Conserving the Puerto Rican herpetofauna

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Abstract. With a total area of 8900 km^2, Puerto Rico is the smallest of the Greater Antilles. It is divided in three physiographic regions or areas of relief: the mountainous interior, the karst region, and the coastal plains and valleys. The island comprises six ecological life zones: subtropical dry forest, subtropical moist forest, subtropical wet forest, subtropical rain forest, lower montane wet forest and lower montane rain forest. The herpetofauna of Puerto Rico consists of 25 species of amphibians (19 native, six introduced) and 56 species of reptiles (52 native, four introduced). The goal of this paper is to describe some of the present studies directed towards the conservation of Puerto Rican herpetofauna. *Eleutherodactylus karlschmidti*, *E. jasperi* and *E. eneidae* have not been seen or heard since 1976, 1981 and 1990, respectively, and are probably extinct. Since 2000, the potential causes of amphibian declines in Puerto Rico have been studied, and a synergistic interaction between climate change (increased dry periods) and disease (chytridiomycosis) have been proposed as an explanation for the patterns observed. Recovery efforts for *Peltophryne lemur* include a captive-breeding program, reintroductions island-wide educational outreach, protection and restoration of existing habitat, and the creation of new breeding ponds. Among reptiles, the first conservation efforts to protect *Epicrates inornatus* were limited to trying to halt collection and hunting. However, current strategies to preserve the boa include gathering basic biological information, habitat conservation, and educational outreach. Recent efforts for the conservation of *Trachemys s. stejnegeri* combine three research approaches to clarify the status of local populations: a mark-recapture-release study, field monitoring of reproductive activity (i.e., nocturnal patrolling to identify nesting activity), and field assessment of the potential impact of introduced species, particularly identification of predatory species and exotic turtles. Recovery initiatives for *Cyclura stejnegeri* include management of invasive

APPLIED HERPETOLOGY 4: 327-345
Also available online - www.brill.nl/ah

mammals, a headstart program for hatchling iguanas, and the assessment of the etiology of a condition causing blindness in adult iguanas. A reforestation project aimed at recovering a local herpetofaunal assemblage after disturbances in a limestone valley in northern Puerto Rico is discussed. As population sizes of common colonizers such as *Eleutherodactylus* and *Anolis* increased, larger forest-interior and predatory species like *Epicrates inornatus*, *Alsophis portoricensis* and *Anolis cuvieri* followed. Finally, the Mona Island marine turtle monitoring program is discussed and compared to other similar programs in Puerto Rico. As these and other similar conservation efforts provide scientifically based management recommendations, we hope to succeed in conserving the diverse herpetofauna that characterizes Puerto Rico.

Key words: Amphibian; biodiversity; Caribbean; chytrid; climate change; conservation; Puerto Rico; reptile; West Indies.

Introduction

Puerto Rico is the easternmost of the Greater Antilles and it is located between 18°35′–17°55′N and 67°15′–65°35′W. It is the smallest of the Greater Antilles with a total area of 8900 km^2, 12.9, 8.6 and 1.3 times smaller than Cuba, Hispaniola, and Jamaica, respectively. It is 179 km long and 58 km wide, and its highest peak is Cerro Punta in Jayuya (elevation 1338 m). The highest peaks on Cuba, Hispaniola, and Jamaica, respectively, are 1.5, 2.3 and 1.7 times higher than Cerro Punta. The three largest Puerto Rican satellites islands are Vieques (138 km^2) and Culebra (27 km^2) in the east, and Mona (57 km^2) in the west.

Physiography and general ecology

Puerto Rico is divided in three physiographic regions or areas of relief: (1) the mountainous interior; (2) the karst region; and (3) the coastal plains and valleys (Cruz and Boswell, 1997; Gannon et al., 2004).

The mountainous interior is the largest of the three regions, and it is the cradle of the main rivers of the island. This ‘backbone’ or mountainous spine is composed of the Cordillera Central and the Sierra de Luquillo. The Cordillera Central extends in an east-west direction from Sierra de Cayey in the southeast running almost without interruptions to Mayagüez, which lies close to the west coast. Sierra de Luquillo, an isolated upland region in the northeast, and the largest natural protected area of Puerto Rico, shelters montane rainforests at lower elevations and cloud forests and elfin woodland at the highest elevations; one of the largest tracks of elfin woodland in the Caribbean is found in these mountains (Hedges, 1999).

