Conservation of amphibians and reptiles in The Bahamas

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Abstract. The Bahamas are unique relative to other countries and dependent territories in the West Indies because they comprise 29 islands, hundreds of cays, and thousands of emergent rocks spread over 215,000 km^2 of ocean. The native herpetofauna of The Bahamas is derived primarily from Cuba and Hispaniola, and numbers 46 species comprised of three frogs (including one endemic), 25 lizards (13 endemic), 11 snakes (7 endemic), two freshwater turtles, and five sea turtles. Of the native terrestrial species, 85% are either not assessed or data deficient to affirm IUCN listing, thus stressing the need for more research in The Bahamas. Currently, there are few legislative laws directly protecting the herpetofauna of The Bahamas although all three rock iguanas (*Cyclura*) are technically given full protection under the Wild Animals (Protection) Act of 1968. In 2009, the Bahamian Ministry of Agriculture and Marine Resources amended the Fisheries Regulations governing marine turtles in order to give full protection to all sea turtles found in its waters. Other species are afforded protection in a fairly extensive system of 25 national parks, though threats from various fronts hinder safeguarding all species. Major threats to the Bahamian herpetofauna include inappropriate development, apathy, over-exploitation of wildlife, lack of law enforcement, hurricanes, introduced species, and disturbance by tourist activities. We explore the challenges for long-term conservation of the Bahamian herpetofauna and provide suggestions to help mitigate pressures on amphibian and reptile populations.

Key words: Bahamas National Trust; Conservation; *Cyclura*; development; sea turtle; tourism; *Trachemys*.

Introduction

The Commonwealth of the Bahamas encompasses an extensive, northwest to southeast-trending archipelago of low (maximum elevation 63 m), limestone islands and cays spread over a distance of approximately 870 km in the western Atlantic Ocean. The geographic archipelago, however, extends farther southeast to include

the Turks and Caicos Islands (TCI), which are a separate political entity. The Bahamas are unique relative to other countries and dependent territories in the West Indies because they comprise 29 islands, hundreds of cays, and thousands of emergent rocks spread over 215,000 km^2 of ocean. The vast expanse of territorial waters and remote islands promotes both challenges and opportunities to the study and conservation of its herpetofauna. The remoteness of many islands over an expansive sea makes continued monitoring and law enforcement difficult and logistically challenging. The numerous islands and cays, however, are ideal natural laboratories for the study of ecology, evolution, and natural history (e.g., Calsbeek and Smith, 2003; Losos et al., 2004; Iverson et al., 2004a; Schoener et al., 2004; Knapp et al., 2006; Bjorndal and Bolten, 2008; Losos, 2009; Cox and Calsbeek, 2010; see also Franz et al., 1996 for a detailed compilation of earlier references). From a conservation perspective, the numerous cays scattered within this expansive archipelago offer an equal opportunity to study conservation mitigation strategies such as translocation (Knapp, 2001; Knapp and Malone, 2003) or non-native species eradication (Hayes et al., 2004). Yet, in relation to their accessibility from North America and biological interest, the herpetofauna of the Bahamas have been relatively insufficiently studied. Here we encourage further study of the Bahamian herpetofauna that will advance our understanding of its ecology and facilitate its conservation management. For this review, we limit our treatment to include only the herpetofauna, conservation concerns, priorities, and policies of the Commonwealth of The Bahamas. However, because the TCI share the same geographic archipelago and were affected similarly by prehistoric peoples, we include discussion of the TCI in a historical perspective.

Annotated History of The Bahamas

In October 1492, Christopher Columbus made landfall on the island of San Salvador in The Bahamas. The origin of the name "Bahamas" is unclear, but it is thought to be derived from the Spanish baja mar, meaning "shallow seas" (Albury, 1975) or the Lucayan word for Grand Bahama Island, ba-ha-ma "large upper middle land" (Granberry and Vescelius, 2004). At the time of Columbus' arrival there were from 40,000 to 80,000 native people known as Lucayans inhabiting most of the larger islands in the archipelago. Within 30 years these people were eliminated by disease, hardship, and slavery (Keegan, 1997).

The Bahamas were mostly deserted from 1513 to 1648 until English Puritans from Bermuda sailed to Eleuthera in 1648 and established the first permanent European settlement in The Bahamas. In 1670, King Charles II granted The Bahamas to the Lords Proprietors of the Carolinas, who rented the islands from the king with rights of trading, tax, appointing governors, and administering the country. The Bahamas were made a British crown colony in 1718 (Albury, 1975).

The first evidence of extensive, human-mediated habitat degradation followed the American War of Independence when thousands of pro-British loyalists and

enslaved Africans moved to The Bahamas to establish a short-lived plantation economy. From 1784 to 1788 the Bahamian population more than doubled to nearly 10,000 because of the loyalist influx. During the late 18th and early 19th centuries, thousands of forested hectares were cleared for timber, cotton, and sisal (Albury, 1975).

Slavery was abolished in 1834 and the descendants of enslaved and liberated Africans comprise the current majority of the population. In 1964 Great Britain granted The Bahamas limited self-government and in 1969 the colony became The Commonwealth of The Bahamas. On 10 July 1973 The Bahamas became an independent country and a member of the British Commonwealth which is now known as The Commonwealth of Nations. Today the human population of 307,552 is centered predominantly in the capital of Nassau on New Providence, and on Grand Bahama Island. The Bahamas is one of the wealthiest West Indian countries with an economy heavily dependent on tourism and offshore banking. Tourism together with tourism-driven construction and manufacturing accounts for approximately 60% of Gross Domestic Product and directly or indirectly employs half of the archipelago's labor force (Central Intelligence Agency, 2010).

Physical Geography

The Bahamas is composed of an extensive group of 29 major islands and 661 smaller cays associated with an exposed, shallow water carbonate bank system located between 20°53′-27°30′N and 72°37′-80°54′W. The northwestern Bahamas are composed primarily of two large banks — the Great Bahama Bank and Little Bahama Bank (fig. 1). The Great Bahama Bank is the largest in the geographic archipelago and includes Andros, the Berry Islands, Bimini Islands, Cat Island, Eleuthera, Exuma Cays, Long Island, New Providence, and the Ragged Islands. These islands are separated from each other by shallow (up to 30 m) marine waters (Olson and Pregill, 1982). The Little Bahama Bank caps the northern extent of the Bahamas and includes Grand Bahama and Abaco. The southeastern Bahamas consists of smaller carbonate platforms (e.g., Crooked and Acklins Islands), many of which are almost entirely exposed as single islands (e.g., Conception Island, San Salvador, Rum Cay, Samana Cay, Mayaguana, Great Inagua, and Little Inagua).

At the height of the Wisconsin glaciation 17,000 years before present (BP) sea levels were as much as 135 m below modern levels (Clark and Mix, 2002), thus consolidating many of the contemporary islands rising from the major banks throughout the archipelago (fig. 1). As a result, land area in the Bahamas was increased by more than an order of magnitude, from 11,406 km^2 at present, to ~124,716 km^2 (Morgan, 1989). The Great Bahama Bank constituted the majority of land area and was separated from Cuba by the 17 km-wide Old Bahama Channel, which presumably facilitated the northward dispersal of flora and fauna. Between 14,000 and 6000 years BP sea level rose and fragmented the carbonate banks into the smaller islands and cays representing the present topography of The Bahamas

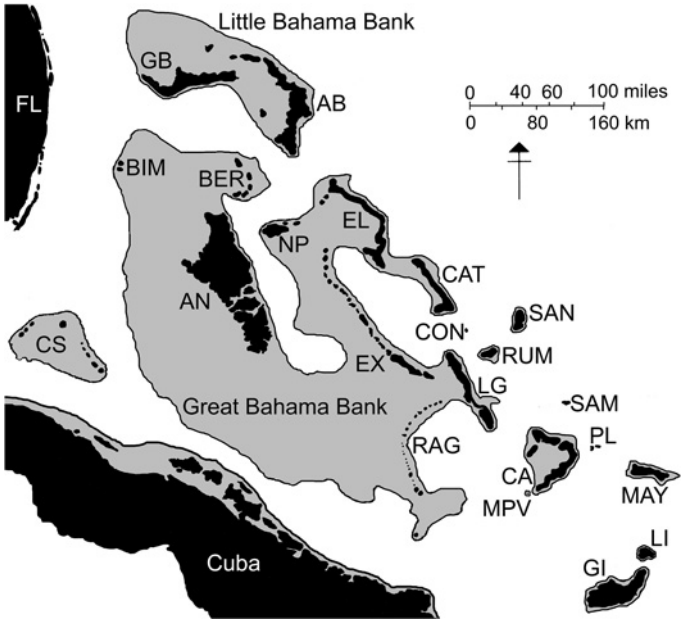

Figure 1. Map of the major land units of The Bahamas. Current extent of islands indicated in black; extent during the height of the Wisconsin glaciation indicated in gray. Abbreviations are AN = Andros; AB = Abaco; BER = Berry Islands; BIM = Bimini; CAT = Cat Island; CON = Conception Island; CS = Cay Sal; CA = Crooked and Acklins Islands; EL = Eleuthera; EX = Exuma Cays; GB = Grand Bahama; GI = Great Inagua; LI = Little Inagua; LG = Long Island; MAY = Mayaguana; MPV = Mira Por Vos; NP = New Providence; PL = Plana Cays; RAG = Ragged Islands; RUM = Rum Cay; SAM = Samana Cays; SAN = San Salvador.