The Puerto Rican karst region includes two separate zones: (1) the northern karst, which ranges from Loiza in the northeast to Aguadilla in the northwest; and (2) the southern karst, which extends from Juana Díaz (east of Ponce) to Guayanilla to the west (Cruz and Boswell, 1997; Lugo, 2005). The Puerto Rican northwestern karst topography is similar to that in Cockpit Country of Jamaica, Los Haitises of Hispaniola, and the Viñales region of western Cuba (Hedges, 1999).

According to the Holdridge system of classification, Puerto Rico has been divided into six ecological life zones: (1) subtropical dry forest; (2) subtropical moist forest; (3) subtropical wet forest; (4) subtropical rain forest; (5) lower montane wet forest; and (6) lower montane rain forest (Ewel and Whitmore, 1973). Average annual rainfall is 60-110; 100-220; 200-400 cm in the first three zones, respectively, with a lower rainfall limit of 380 cm in the fourth zone, and with elevations over 1000 m in the lower montane wet forest and lower montane rain forest. An alternative system has been proposed by Lugo (2005), in which geological data were incorporated with temperature, precipitation, and elevation information of the Holdridge system to generate ten geoclimatic zones or forest types for Puerto Rico.

Conservation in Puerto Rico

Because Puerto Rico is a US Territory governed by a commonwealth, state and federal agencies and their laws are involved in the island's conservation practices. At the state level, the Planning Board, the Environmental Quality Board, the Department of Agriculture, the Department of Natural and Environmental Resources, and all 78 municipalities through their Territorial Arrangement Plan, deal with corresponding conservation issues (Quevedo, in press). The main state agency actively engaged in conservation in Puerto Rico is the Department of Natural and Environmental Resources (DNER). Established in 1972, this agency has the difficult responsibility of protecting and managing Puerto Rican natural resources, including biodiversity. Among many other responsibilities, the DNER is in charge of endangered species, forest reserves, wildlife refuges, and corridors. The DNER's capacity to accomplish these goals and responsibilities are seriously limited by (1) political pressures, (2) budget and (3) excessive responsibilities. At the federal level, the two most important agencies involved in conservation are (1) the U.S. Fish and Wildlife Service (USF&WS) as part of the US Department of Interior (USDI), and (2) the U.S. Forest Service (USFS) as part of the U.S. Department of Agriculture (USDA). Other federal agencies such as the U.S. Environmental Protection Agency (EPA), the USDA Natural Resources Conservation Service (NRCS) and the U.S. Corps of Engineers, are also involved. The USF&WS is responsible for endangered species and their habitats and for managing several federal wildlife refuges, such as Desecheo, Vieques and Cabo Rojo. The USFS is responsible for protecting and managing El Yunque, the largest forest reserve in Puerto Rico. Within the USFS, the International Institute of Tropical Forestry (IITF) is in charge of research and management of forest resources. As in the Continental USA, in Puerto Rico the USF&WS has not been effective at listing endangered species and declaring and protecting critical habitat for listed species. This shows that political pressures and budget limitations for conservation agencies are also a problem at the federal level.

Puerto Rico's history of protecting areas for conservation purposes goes back to 1876, when the Spanish Crown protected areas in El Yunque and Utuado. Laws of the Spanish Crown protected forests, mangroves and water resources. Since then, Puerto Rico has created a system of forest reserves that includes 21 forest reserves (such as Maricao, Toro Negro, Carite, Cambalache and Susua) administrated by the state government (DNER), El Yunque administrated by the federal government (USFS-USDA), and San Patricio, Monte La Choca, Nuevo Milenio and Del Pueblo are co-managed by the state government and local environmental groups that are actively involved in managing and protecting these areas (Sanchez-Martínez, 2007). In addition to these 26 forest reserves, Puerto Rico also has wildlife refuges (federal and state) and natural reserves such as Mona Island and Caja de Muertos. Since all these areas are isolated from each other, a series of corridors have been proposed to connect some of them and increase their conservation value.

A very important asset to the conservation of land and biodiversity in the island is the Puerto Rico Conservation Trust, a private corporation. Since 1970 it has managed to acquire and protect 20 natural areas for conservation for a total of 21 364 acres (86.5 km^2) which is the size of Mona Island and Culebra combined. In addition, they offer excellent interpretative nature programs at Las Cabezas de San Juan Natural Reserve in Fajardo, Hacienda Buena Vista in Ponce and in La Esperanza en Manatí.

Taking all protected areas into consideration, including state and federal forest reserves, wildlife reserves and other preserved areas mentioned above, Puerto Rico protects 7.2% of its territory for conservation. To put this number in perspective, the United States protects 25% of its territory, Costa Rica 34%, Cuba 32%, the Dominican Republic 42% and the Virgin Islands, where tourism plays an important role in the economy, 54% (Lloveras, in press). In 2007 a group of scientists discussing the effect of climate change on Puerto Rican biodiversity and natural resources requested the government to protect 25% of the Puerto Rican territory. We hope that this goal is met in the near future and surpassed thereafter.