(Morgan, 1989). Today, the Bahamian region is separated from neighboring Florida (90 km from Bimini to the southeastern coast of Florida), Cuba (17 km from Cay Lobos to the northern coast of Cuba), and Hispaniola (110 km from Great Inagua to Ile des Tortues, Haiti) by deep channels and basins (Franz et al., 1996).

Despite the overall low elevation of the Bahamas, Correll and Correll (1982) describe nine rather diverse plant communities: coastal rock, sand strand formation and Uniola, coastal coppice, whiteland, fresh water formations, tidal flats and salt marshlands, mangrove, blackland, and pineland. These communities are not distributed evenly throughout the archipelago because their occurrence is dependent on location, topography, and substrate. In general however, the larger islands are predominantly in the northern region of the archipelago and are characterized by tropical to subtropical dry forest with pine (*Pinus caribaea* var. *bahamensis*) representing the signature species. Relative to the entire archipelago, the northern islands experience more rainfall and more seasonal and cooler conditions. This region (Grand Bahama, Abaco, New Providence, and North Andros) receives rainfall ranging from 1250 to 1500 mm per year. Rainfall decreases southward across the archipelago, ranging from 750 to 1000 mm in the south central islands (Exumas, Long Island, Crooked and Acklins Islands, Mayaguana) and 625 to

750 mm in the southeastern islands (Inagua Islands; Little et al., 1976). The forest type in these southern regions is considered dry tropical forest dominated by xerophytic broadleaf scrub communities.

History of Human Impacts

Colonization of The Bahamas by Amerindians was relatively late in the cultural history of the West Indies. The Lucayan people began to colonize the islands ca. A.D. 600 and like other prehistoric societies in the West Indies, were the first humans to exploit the terrestrial and marine herpetofauna of the region (Keegan, 1997). Archeological excavations from middens throughout the geographic Bahama archipelago (including TCI) reveal a number of reptilian genera, including *Chelonia*, *Eretmochelys*, and *Trachemys*. The most notable remains include an extinct tortoise (*Chelonoidis*; formerly *Geochelone*) species (Newsom and Wing, 2004; Franz and Franz, 2009). Christopher Columbus reported that rock iguanas (*Cyclura*) were one of the Lucayan's favorite foods in The Bahamas (Campbell, 2006). *Cyclura* are also the dominant terrestrial vertebrate recovered from one archaeological site in the TCI. This same site also revealed a decline in number and sizes of green turtles (*Chelonia mydas*) harvested over time (Carlson, 1999). To date, it cannot be demonstrated unequivocally that the Lucayan people were responsible for the extinction or extirpation of terrestrial herpetofauna in The Bahamas, as demonstrated on other oceanic islands after the arrival of prehistoric people (Steadman et al., 2002). However, the coincidence of human colonization and extinction of tortoises in The Bahamas and TCI suggest that Lucayans directly or indirectly caused the demise of some species or populations (Newsom and Wing, 2004; Franz and Franz, 2009).

Though the Lucayans initially impacted the herpetofauna of The Bahamas, the period after European discovery was the most severe for species and populations. Marine turtles were heavily exploited throughout the West Indies, and Carr (1956) noted that "More than any other dietary factor, the green turtle supported the opening up of the Caribbean…". As a result of unsustainable harvest throughout the West Indies over the past 500 years, green turtle populations have been reduced to less than 1% of pre-Columbian population levels (Bolten and Bjorndal, 2003). With the exception of hawksbill turtles (*Eretmochelys imbricata*), which received protection in 1986, sea turtles have been harvested legally in the Bahamas (but see the 2009 ban, below). Even in marine protected areas sea turtles were harvested occasionally by Bahamians and cruising yachtsmen (Bjorndal et al., 2003).

McKinnen (1804) described accounts of Bahamians at times eating crocodiles on Acklins Island while rock iguanas have always been valued highly for food and were often caught in baited crayfish pots in the Exumas (Bailey, 1925), or more recently on Andros using hunting dogs and guns (Charters, 1999). It is postulated that the irregular distribution of ground-dwelling *Ameiva* and *Leiocephalus* lizards in the Exumas is the result of human perturbations during the Loyalist Era (Dodd

and Franz, 1996). Indeed, for 200 years all islands inhabited during this period were most likely affected by introduced domesticated animals and habitat degradation, thereby making interpretations of contemporary biogeographic patterns problematic (Dodd and Franz, 1996).

The Native Herpetofauna

The native herpetofauna of The Bahamas (table 1) numbers 46 species comprised of three frogs (including one endemic), 25 lizards (including 13 endemics), 11 snakes (including 7 endemics), two freshwater turtles, and five sea turtles. General natural history information (or lack thereof) with pertinent references for the Bahamian herpetofauna can be found in Henderson and Powell (2009). We retain the Bahamian locality record for the snake, *Hypsirhynchus parvifrons*, until additional surveys are conducted. This snake is endemic to Hispaniola but a partial specimen was collected in 1974 by D.W. Buden on Little Inagua and was presumed to be from a local population of unknown taxonomic status (Schwartz and Thomas, 1975). Later, Schwartz and Henderson (1991) considered the population status as unknown while more recently Henderson and Powell (2009) presumed the specimen previously collected as a vagrant. The recent addition of Little Inagua into the Bahamian national park system will hopefully facilitate future survey expeditions to the island.

The herpetofauna of The Bahamas is expanded further with the inclusion of 22 non-native species (5 frogs, 7 lizards 5 snakes, 4 turtles, and 1 crocodilian), of which a minimum of 16 are established and breeding. Of the native herpetofauna, there are 21 endemic Bahamian species, an additional four species that are endemic to the Bahamian archipelago (including the TCI), and 21 species that are endemic to the West Indies (table 1). A native giant tortoise species (*Chelonoidis*; formerly *Geochelone*) is extinct (Auffenberg, 1967; Steadman et al., 2007; Franz and Franz, 2009) and the Cuban crocodile (*Crocodylus rhombifer*) is now extirpated (Franz et al., 1995; Steadman et al., 2007). The Cuban crocodile was once widespread throughout The Bahamas and may have been a major terrestrial and aquatic predator in the past (see comments in Franz and Franz, 2009). Fossils of large iguanas (*Cyclura*), which most likely predate human occupation, have been recovered from Abaco on the Little Bahama Bank suggesting that their range was once more widespread (R. Franz, pers. comm.). The herpetofauna of the Great Bahama, Little Bahama, and Cay Sal Banks are generally derived from Cuba (e.g., Malone et al., 2000; Glor et al., 2005; also see earlier references summarized in Franz et al., 1996). The relationships of species in the southeastern Bahamas are not fully resolved, although many have affinities with Hispaniola or Puerto Rico (e.g., Hower and Hedges, 2003; also see earlier references summarized in Franz et al., 1996). This biogeographic pattern is consistent with regional ocean currents facilitating overwater dispersal.

Recent taxonomic and biogeographic investigations have modified traditional nomenclature (e.g., *Cubophis vudii*, *Epictia columbi*; Hedges et al., 2009; Adal-

Table 1. Distribution of native amphibians and reptiles of The Bahamas with their IUCN status designations. Distributions are arranged by bank system or single islands (if not associated with a bank). Endemic species to The Bahamas are identified with an asterisk while species endemic to the Bahamian archipelago (including TCI) are identified with a dagger. Sea turtles are not identified to bank system. Abbreviations are as follows: CS = Cay Sal; LBB = Little Bahama Bank; GBB = Great Bahama Bank; CON = Conception Island; RUM = Rum Cay; SAN = San Salvador; CA = Crooked and Acklins; PL = Plana Cays; SAM = Samana; MAY = Mayaguana; GI = Great Inagua; LI = Little Inagua. IUCN status abbreviations are CR = Critical; EN = Endangered; VU = Vulnerable; LC = Least Concern; DD = Data Deficient; NE = Not Evaluated.

Species	IUCN status	CS	LBB	GBB	CON	RUM	SAN	CA	PL	SAM	MAY	GI	LI
AMPHIBIA, ANURA													
Family Eleutherodactylidae													
Eleutherodactylus planirostris	LC		●	●								●	
*Eleutherodactylus rogersi**	DD			●			●						
Family Hylidae													
Osteopilus septentrionalis	LC		●	●	●	●	●	●				●	
REPTILIA, SQUAMATA													
Family Iguanidae													
Cyclura carinata†	CR										●		
*Cyclura cychlura**	VU			●									
*Cyclura rileyi**	EN			●			●	●					
Family Leiocephalidae													
Leiocephalus carinatus	NE		●	●									
*Leiocephalus greenwayi**	NE								●				
*Leiocephalus inaguae**	NE											●	
*Leiocephalus loxogrammus**	NE				●	●	●						
*Leiocephalus punctatus** (also recorded from MPV — see Fig. 1)	NE							●		●			
Family Phyllodactylidae													
Tarentola americana	NE			●									
Family Polychrotidae													
Anolis angusticeps	NE			●									
*Anolis brunneus**	NE							●	●				
Anolis distichus	NE		●	●		●	●						
*Anolis fairchildi**	NE	●											
Anolis sagrei	NE	●	●	●	●	●	●	●					
Anolis scriptus†	NE								●	●	●	●	●
*Anolis smaragdinus**	NE			●									
Family Sphaerodactylidae													
*Aristelliger barbouri**	NE											●	●
Sphaerodactylus argus	NE			●									
*Sphaerodactylus corticola**	NE					●	●	●	●	●			
*Sphaerodactylus inaguae**	NE											●	
Sphaerodactylus mariguanae†	NE										●		
Sphaerodactylus nigropunctatus	NE	●		●	●	●							
Sphaerodactylus notatus	LC		●	●		●						●	
Family Teiidae													
Ameiva auberi	NE			●									
*Ameiva maynardi**	NE											●	●

Table 1. (Continued.)

Species	IUCN status	CS	LBB	GBB	CON	RUM	SAN	CA	PL	SAM	MAY	GI	LI
Family Boidae													
Epicrates chrysogaster†	NE							●				●	
*Epicrates exsul**	NE		●										
Epicrates striatus	NE			●	●								
Family Dipsadidae													
*Cubophis vudii**	NE		●	●				●				●	
Hypsirhynchus parvifrons (see the native herpetofauna)	NE												●
Family Leptotyphlopidae													
*Epictia columbi**	NE						●						
Family Tropidophidae													
*Tropidophis canus**	NE											●	
*Tropidophis curtus**	NE	●		●									
Family Typhlopidae													
*Typhlops biminiensis**	NE	●		●									
Typhlops lumbricalis	NE		●	●									
*Typhlops paradoxus**	NE											●	
REPTILIA, TESTUDINES													
Family Chelonidae													
Caretta caretta	EN												
Chelonia mydas	EN												
Eretmochelys imbricata	CR												
Lepidochelys olivacea	VU												
Family Emydidae													
Trachemys stejnegeri	NE											●	
Trachemys terrapen	NE			●									
Family Dermochelyidae													
Dermochelys coriacea	CR												

steinsson et al., 2009), resulting also in the addition of Bahamian endemics (e.g., *Eleutherodactylus rogersi*, *Tropidophis curtus*, *Typhlops biminiensis*, *T. paradoxus*; Lynch and Duellman, 1997; Hedges, 2002; Heinicke et al., 2007; Thomas and Hedges, 2007; Hedges et al., 2008) or the collapse of former endemic subspecies (*Cyclura carinata bartschi*) into regional species designations (Bryan et al., 2007), thus underscoring the need for additional taxonomic research with associated ecological investigations for the Bahamian herpetofauna. Although some species such as *Anolis sagrei* and *Osteopilus septentrionalis* have broad ranges throughout the larger bank systems (table 1), other species from large bank systems have restricted and fragmented ranges of only a few islands (e.g., *Cyclura cychlura figginsi*, *C. c. inornata*, *C. rileyi cristata*). In addition, other species not associated with large bank systems are often restricted to one or a few isolated islands (*Anolis fairchildi*, *Leiocephalus greenwayi*, *L. inaguae*, *Sphaerodactylus inaguae*, *Epictia columbi*, *Typhlops paradoxus*; table 1).

Threats

Major threats to the herpetofauna of The Bahamas include inappropriate development, apathy, over-exploitation of wildlife, lack of law enforcement, hurricanes, introduced species, and disturbance by tourist activities. Mean number of annual foreign human arrivals to the Bahamas from 1998 to 2008 numbered 4,353,769 (range 3,347,665 to 5,003,967), roughly half of which were cruise ship passengers (Bahamas Ministry of Tourism, 2010). The surge in tourism has spurred unprecedented development projects throughout the country.

Until recently most high-density and large-impact development projects were confined to New Providence and Grand Bahama. However, visitation to the Family Islands (i.e., more remote islands away from the two main population centers) comprises approximately 16% of all Bahamian tourism (Lowe and Sullivan-Sealy, 2003) and is projected to increase as more development projects gain momentum on these islands. The entry into formerly pristine areas by large-scale developers has been welcomed by some interested in new employment and business opportunities, but feared by others concerned about the environment. Indeed, many of these large-scale development projects (e.g., Baker's Bay, Abaco; Bimini Bay, Bimini) incite confrontation between job production and economic development versus sound environmental policy and social considerations (Gruber and Parks, 2002). Moreover, the Bahamian government is challenged with a lack of institutional capacity and adequate human resources to fully implement and monitor environment-friendly policies across the spectrum of ministries and departments. When environmental impact assessments are conducted, they lack focus towards amphibians and reptiles, likely because of their secretive habits, small population sizes, and the difficulty in finding them in the field during rapid assessments (Gibbons et al., 2000; Tolson and Henderson, 2006). Realistically, however, amphibians and reptiles in general are often ignored and underappreciated relative to other fauna in the archipelago. Indeed, reptiles generally, but snakes in particular, are feared and often killed on sight (Tolson and Henderson, 1993).

The remoteness of most islands throughout the archipelago, and general lack of law enforcement, facilitates inappropriate activities and illegal wildlife exploitation. Though most illegal acts are likely unrecorded, in 1999 two Florida men were found guilty of illegally trafficking two species of protected rock iguanas (*C. cychlura figginsi* and *C. rileyi cristata*) from The Bahamas (U.S. Department of Justice, 1998). In 2001 three individuals were apprehended collecting lizards in the Cayman Islands, having been tracked smuggling *Ameiva*, *Anolis*, and *Leiocephalus* species out of the Bahamas from Eleuthera and Grand Bahama. More recently, two tourists in 2009 were arrested for capturing and eating an Allen Cays rock iguana (*C. cychlura inornata*) after the offenders posted pictures on the social networking website Facebook (IRCF, 2009). Rock iguanas, and non-native iguanas, are also moved illegally within The Bahamas in order to establish personal populations or remove potential problem animals from tourist destinations (Smith and Iverson, 2006; S. Buckner, J. Iverson, C. Knapp, pers. obs.). These unauthorized translocations are never based

on science and disregard population management protocols, and the unique genetic and behavioral structure of isolated populations (Malone et al., 2003; Bissell and Martins, 2004). The island of South Bimini once harbored a dense population of boas (*Epicrates striatus fosteri*), but these animals were removed illegally by the hundreds during the 1970s for the pet trade (Tolson and Henderson, 1993). Though numbers are unclear, non-Bahamians also visit Andros Island and smuggle boas (*E. striatus fowleri*) for the pet trade (H. Saunders, pers. comm.). For example, in 2001 a Florida man pled guilty for attempting to smuggle three *E. striatus fowleri* from Andros out in his hand luggage at Nassau International Airport. The snakes were confiscated by the Royal Bahamas Police Force, but as the individual had already passed through US Customs and Immigration, he was prosecuted in the U.S. District Court in Miami (U.S. Department of Justice, 2001).

Even with a nationwide ban on sea turtle harvest, enforcement in remote areas such as the uninhabited Conception Island National Park is problematic, and green turtles are occasionally removed from Conception Creek by humans from neighboring islands or on visiting yachts (Bjorndal et al., 2003). In the southern region of the archipelago, non-nationals illegally take sea turtles or remove them from nesting beaches (Franz et al., 1996; K. Bjorndal, pers. comm.). Rock iguanas are also hunted illegally for food on Andros Island (Knapp, 2007). Historically, most rock iguana hunting occurred on North Andros because of the extensive logging roads and larger human settlements. Poachers now travel south to catch rock iguanas because of their scarcity on North Andros. At least two interior camps that people use periodically while hunting iguanas (among other activities) have been identified on Alcorine and Mangrove Cays (Knapp, 2005, 2007).