The Puerto Rican Herpetofauna and Their Conservation

Twenty-five species of amphibians occur in Puerto Rico: 19 are native and six are introduced (Joglar, 2005a; Rios-López and Thomas, 2007; see the appendix for a complete list). The number of native species of amphibians in Puerto Rico (19) is high, especially considering the size of the island. Puerto Rico has the highest number of species of amphibians per area in comparison to the other Greater Antillean islands (table 1) and many other islands of the world (Duellman, 1999a,b; Joglar, 2005a). However, the number of families and genera of native amphibians is low, with only two families (Leptodactylidae and Bufonidae) and three genera (*Eleutherodactylus*, *Leptodactylus* and *Peltophryne*) present. Most of the native species belong to the genus *Eleutherodactylus* (89.5%) and to the family Leptodactylidae (94.7%). Endemism is high; most native species ($15/19 = 78.9\%$) are endemic to Puerto Rico (Mona Island included); however, four additional species are endemic to the Greater Puerto Rican Bank, as they are also found in the Virgin Islands and on other islands that were connected to Puerto Rico during low sea levels associated with glacial maxima. Six species of amphibians have been

Table 1. Species of amphibians (native, endemic and introduced) and percentage of endemism. Adapted from Hedges (1999) and Duellman (1999a,b). Hispan refers to Hispaniola, PR Bank to Puerto Rican Bank, PR to Puerto Rico and Lesser A. to Lesser Antilles.

	Native species	Endemic species	Percentage of endemism	Introduced species	Total species	Area (km^2)	Species/ 10^6 km^2
Cuba	52	50	96	2	54	110 922	469
Hispan	63	63	100	2	65	76 470	824
Jamaica	22	22	100	4	26	10 990	2002
PR Bank	21	21	100	6	27	9 511	2103
PR	19	15 (19)	78.9 (100)	6	25	8 990	2002
Lesser A.	10	9	90	4	14	5 840	1712
Bahamas	2	0	0	4	6	11 296	177

Table 2. Number of reptiles; [a]according to Uezt (2000; web page); [b]according to Powell et al. (1996).

	World[a]	West Indies	Puerto Rico	Exotics in PR	Endemic species	Threatened/ endangered
Reptiles	8002	500[a]	56	4	89% (42/47)	22-24%
Turtles	296	13[b]	7	1	0	83% (5/6)
Lizards	4610	321[b]	34	2	87% (28/32)	12% (4/32)
Amphisbaenians	160	12[b]	4	0	100%	0
Snakes	2911	107[b]	10	?	90%	22% (2/9)
Crocodilians	23	4[b]	1	1	0	0
Tuataras	2	0	0	–	–	–

introduced in Puerto Rico since the 1920s (Joglar, 2005a); Puerto Rico has the highest number of introduced species in the Greater Antilles (table 1).

Fifty-six species of reptiles occur in Puerto Rico; 52 are native and four are introduced (Joglar, 2005b; see the appendix for a complete list). Included as native species are five marine turtles that have a wide distribution in the West Indies and in the rest of the world. Of the terrestrial native species, 89.4% (42/47) are endemic to Puerto Rico and the Puerto Rican Bank (table 2).

The status of Puerto Rican amphibians has been reviewed extensively (Joglar and Burrowes, 1996; Joglar, 1998; Burrowes et al., 2004; Burrowes and Joglar, 2005) — see next section. Eleven reptilian species are currently protected as threatened or endangered (appendix). Some common characteristics among these species are: (1) large body size; (2) specialists in habitat, behavior, or morphology; (3) limited distributions; (4) human consumption or commercial value; and (5) feared and persecuted by humans (Joglar, 2005b). For a summary of factors affecting vulnerability, major threats, conservation activities, and recommendations, see Wilson et al. (2006). The following sections summarize seven important efforts regarding the conservation of Puerto Rican amphibians and reptiles; additional efforts and conservation projects have been implemented but are not included here.