Hurricanes commonly are interpreted to be a major catastrophic event affecting marine and terrestrial systems (e.g., Spiller and Agrawal, 2003; Scheffers and Scheffers, 2006; Crabbe et al., 2008). Though multiple factors influence species persistence on islands after a catastrophic event (Schoener et al., 2004), the herpetofauna and vegetation tend to be relatively more affected on low-elevation islands (Schoener et al., 2001; Spiller and Agrawal, 2003). This is a major concern for the Bahamian herpetofauna because most islands are low in elevation, and the entire range for some species and subspecies is one or a few small islands (e.g., *Anolis fairchildi*, *C. cychlura inornata*, *Leiocephalus greenwayi*, *L. inaguae*), thereby increasing their susceptibility to potential extirpation from impacts associated with storm-surge inundation and strong winds. Indeed, populations of *A. sagrei* in the Exuma Island chain have been extirpated after hurricanes, though recolonization for this widespread species often occurs via overwater dispersal (Schoener et al., 2001; Calsbeek and Smith, 2003). Other taxa are single-island endemics (table 1; Schwartz and Henderson, 1991), or less likely to overwater disperse at such rapid rates (e.g., rock iguanas; Malone et al., 2003), and are therefore more susceptible to extirpation. Finally, though some reptile eggs can survive periods of seawater immersion (Losos et al., 2003), hatch failure of Bahamian species ovipositing in

Figure 2. A minimum of 20 *C. cychlura inornata* rock iguanas congregate on a small section of Leaf Cay beach to be fed by Exuma tourists. This is not typical behavior (Color original — see www.ahailey.f9.co.uk/appliedherpetology/cariherp.htm).

subterranean chambers has been attributed to major storm events and elevated water tables (Iverson et al., 2004a).

Recently, the threat of tourism and associated food provisioning has emerged as a considerable problem. This activity is increasingly common in the Exumas and may pose a severe threat to the long-term survival of the native endangered rock iguanas. Tourist visits to some of these small islands have increased from approximately 20 persons per day in the 1980s to currently more than 150 persons per day (Iverson et al., 2004a). Presently, most tourists are brought to islands by operators using fast powerboats from Nassau in the north or Great Exuma in the south of the island chain. Throughout the Exumas, however, cruising yachtsmen or resort guests are visiting and feeding rock iguanas at an increasing daily rate (fig. 2). These daily island visits, especially to cays not commonly visited in the past, have caused rapid (within 1.5 years) behavioral changes in rock iguana populations (C. Knapp, pers. obs.). Island visits by tourists are expected to increase throughout the Exumas, leaving virtually no rock iguana population free from the potential impacts of food provisioning, often with unsuitable items (e.g., bread, cereal, ground beef; Hines, 2007; Knapp et al., 2008).

The disastrous effects of feral, non-native mammals (e.g., hogs, mongoose, cats, dogs, rats, mice, hoofed stock, etc.) on island reptile populations are well-documented (Iverson, 1978; Henderson, 1992; Haneke, 1995; Mitchell, 1999; Tolson, 2000; Hayes et al., 2004; Borroto-Paez, 2009). The problem is exacerbated by the difficulty in restricting pet ownership rights of private individuals, who often visit properties or islands other than their own. For example, despite the fact that since 1992 signs have been erected intermittently on the private islands of Leaf Cay

Figure 3. Representative sign erected on cays inhabited by rock iguanas in the Bahamas (Color original — see www.ahailey.f9.co.uk/appliedherpetology/cariherp.htm).

and U Cay in the Allen Cays (home of *C. cychlura inornata*) banning dogs (e.g., fig. 3), visitors must regularly be asked to remove their dogs (or cats) from these islands. A particularly striking Bahamian example involves the single population of White Cay rock iguanas (*C. rileyi cristata*) in the southern Exumas. This population was decimated in the mid-1990s when a person thoughtlessly removed a non-native raccoon from a private island and released it on White Cay (Iverson, unpublished; Hayes et al., 2004). The serendipitous discovery of the raccoon on White Cay in 1996, soon after its arrival, allowed for its removal in 1997, likely saving the taxon from extinction (Hayes et al., 2004).

The invasion of The Bahamas by black and norway rats (*Rattus* sp.) continues (Lee and Clark, 1995; Hall et al., 1998; Hayes et al., 2004), and their negative effects on island reptiles have been clearly demonstrated for many species (Case and Bolger, 1991; Cree et al., 1995; Tolson, 2000; Towns et al., 2007). Although suspected (Hayes et al., 2004), the direct negative impact of rats on rock iguanas (*Cyclura*) in the West Indies has not been confirmed directly, and positive population responses of rock iguanas following rat removal are not yet available (Hayes et al., 2004). Nevertheless, rat eradication programs (Hayes et al., 2004) have been successful on both White Cay (Exumas) and Low Cay (San Salvador), and

current efforts to eradicate rats on islands with important breeding bird populations (W. Mackin, pers. comm.) should also benefit the herpetofauna on those islands.

Feral pigs affect almost all aspects of ecosystem structure and function (Singer et al., 1984; Lacki and Lancia, 1986) as well as negatively influence wildlife by competing for resources, altering habitat structure and quality, and preying on native species including amphibians and reptiles (Coblentz and Baber, 1987; Taylor and Hellgren, 1997; Jolley et al., 2010). For example, Bratton (1975) reported a decline in species richness of small mammal and herpetofaunal communities in deteriorated habitat where wild pigs forage. Pigs were introduced in the early 20th century to Abaco, Andros, and Great Inagua and are a particular concern in locations where native species are already struggling. For example, Knapp (unpubl. data) found a negative correlation across 39 sites between the presence of feral pigs and the number of amphibian and reptile species on Andros Island as well as observing no rock iguanas from sites with feral pig activity. More studies need to be conducted to quantify the impacts of feral pigs, and efforts must be made to eliminate or reduce population sizes whenever possible.

Introduced Herpetofauna

The number of non-native amphibians and reptiles introduced into The Bahamas is becoming a pervasive problem and likely to increase unless proactive steps are taken to mitigate causes. There are currently a minimum of 16 documented breeding and established species of non-native amphibians and reptiles in The Bahamas (table 2) representing 26% of its terrestrial herpetofaunal diversity. These introductions are derived from both accidental and intentional actions, and are exacerbated by a combination of factors including the proximity to the United States, importation of materials and ornamental plants, the pet trade, interisland translocations within country, and tourism (Lee, 2004).

Only a single genus of iguana (*Cyclura*) is native to The Bahamas; however, two additional genera have established breeding populations in the Berry Islands. The green iguana (*Iguana iguana*) was first observed on Great Stirrup Cay in the Berry Islands in 1992 (S. Buckner unpubl. data) after apparently being released by an unidentified individual. In 2000, an agent for the cruise line that uses the cay for tourists expressed concern that the green iguana population was multiplying and was considered a “menace”. He also reported that another unidentified species of iguana was present on the cay. In 2009 green iguanas were observed on both Great Stirrup and Little Stirrup Cay (J. Wasilewski, unpubl. data). Additionally, spiny-tailed iguanas (*Ctenosaura similis*) were also observed on Great Stirrup Cay (E. Freid, unpubl. data) and in Bullock’s Harbour on Great Harbour Cay all in the Berry Islands (J. Wasilewski, unpubl. data). While *Iguana iguana* is not listed as being introduced on New Providence, Abaco or Great Exuma, individual green iguanas have been located intermittently over the last two decades and subsequently held captive at Ardastra Gardens, Zoo and Conservation Centre, or other facilities.

Table 2. Non-native amphibians and reptiles recorded from The Bahamas. Refer to fig. 1 for island abbreviations.

Family Species	Location	Breeding population	Source
Hylidae			
Hyla squirella	GB, SAN	yes	Crombie, 1972; Lee, 2004; S. Buckner, unpublished data
Microhylidae			
Gastrophryne carolinensis	GB, NP	yes	Schwartz and Thomas, 1975; Lee, 2004
Ranidae			
Lithobates clamitans	GB	unknown	Lee, 2004
Lithobates grylio	AB, AN, NP	yes	Schwartz and Thomas, 1975; Franz et al., 1996; Lee, 2004
Lithobates sphenocephala	GB	unknown	Schwartz and Thomas, 1975; Schwartz and Henderson, 1991
Gekkonidae			
Hemidactylus garnotii	AB, NP	yes	Buckner and Franz, 1994a; Meshaka, 1995; Lee, 2004
Hemidactylus mabouia	AB, EL, EX, LG, NP, SAN	yes	Franz et al., 1993; Buckner and Franz, 1994b; Lee, 2004; Krysko and Borgia, 2005; Krysko and Thomas, 2007; S. Buckner and W. Hayes, unpublished data
Sphaerodactylidae			
Sphaerodactylus copei	AN, NP	yes	Garman, 1888; Schwartz and Henderson, 1991; Lee, 2004
Polychrotidae			
Anolis equestris	NP	yes	S. Buckner and S. Cant, unpublished data
Corytophanidae			
Basiliscus sp.	NP	unknown	S. Buckner, unpublished data
Iguanidae			
Ctenosaura similis	BER	yes	E. Freid and J. Wasilewski, unpublished data
Iguana iguana	BER	yes	S. Buckner and J. Wasilewski, unpublished data
Colubridae			
Pantherophis guttatus	GB, NP	yes	Buckner and Franz, 1994c; Lee, 2004
Pantherophis alleghaniensis	AB	yes	Buckner and Franz, 1994d; Lee, 2004
Opheodrys aestivus	EL	yes	S. Buckner, unpublished data
Natricidae			
Thamnophis sauritus	NP	no	Buckner and Franz, 1998a; Lee, 2004
Thamnophis sirtalis	AB	no	Buckner and Franz, 1998b; Lee, 2004
Storeria dekayi	GB	yes	Lee, 2004, 2005

Table 2. (Continued.)

Family Species	Location	Breeding population	Source
Emydidae			
Terrapene carolina	GB	unknown	Lee, 2004
Trachemys decorata	NP	yes	Lee, 2004
Trachemys scripta	GB	yes	Lee, 2004
Trachemys sp.	AN, BIM, EL, EX, GB, LG	yes	Seidel and Adkins, 1987; Schwartz and Henderson, 1991; Franz et al., 1993; Mealey et al., 2002; Lee and Ross, 2001; Lee, 2004
Alligatoridae			
Alligator mississippiensis	BER	no	Carey, 2002; Lee, 2004

It is suspected that in some of these incidences, green iguanas were pets that had escaped from cruising boats (S. Buckner, unpubl. data). The potential impact of these two introduced iguanas on the native endangered rock iguanas is unknown, but efforts should be directed to extirpate these introduced species before they are transported to other islands in the archipelago. At least two American Alligators (*Alligator mississippiensis*) are known to have been introduced to The Bahamas (Carey, 2002; Lee, 2004). The first was observed in a golf course pond on Great Harbour Cay in 1995, which was removed in 2002 with no evidence of reproduction at that time (Lee, 2004). The second was removed from the same golf course in 2009 (Bahamas National Trust, 2009) suggesting that there was more than one animal introduced originally, reproduction had taken place, or a later introduction occurred.

The native reptiles most severely affected by non-native introductions currently are freshwater turtles. The genus *Trachemys* has a wide distribution across North, Central, and South America, as well as the West Indies (Iverson, 1992). One subspecies (*T. stejnegeri malonei*) is endemic to Great Inagua in the Bahamas. In addition, a population of *Trachemys* on Cat Island was originally described as an endemic species, *Trachemys felis* (Seidel, 1996). However, subsequent research demonstrated that the Cat Island population was the same species as the Jamaican slider (*Trachemys terrapen*; Seidel, 1988, 1996). Most authors have speculated that this turtle was introduced to Cat Island by humans (e.g., Iverson, 1992; Seidel, 1988, 1996); however, Lee and Ross (2001) argued that it is also possible that the species was originally endemic to the Bahamas, and subsequently introduced to Jamaica.

In either case, because of their use for human consumption (Berman, 1994; Seidel, 1996), sliders have probably been transported among islands by humans for perhaps 1300 years (Lee and Ross, 2001). Over the past 50 years the genus has also become popular in the pet trade, with turtles (especially juveniles) translocated around the world (Close and Seigel, 1997). As a result, sliders have been reported from New Providence, Grand Bahama, Bimini, Eleuthera, the Exumas, Andros, and Long Island (Franz et al., 1993; Lee and Ross, 2001; Mealey et al., 2002; Lee,

2004). Unfortunately, genetic identification of most of these records is lacking. The population on New Providence, however, represents a hybrid swarm of *T. s. malonei* and *T. terrapen* (Seidel and Adkins, 1987; Seidel, 1996), and possibly also North American red-eared sliders, *T. scripta elegans* (Lee and Ross, 2001). Populations on Great Exuma and Andros are also considered hybrid swarms possibly originating from New Providence (Seidel, 1988; Franz et al., 1993). These unauthorized translocations represent a considerable threat to the genetic integrity of the two long-established Bahamian forms, the Cat Island slider (*Trachemys terrapen*) and the Inagua slider (*T. stejnegeri malonei*). Unfortunately, no conservation efforts have been developed at this time for *Trachemys* management and habitat protection (Lee and Carey, 2001).

Conservation Legislation

Currently, there are few legislative laws directly protecting the herpetofauna of The Bahamas. All *Cyclura* are given full protection under the Wild Animals (Protection) Act of 1968. Under this act it is illegal to take or capture (or attempt to take or capture), or attempt to export any wild animal specified in the Schedule. With the exception of hawksbill turtles (*E. imbricata*), which received protection in 1986, sea turtles have been harvested legally by Bahamians in The Bahamas annually from 1 August to 31 March. The only restriction was a carapace length of 76 cm for loggerhead (*C. caretta*) and 61 cm for green (*Chelonia mydas*) turtles. In 2009, the Bahamian Ministry of Agriculture and Marine Resources amended the Fisheries Regulations governing marine turtles in order to give full protection to all sea turtles found in its waters. The new regulations prohibit the harvesting, possession, purchase and sale of turtles, their parts and eggs, as well as the molestation of marine turtle nests.

The Bahamas is party to multilateral environmental agreements that include the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). The Bahamas has been a signatory since 1979 and though no Bahamian amphibians are CITES listed, reptiles listed under Appendix I include all five sea turtle and three rock iguana (*Cyclura*) species. Reptiles listed under Appendix II include *Epicrates chrysogaster*, *E. exsul*, *E. striatus*, *Tropidophis canus*, and *T. curtus*. The Bahamas also enacted the Wildlife Conservation and Trade Act, 2004. The purpose of this act is to implement the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), with a view to the protection of wild species from harm through unsustainable exploitation.

The Bahamas signed the Convention of Biological Diversity in 1992. This convention concerns the conservation of biological diversity as a whole and the sustainable use of its resources. Under this convention The Bahamas is obliged to address the threat of invasive species and require environmental impact assessments for development projects. The Convention on Wetlands of International Importance — the Ramsar Convention was signed by the Bahamas in 2007. The Ramsar Convention

is an intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. This convention has brought about the creation of the National Wetland Policy and the National Wetlands Committee which oversees many development projects that affect wetlands in The Bahamas.

In 2008, The Bahamas along with the Dominican Republic, Jamaica, Grenada, St. Vincent, and the Grenadines launched the Caribbean Challenge, which is an effort by regional governments to build political support and generate long-term funding to protect at least 20 percent of participating countries' marine and coastal habitats by 2020.

Protected Areas Relevant to Herpetofauna

All national parks in The Bahamas are managed by the Bahamas National Trust (BNT). The BNT was mandated by an act of Parliament in 1959 with the responsibilities and legal authority to manage the national parks of the country. The BNT is the only non-governmental organization in the world to have ultimate responsibility for a country's entire national park system. In 2002, the size of the national park system of The Bahamas doubled with the addition of 10 new protected areas. These new areas, incorporating both marine and terrestrial habitats, increased the total national system to more than 283,280 ha and the total number of protected sites to twenty-five. One additional national park and the expansion of two others were declared in 2009 with official boundaries currently being drafted. Although the expansion of protected areas is admirable in principle, many of the parks are remote, making it an extreme challenge to manage, monitor, and staff them. Thus, some parks remain "parks on paper". For example, Grand Bahama has two park wardens for three national parks, Abaco has one warden for five national parks, Andros has one warden for five national parks, New Providence has one warden for four national parks, the Exuma islands have two wardens for two national parks, and Great Inagua has one warden for two national parks. Wardens have the power, authorities, and protection of an officer of the law while inside the boundaries of BNT property.

With the doubling of the park system in 2002, the Central Andros National Parks (total area 115,770 ha) were established to protect inland forest, coral reef, and wetland nursery areas on North Andros Island. Unfortunately, these protected areas are not ideal for rock iguana conservation because they are located on North Andros Island, which was severely degraded habitat for rock iguanas because of feral animals, loss of habitat, logging roads that allow access to the island interior, and illegal hunting pressure. Therefore, after nearly a decade of rock iguana research and advocacy on South Andros, the government of The Bahamas expanded the Central Andros National Parks to include critical habitat for the Andros rock iguana (*C. cychlura cychlura*) in the southern and central parts of the island. The expansion is significant because it is the first Bahamian protected area designated in part to

protect a terrestrial reptile. The expansion also includes newly documented juvenile loggerhead (*Caretta caretta*) sea turtle aggregations, which hold vast promise for future research (A. Bolten and K. Bjorndal, pers. comm.).