Puerto Rican Amphibians, Pathogens and Climate Change

Puerto Rico was one of the first countries in the world which noticed what has become an international phenomon known as ‘declining amphibian populations’. We started monitoring amphibian populations in 1988 at El Yunque and, since then, have monitored more than 20 sites with an emphasis on the highlands. We have not found *Eleutherodactylus karlschmidti*, *E. jasperi*, or *E. eneidae* since 1976, 1981 and 1990, respectively, in spite of continuous field expeditions. An interesting population effect is observable at our elfin forest site in the Caribbean National Forest (El Yunque), where *E. portoricensis* and *E. coqui* seem to be recovering from population declines observed in the early 1990s. However, populations of three other species (*E. wightmanae*, *E. richmondi* and *E. locustus*) have not recolonized some areas at El Yunque where they were abundant in the past, and are still very scarce in that forest. Fortunately, these species still occur in some parts of the island, and we are monitoring them carefully. Since 2000, we have been studying the potential causes of amphibian declines in Puerto Rico, and have proposed a synergistic interaction between climate change (increased dry periods) and disease (chytridiomycosis) as an explanation for the patterns observed (Burrowes et al., 2004). Our data suggest that, during times of drought, frogs may clump in humid patches of the forest where the fungus is most likely to occur. This could provoke a situation where frogs, stressed from lack of water and clumping, become immunologically deprived in an area where the fungus is potentially abundant. As a consequence, infections by chytrid may increase, generating an epidemic that results in amphibian declines. Recent work led by a graduate student at our lab (Ana Longo) has tested part of this hypothesis. We established a controlled experiment with six terraria in which the number of refugia, food, light and temperature remained constant. Water was applied to the soil on only one half, and later to one fourth of the experimental terraria, while controls received water over the entire surface. The use of retreat sites by high-mountain *E. coqui* was monitored daily. Frog dispersion within the terraria changed significantly as a result of the water treatments (ANOVA $F_{1,35} = 13.6$; $P = 0.001$). In the experimental terraria, frogs moved from dry to humid sides within three days of drought. Thus, in spite of their territorial behavior, frogs facing limited water supplies clumped in the humid retreat sites, whereas control frogs used refuges on both sides. The next step of this experiment is to inoculate frogs with equal numbers of chytrid zoospores to determine if those forced to clump by a limited water regime are more susceptible to chytridiomycosis. We expect to have results on this work in the near future to better understand patterns of infection and prevalence of this disease among Puerto Rican frogs.

Fieldwork involving amphibian monitoring and chytrid detection at various sites on the island (El Yunque, Patillas, Toro Negro and Maricao) suggests that chytrid is abundant throughout the highland forests of Puerto Rico. Efforts to detect chytrid among five amphibian species (157 individuals) at six localities in the lowlands have yielded negative results. Our monitoring program includes four different highland forests in Puerto Rico where we estimate frog densities by species, and sample for the incidence of chytridiomycosis during dry versus wet seasons, in specific microhabitats, and as a function of gender and ontogenetic stage. An interesting pattern of cyclic decline, survival, and recuperation of the heartiest species is becoming apparent. This has led us to question whether a synergy between climate and disease is playing a role in the prevalence of the fungus in Puerto Rico, as has been described in Australia (Berger et al., 2004; Retallick et al., 2004). To answer this question we have expanded geographical and taxonomic monitoring of amphibian populations and chytrid detection, and have included fine-scale weather data collection at some localities. Finally, we expect to complete historic sampling at other localities to test disease dispersion hypotheses for the chytrid fungus in Puerto Rico.

In 2004, with Marcelino Hernandez from the Dominican Republic, we initiated collaborations that included a workshop on monitoring amphibians (by R.L. Joglar), followed by several days of fieldwork in the Cordillera Central. This work resulted in baseline population data for the localities of Ebano Verde (1440 m) and Valle Nuevo (2500 m) and the first records of chytrid for the Dominican Republic in three species of anurans: *Eleutherodactylus pituinus*, *E. patriciae* and *Hyla vasta*. Luis M. Diaz, from Cuba, participated in this training activity, and we hope to develop similar collaborations in the near future.

The Puerto Rican Crested Toad (*Peltophryne (Bufo) lemur*)

This species once occurred on Puerto Rico and Virgin Gorda. Habitat loss and introduced species, such as *Bufo marinus*, are major causes for the toad's decline and have led to a listing as Threatened (U.S. Fish and Wildlife Service, 1992) and Critically Endangered by the International Union for Conservation of Nature and Natural Resources (IUCN, 2004). This is the only toad native to Puerto Rico, and is easily distinguished from introduced forms by its unique head crests. It lives in arid to semi-arid climates in karst limestone formations. In Puerto Rico, toad populations once were divided into two distinct populations, one in the north and one in the south. Mitochondrial DNA analyses suggest that these two populations have been separated for up to 1 million years and are genetically distinct (CBSG, 2005). Unfortunately, northern toads have not been seen in the wild since 1988, and biologists consider the population extirpated (Johnson, 1999). Currently, the only known wild population is the southern form, which resides in small ponds located in the Guanica National Forest (CBSG, 2005).