Union Creek Reserve (UCR) comprises an area of approximately 2000 ha and is located on the north coast of Great Inagua. The UCR is populated by hawksbill (*E. imbricata*) and green (*C. mydas*) sea turtle aggregations, which have been studied continually since 1975 (Bjorndal and Bolten, 1988a, 1988b, 2010; Bolten and Bjorndal, 1992; Bjorndal et al., 2000, 2003, 2005). Turtles in UCR have had legal protection from exploitation since 1965, which is well enforced by wardens of the Bahamas National Trust. Recently, however, all turtles have received legal protected status throughout The Bahamas (see Conservation legislation). Both hawksbill and green turtle aggregations in UCR are mixed stocks derived from several rookeries in the Atlantic, based on analyses of mtDNA sequences (Bowen et al., 2007; Bjorndal and Bolten, 2008). Another important green sea turtle aggregation is protected at Conception Creek within the Conception Island National Park. This population has also been under long-term study (Bjorndal et al., 2003), but it is remote and difficult to monitor.

Little Inagua National Park was established in 2002 and is the largest uninhabited island in the West Indies (12,691 ha). The biodiversity implications for its terrestrial herpetofauna are enormous. The only Bahamian record for the snake, *Hypsirhynchus parvifrons* is from the island. The island exists in an undeveloped condition, although feral animals and poaching of wildlife by non-Bahamians are serious problems, particularly for sea turtles. Little Inagua is also a documented nesting location for green sea turtles primarily, but also hawksbill and loggerhead turtles (K. Bjorndal, pers. comm.).

Established in 1958, the Exuma Cays Land and Sea Park (ECLSP) was the first park of its kind in the world and is the oldest national park in The Bahamas. The ECLSP is located in the central Bahamas and encompasses a 35 km long section of the northern Exuma Cays, covering an area of 45,600 ha. The waters of the ECLSP have been managed as a no-take marine fishery reserve since 1986, offering populations of commercially important marine species respite from over-exploitation. Though the park is mostly water, the cays provide vital refuge for snakes (*Cubophis*, *Epicrates*, and *Tropidophis*) and endangered rock iguanas. Translocated populations of three rock iguanas (*C. rileyi nuchalis, C. cychlura inornata,* and *C. cychlura figginsi*) have been established within the ECLSP as safeguard populations.

Conservation Initiatives

It is difficult to gain traction for conservation programs that focus on the herpetofauna of The Bahamas. As a maritime nation, conservation concerns and management of marine resources receive considerably more attention. In addition, humans instinctively fear reptiles (LoBue and De Loache, 2008) and as a consequence most

people want to eliminate, rather than study or conserve them (Tolson and Henderson, 2006). Therefore, conservation programs for amphibians and reptiles are limited, with the majority of effort focused on the most critically threatened taxa.

Rock iguanas

Determined efforts to raise awareness for protecting the three species of endangered Bahamian rock iguanas (*Cyclura*) have been ongoing since the 1990s. Because the remoteness of many rock iguana populations makes monitoring difficult, signs have been erected advertising the protected status of rock iguanas and informing tourists of their dwindling numbers and susceptibility to domestic pets (fig. 3). This is especially important given that Allen Cays rock iguanas (*C. cychlura inornata*) were recently poached and eaten by North American yachtsmen from a cay without signs.

To raise awareness and create talking points among Bahamians, rock iguana tee shirts, brochures, and posters endorsed by the Bahamas National Trust, and funded by a variety of private sources and non-profit organizations, have been distributed throughout the archipelago. In 1992 the San Salvador rock iguana (*C. rileyi rileyi*) was depicted on the Bahamian $1 bill to commemorate the Quincentennial of Columbus' landing on San Salvador. Additionally, Bahamian amphibians and reptiles have been depicted on a number of postage stamps within country. In 2009, The Bahamas National Trust initiated a revenue-generating mechanism for rock iguana conservation that is linked with signs and brochures recently produced. The mechanism is an "Iguana Fund" link on the BNT website (www.bnt.bs) where people can donate specifically to rock iguana conservation causes.

Two rock iguana conservation workshops have been held in The Bahamas with members of the International Union for the Conservation of Nature (IUCN) Iguana Specialist Group. The first meeting on San Salvador in 2000 involved a protected areas management strategy for Bahamian rock iguanas and seabirds. The document (Carey et al., 2001) produced from that workshop prioritized critical areas requiring protection in order to ensure the long-term survival of the three rock iguana taxa in The Bahamas. The second workshop was convened in 2005 on South Andros Island with local experts and stakeholders to draft a cooperative species conservation and management plan for the Andros rock iguana. The overall goal of the plan was to prioritize the conservation actions necessary to ensure the long-term survival of the Andros rock iguana throughout its range. The work presented in the plan detailed the management of the wild population, implementing education awareness programs, establishing and managing a national park, and mobilizing financial, technical and human resources (IUCN, 2010). The recovery plan was also intended to guide decision makers in government, and inspire funding agencies and the international conservation community to provide the attention this unique rock iguana species deserves.

An innovative, grassroots rock iguana conservation effort was initiated in 2005 by Ricardo Johnson, a local high school teacher on Andros Island. The foundation

for this initiative is the Central Andros Iguanas Football Club, which today has approximately 75 members aged 7 to 16. Mr. Johnson and Club members are personally spearheading an effort to increase local pride for their native rock iguana by wearing jerseys depicting rock iguanas and by distributing information cards. Though the Shedd Aquarium and the International Reptile Conservation Foundation donated initial funds for jerseys and equipment, it is the push from the local stakeholder level which makes this initiative so promising, important, and in need of a dedicated funding source.

Educating local stakeholders about conservation and habitat protection is critical for any successful conservation program. Working with the Andros Ministry of Education, teacher training workshops facilitated by the San Diego Zoo and Bahamas National Trust were held on Andros Island in 2007. The workshops engaged teachers with novel activities that advanced interest in the pine woodland ecosystem and its flagship species, the Andros rock iguana. Transportable education kits were also distributed to schools. These kits contained all necessary instructions and materials for lessons focused on the science of understanding the iguanas' decline and management actions needed to ameliorate it. In 2002, scientists from Loma Linda University and the Gerace Research Center developed an innovative, hands-on experience for the educators and students (grades 4-10) of San Salvador Island (Carter et al., 2005). The three, one-day programs were titled "Celebrating Biodiversity 2002". Following an introductory multimedia presentation, approximately 150 participants were engaged in three one-day activities including a boat trip to visit the endangered rock iguanas (*C. rileyi rileyi*) on Green Cay and the nearby seabird colonies, a hands-on learning experience about research techniques at a mock field camp, and an introduction to the island's rich biodiversity including invertebrates, plants, seabirds, and reptiles. At the end of the program, students were given tee shirts, a certificate, and a challenge to become better-informed stewards of their unique and fragile ecosystems.

Sea turtles

Concerted education outreach efforts for sea turtles have been ongoing since 1979, when Carr and Bjorndal (1979) published an article in The Bahamas Naturalist. Since that time, many programs and individuals have been involved, culminating in the passage of regulations banning all harvest of sea turtles in The Bahamas, effective September 2009. A current effort by the organization, Family Island Sea Turtle Research and Education, established by Steve Connett and Barbara Crouchley promotes education about sea turtles in many of the Family Islands throughout The Bahamas. During presentations, fishery regulations are discussed and the work of the BNT is advanced to local inhabitants. At times, school children participate with tagging turtles. The program has been successful in reaching even remote areas of the archipelago (e.g., Rum Cay and Crooked Island). In addition, the Bahamas Sea Turtle Conservation Group (BSTCG) works to increase awareness about sea turtles and the threats facing them. Through education and protection, the

group hopes to motivate humans to respect the ocean ecosystems and conserve sea turtles. In the years just prior to the ban on sea turtle harvesting in The Bahamas, the BSTCG website recorded more than 5500 online signatories petitioning for the ban. Finally, educators from the Bahamas Reef Environment Educational Foundation (BREEF) speak to about 1500 children annually about sea turtle conservation during general marine conservation talks.

Some protected areas in The Bahamas include important sea turtle foraging aggregations and habitat, such as the Union Creek Reserve and Conception Island National Park. Little Inagua National Park includes important nesting areas for sea turtles in The Bahamas. The Department of Marine Resources is now working on designating more marine protected areas, some of which will be important for sea turtle populations.

Snakes and other reptiles

The Bahamas lack a large, public zoological institution, yet confiscated reptiles are often housed at the Ardastra Gardens, Zoo and Conservation Centre in Nassau. Ardastra also exhibits, among other reptiles, Bahamian boas (*Epicrates striatus*), dwarf boas (*Tropidophis curtus*), and curly-tail lizards (*Leiocephalus carinatus*). Snake education is a priority at Ardastra and since 1998 approximately 10,000 local area students annually receive interactive educational experiences with snakes. Small scale workshops are sometimes conducted at Ardastra where the public is invited to learn how to handle a wild snake in the event that one is found in the home. At times, snakes are taken to public events at shopping malls to reach members of the public that do not usually enter Ardastra Gardens. The Bahamas National Trust (BNT) also educates 10,000 students annually through environmental educational programs, yet only a fraction of these programs concern snakes. Consequently, approximately 250 and 200 students participate annually in BNT snake conservation education on New Providence and Grand Bahama, respectively. Other than these few programs, snakes receive no conservation attention, which is problematic given the general fear of snakes among residents and tourists. In 1994, the BNT launched the Discovery Club program to implement fun environmental education programs for its young members. Discovery Club kids participate in activities that lead toward badge awards including bugs, astronomy, camping, coral reefs, and muddy mangroves. Recently, a "Herps" badge was included, which will optimistically expand amphibian and reptile awareness throughout the country, especially since the Discovery Club has been expanded from Nassau and Grand Bahama to include the Family Islands of Abaco (spearheaded through "Friends of the Environment"), Andros, Eleuthera, and the Exumas.

Long-term research

The Bahamian archipelago serves as a natural laboratory and from an ecological perspective the long-term research of Thomas Schoener and Jonathan Losos,

with their graduate students, should be recognized for its importance to our understanding of ecology (Losos and Spiller, 1999; Losos et al., 2004), evolution (Losos et al., 1997; Schoener et al., 2005), and ecosystem impact and recovery after catastrophic events (Spiller et al., 1998; Schoener et al., 2001, 2004). See also Franz et al. (1996) for a complete list of references prior to 1996.

From a conservation perspective, long-term studies of natural populations and communities are generally regarded as indispensable for understanding normal population trends and fluctuations, or direct responses to disturbance (Tinkle, 1979). Evaluating the real and potential impacts of disturbance, however, requires good quality life history and demographic data (Iverson et al., 2006). Unfortunately, little of such research has focused on long-lived lizards (i.e., those that mature at >5 years; e.g., reviews in Vitt and Pianka, 1994). This is particularly disconcerting because long-lived lizards, especially those on islands, are disproportionately threatened with extinction (Alberts, 2000). The longevity of such lizards presents an obstacle to obtaining multi-generational data that can be used to quantify life history traits and permit population modeling because the work is often time-consuming and expensive. Consequently, developing sound management strategies for such species are often hindered.

In 1980 John Iverson led an Earthwatch program to The Bahamas for the primary purpose of surveying the rock iguanas in the Exuma Island chain from the Allen Cays in the north to White (Sandy) Cay in the south (ca. 200 kilometers). An attempt was made to visit every island previously reported to harbor rock iguanas, as well as those suggested by local Bahamians or known to have suitable habitat. A secondary purpose of that program was to identify a long-term field site for Earlham College student-faculty research on rock iguanas. Because of its proximity to other inhabited islands and (at that time) its low visitation rate by tourists, the Allen Cays were selected for ongoing mark-recapture studies.

Between 1982 and 2010, Iverson made 26 research trips to the Allen Cays, ranging in duration from 3 to 31 days (mode 9 days), and involving two to twelve Earlham students, faculty, or alumni per visit (mode 12). Most of those trips were self-funded by the participants, with some supplemental funding provided by endowed student-research funds through Earlham College.

The long-term study of the Allen Cays populations has provided data on growth (Iverson et al., 2004b), reproduction (Iverson et al., 2004a; Knapp et al., 2006), demography (Iverson et al., 2006), variation in sex ratio (Smith and Iverson, 2006), longevity (Iverson et al., 2004a), and the second life table for a West Indian rock iguana (Iverson, 2007). This work has also produced numerous anecdotal natural history observations (e.g., Smith et al., 2008, 2009a, 2009b; Hines et al., 2010), and has provided valuable research and practical experiences for undergraduate students (e.g., Valiulis et al., 2004; Pieper et al., 2009). Ultimately, this study has provided baseline demographic data for managing this subspecies, identifying factors that may contribute to population increases and declines, and can be extrapolated to similarly imperiled species with the goal of reversing their declines.

Two additional long-term research projects have been on-going since the early 1990s for Bahamian rock iguanas. Along with their graduate students, William Hayes and Ron Carter from Loma Linda University have been studying the ecology of all three *Cyclura rileyi* subspecies including population assessments, behavioral ecology, reproduction, movement patterns, and morphological variation (Carter and Hayes, 2004; Hayes et al., 2004). Long-term studies of *Cyclura cychlura* have also been conducted in the Exumas and on Andros Island by Charles Knapp from Shedd Aquarium and the San Diego Zoo Institute for Conservation Research. Work in the Exumas quantified the success of a rock iguana translocation program (Knapp, 2001; Knapp and Malone, 2003), while on Andros the research has included home range and habitat preference (Knapp and Owens, 2005), nesting ecology and reproductive variation (Knapp et al., 2006; Knapp and Owens, 2008), dispersal and survival of hatchlings (Knapp et al., 2010), and tourist and local attitudes towards rock iguanas (Knapp, 2007). The research and educational outreach endeavors of Carter, Hayes, and Knapp have been applied directly toward national park recommendations on San Salvador and Andros Islands (e.g., Hayes, 2003).

Sea turtles are also long-lived reptiles with life history traits that make them vulnerable to overexploitation. Accurate analyses of population trends and demographic parameters are critical for modeling population growth, understanding recovery of depleted populations, and for developing and assessing management plans for these species (Bjorndal et al., 2005). However, not only are long-term research programs involving sea turtles time consuming and expensive, many species disperse over large geographic areas and/or have life stages inaccessible to scientists. Research on sea turtles contributing to both local and regional conservation management has been on-going in The Bahamas since 1975 by Karen Bjorndal and Alan Bolten from the University of Florida. The majority of work has been conducted on three species at two sites — Union Creek, Great Inagua and Conception Creek, Conception Island.

Selected results stemming from the long-term program include investigating nutrition and grazing behavior of green turtles (Bjorndal, 1980), examining growth rates of green, hawksbill, and loggerhead turtles (Bjorndal and Bolten, 1988a, 1988b, 2010), exploring size- and sex-specific relationships of blood profiles for green turtles (Bolten and Bjorndal, 1992), evaluating a density-dependent effect on growth rates of green turtles (Bjorndal et al., 2000), estimating annual survival probabilities of green turtles (Bjorndal et al., 2003), generating estimates of annual abundance for juvenile green turtles and suggesting best approaches for monitoring sea turtle population trends (Bjorndal et al., 2005), reporting that estimates of connectivity and genetic diversity in sea turtle populations are affected by the level of temporal variation in contributions from source stocks (Bjorndal and Bolten, 2008), and evaluating hawksbill turtle success in a peripheral habitat (Bjorndal and Bolten, 2010).

There is often a disconnect between conservation biology within the academic environment and conservation action outside of academia (Kainer et al., 2006). The

research of Bjorndal, Bolten, Hayes, Iverson, and Knapp attempt to bridge the gap between conservation research and applied management. The long-term commitment by these researchers has earned them the trust and respect of the Bahamian government and Bahamas National Trust. All either serve as scientific advisors on the BNT Council, or chair and/or serve as members on the BNT science advisory committee (SAC). The SAC is a multi-disciplinary network of scientists and experts whose knowledge, experience, and interest in the Bahamian environment and its natural resources provide immeasurable contributions to advancing the mission of the BNT. The purpose of the SAC is to advise the Council of the Bahamas National Trust on science-related matters and conservation issues in the Bahamas.

Ecotourism Endeavors

In The Bahamas, tourism has traditionally been a coastal industry focusing on cruise ship and resort clientele (Lowe and Sullivan-Sealy, 2003). However, studies elsewhere demonstrate that revenues earned through ecotourism, if managed properly, have potential to augment local economies, positively influence local attitudes, and fund conservation initiatives (Archabald and Naughton-Treves, 2001; Walpole and Goodwin, 2001; Walpole et al., 2001). A major component attracting ecotourists is a flagship species (Krüger, 2005), and if such species are absent, the ecotourism market can be severely limited (Munn, 1992). The Bahamas, however, do not retain traditionally charismatic, mammalian megafauna, but instead are inhabited by three species of rock iguana (*Cyclura*) and five species of sea turtles.

Promoting non-traditional flagship species such as reptiles tends to be more difficult than their high-profile mammalian counterparts (but see Tisdell and Wilson, 2002; Walpole and Leader-Williams, 2002 for exceptions with nesting sea turtles and the Komodo dragon, respectively). However, because rock iguanas are large, photogenic, and charismatic, they have the potential to serve as flagship species for ecotourism endeavors and conservation of the tropical dry forest and beach scrub ecosystems they inhabit. Tourist surveys from Andros Island revealed that visitors specific to that island are nature-oriented and supportive of national parks and associated entrance fees. There also is visitor interest in guided field tours to observe rock iguanas and other wildlife on the island (Knapp, 2007).

Currently, a small ecotourism market exists in the form of annual "citizen scientist" research expeditions dedicated to the study of Bahamian rock iguanas. Participants of these Shedd Aquarium (Chicago, Illinois) research expeditions pay (∼US $2000) to participate in long-term rock iguana research projects on Andros and several islands in the Exuma Island chain (Knapp, 2004). Additionally, tour companies based in Nassau and Great Exuma offer one-day excursions to islands in the northern and central Exuma chain to view rock iguanas. While promoting conservation is not the focal point of the one-day rock iguana viewing excursions, the willingness of tourists (as many as 150 per day; Iverson et al., 2006) to pay (∼US $200) to observe rock iguanas, among other activities, underscores the

potential for a sustainable ecotourism market if company actions are modified to promote conservation and sustainable activities.

Scuba divers also are valuable participants in ecotourism and provide coastal areas with economic incentives to protect and preserve local marine wildlife and habitats (Arin and Kramer, 2002). Thousands of scuba divers visit The Bahamas annually and the ban on killing sea turtles in Bahamian waters not only benefits sea turtles but also could substantially benefit the tourism industry through increased fees. Surveys suggest that scuba divers are willing to pay almost US $30 more per dive for an increased chance to observe a sea turtle in the wild (White, 2008). In order to capture the increased dive value for conservation activities, non-governmental organizations and dive operators should establish conservation funds, or non-governmental organizations establish their own funds and solicit donations from divers.

Recommendations and Conclusions

The Bahamas need more local voices to promote conservation of native amphibians and reptiles. Cultivating respect and concern for Bahamian herpetofauna that may ultimately lead to conservation must be fostered within and outside the classroom. Most (84%) Bahamians live in urban areas (Central Intelligence Agency, 2010), and thus the majority lack awareness about nature and ecological concepts. The Bahamas National Trust has increased its effort to connect people to nature by expanding the national park system and augmenting environmental education opportunities for school groups. However, an environmental curriculum needs to be enhanced in schools and standardized throughout the country. Complimentary educational messages should be implemented and promoted whenever possible. For example, though no potently venomous snakes inhabit The Bahamas, they are still killed routinely by people who fear them. Additionally, domesticated mammals allowed to roam or released intentionally on islands have the potential to decimate the herpetofauna. Therefore, special educational efforts should be implemented to address these issues. The College of The Bahamas must engage students in field research opportunities and promote environmental education as a career. Undoubtedly, careers in environmental sciences are limited in The Bahamas, but the country needs a wider diversity of ecologists with broad interests beyond marine science or ornithology.

The Bahamas National Trust and Bahamian government have made immense progress with efforts to increase the number of protected areas in country. However, the challenge remains to ensure that protected areas are suitably staffed, patrolled, and their benefits advanced to Bahamians. Moreover, amphibians and reptiles are an underappreciated cultural legacy in The Bahamas. Care should be taken to consider the herpetofauna when prioritizing conservation areas based on ecosystem function, rarity, endemism, and sociopolitical, legislative, and economic factors. Areas have been identified and proposed in the past for protection that would include

herpetofauna of concern, such as Cay Sal and Plana Cays, and these proposals should be revisited. Indeed, the greatest sea turtle nesting area in The Bahamas occurs on the Cay Sal Bank (Addison and Morford, 1996; Addison, 1997) and plans to develop these islands are a great risk to these turtles. A proposal is under review by The Bahamas Government, which was submitted by the Bahamas National Trust, for a National Park on San Salvador that would include habitat for endangered reptiles such as *C. rileyi rileyi* and the island endemic *Epictia columbi*. We encourage the acceptance of the proposal. Finally, both within and outside protected areas, law enforcement must serve more as a deterrent to curtail illegal acts perpetrated against wildlife.

One of the most critical issues for the herpetofauna of The Bahamas is habitat loss or alteration due to tourism development or tourism-driven activities. Herpetofaunal inventories should be emphasized in all environmental impact assessments. Correctly managed tourism has the potential to ensure the long-term survival of both endangered species and their habitats via educational and economic opportunities (Giannecchini, 1993; Knapp, 2004). These opportunities, however, rely on healthy animal populations and sustainable management. Behavioral alterations and long-term physiological consequences stemming from tourism activities such as food provisioning should be monitored and managed with species health in mind. Moreover, tourism companies profiting from activities involving the interactions with the native herpetofauna (e.g., scuba diving and rock iguana viewing) should be engaged and encouraged to add a small contribution to each ticket or package sold with proceeds benefiting research and conservation activities for the focal species.

The introduction and naturalization of non-native plants and wildlife is a global problem that particularly affects islands (Gibbons et al., 2000). From a pet trade and tourism attraction perspective, if non-native species continue to be imported into the country, then the problem of invasive species will persist and escalate because most pet owners are not aware of the consequences associated with their release. The colonies of introduced iguanas in the Berry Islands could be devastating if people decide to transport them to other islands, as witnessed in the Exumas with native rock iguana species (S. Buckner, J. Iverson, C. Knapp, pers. obs.). With the exception of *Trachemys*, the Bahamian government does not grant permits for the importation of amphibians or reptiles. To be sure, non-native reptiles are still finding their way into the country (table 1; S. Buckner, unpubl. data). Therefore, the Bahamian government should reduce the risk of accidental importation by educating custom officers about the threat of non-native species, and by eliminating the importation of *Trachemys*.

Research must be initiated for the vast number of Bahamian species that are data deficient or not evaluated in regards to IUCN listings. We cannot protect what is unknown and 85% of the native, terrestrial Bahamian herpetofauna is understudied with little known about their ecology and natural history (table 1). Amphibian population declines were first recognized as a global phenomenon in the early 1990s (Wake, 1991) and current extinction rates for amphibians are estimated as

much as 200 times higher than background (Roelants et al., 2007). While there is no evidence of disease or decline in Bahamian amphibian populations, baseline population and disease-monitoring studies should be initiated prior to the advent of declining populations. In addition, reports of sea turtle nesting in The Bahamas are incomplete (Carr et al., 1982). Thus, additional information concerning the location of significant nesting beaches is invaluable for turtle management and conservation in The Bahamas (Addison and Morford, 1996).

The potential impacts of non-native mammals are understood theoretically, but we have little understanding concerning impacts that non-native herpetofauna will have on Bahamian amphibians and reptiles. Therefore, studies should also focus on native-non-native interactions. At present, Bahamian biodiversity is catalogued nationally through The Bahamas National Herbarium, The Bahamas National Entomological Collection, and a National Collection of Bird Skins, yet there is no national herpetological collection. The Bahamas should establish a national herpetological specimen collection for scientific, training, and educational purposes. In advance preparation of such a collection, Sandra Buckner is currently the custodian of all native and non-native herpetological specimens that have been collected when specimens are found dead.

Finally, long-term monitoring of amphibian and reptile populations is essential and must be aided by establishing standard methods and techniques. It is equally important that the Bahamian government, Bahamas National Trust, College of the Bahamas, and other conservation organizations in country recognize that rigorous field programs focusing on the distribution, abundance, status, and trends of populations and species are critical and worthwhile. When long-term and widespread monitoring becomes the norm, declines are less likely to go unnoticed and more likely to be addressed unequivocally.

Acknowledgements. We thank The Bahamas Environment, Science, and Technology Commission, The Bahamas National Trust, and The Bahamas Department of Agriculture, for permission over the years to conduct research in The Bahamas. Karen Bjorndal and Alan Bolten provided valuable comments to the manuscript. We thank the many researchers who have allowed one or more of us to accompany them in the field and also for their interest in the herpetofauna of The Bahamas. These include J. Bendon, K. Bjorndal, A. Bolten, R. Carter, S. Conners, K. Dodd, R. Franz, C. Hass, W. Hayes, W. Meshaka Jr., S. B. Hedges, K. Hines, L. Roth, J. Rothchild, D. Steadman, and J. Wasilewski. David Lee provided literature. The original manuscript was improved with reviews by Richard Franz, Kenney Krysko, and an anonymous reviewer. This work was made possible in part because of years of research in The Bahamas, supported by (in alphabetical order) the American Zoological Association Conservation Endowment Fund, Chicago Zoological Society Board of Trade Endangered Species Fund, Chicago Herpetological Society, Disney Wildlife Conservation Fund, Earlham College, International Iguana Foundation, John G. Shedd

Aquarium, Tiamo Resorts of South Andros, University of Florida, U.S. Fish and Wildlife Service (USFWS) International Conservation Fund, Zoological Society of San Diego, and the vast number of dedicated students and volunteers who assisted with rock iguana field work.

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Accepted: August 11, 2010 (AH).