In an effort to save this species from extinction, a Species Survival Plan (SSP) was officially created in 1984 through the auspices of the American Zoo and Aquarium Association (AZA). A reintroduction program is a large component of the recovery plan for this species. Each year, captive toads from zoos and aquaria in the United States and Canada are bred, and tadpoles are sent to Puerto Rico for release. Reintroduction efforts began on a small-scale, with the release of northern toadlets in 1982, before the SSP was formed. Between 1982 and 1985, approximately 1300 toadlets were released in the Cambalache National Forest, in northern Puerto Rico. Subsequently, more than 90 000 southern tadpoles were released into the Guanica National Forest from 1987 to 2005 (Lentini, 2000; B. Johnson, pers. comm.). The Guanica release site is an isolated man-made pond, geographically separated from the wild population. Although no formal studies have been conducted on the survival of the captive-hatched tadpoles, none are thought to have survived at the Cambalache release site (B. Johnson, pers. comm.). However, in 2003 and 2005, captive-born adult toads returned to the southern release site to breed (M. Canals, pers. comm.), demonstrating the establishment of a second population.

Recovery goals for this species also include island-wide education outreach, protection and restoration of existing habitat, creation of new ponds to support six self-sustaining populations (three in the north and three in the south), and research (U.S. Fish and Wildlife Service, 1992). Recovery efforts are primarily directed through the USFWS, Department of Natural and Environmental Resources (DNER) and the AZA. Additional recovery group partners consist of the University of Puerto Rico, Juan Rivero Zoo, Ciudadanos del Karso and Inciativa Herptológica, Inc.

Restoration of existing habitat and creation of new ponds has been a continuous process. In 1998, a secondary translocation pond was built in Guanica to serve as an emergency refuge for tadpoles in the event of a large-scale disaster or premature water loss at the last remaining natural breeding pond. Further, in 2000, two ponds (4000 and 9000 sq. ft.) were built adjacent to the release site in Guanica. Unfortunately, infiltration of saltwater has occurred at both ponds and repairs need to be made as soon as a planned hydrology assessment has been completed. In 2005, three small ponds were built in Arecibo (northern Puerto Rico) on private property and northern captive-born toad tadpoles were released there in April 2006.

Future research projects will include intensive monitoring of all ponds during and after the breeding season, with a focus on habitat use by tadpoles and newly metamorphosed toadlets, predation and competition, dietary studies of wild and captive tadpoles and toads, hydrological assessments of all pond sites, amphibian monitoring in Quebradillas, and a dietary and health assessment study to characterize health threats prevalent in *Bufo marinus* that are cohabiting with *Peltophryne lemur*.

During the past twenty years, the Puerto Rican Crested Toad Recovery Program has become a model for amphibian conservation. Much has been learned about this elusive toad, but biologists recognize that many more questions must be answered before this species can fully recover.

Conservation of the Puerto Rican Boa (*Epicrates inornatus*)

The genus *Epicrates* is represented by nine species in the West Indies (Tolson and Henderson, 1993). In Puerto Rico, the genus is represented by the Virgin Island boa (*E. monensis granti*), the Mona Island boa (*E. m. monensis*) and the Puerto Rican boa (*E. inornatus*). The Puerto Rican boa is the largest snake (maximum known SVL = 2.2 m) inhabiting the Puerto Rico Bank. This species was protected by the

U.S. Endangered Species Act of 1973, and a recovery plan was completed in 1986. In 2004, the Department of Natural and Environmental Resources changed its status to Vulnerable, but it was still considered Endangered by the U.S. Fish and Wildlife Service.

The first conservation effort was to protect boas from being collected and hunted (USFW, 1986). More than three decades after its designation as endangered, the ecology and natural history of these snakes still are not well documented. Thus, different conservation strategies are being developed. Recent conservation strategies can be categorized as: (a) gathering of basic biological information; (b) habitat conservation; and (c) outreach.

Biological information available consists of studies of distribution, habitat preferences, and life history in the Caribbean Natural Forest (Reagan and Zucca, 1982), diet and foraging behavior (Rodríguez-Durán, 1996; Puente-Rolón and Bird-Picó, 2004; Rodriguez and Reagan, 1984; Wiley, 2003), spatial ecology and habitat use (Puente-Rolón and Bird-Picó, 2004; Wunderle et al., 2004) and captive breeding (Bloxam, 1981). Also, surveys for locations of unknown populations have been conducted (Bird-Picó, 1994). Current research on the species focuses on habitat preferences and requirements, reproductive ecology, survivorship and thermoregulatory behavior. The goal is to contribute scientifically sound management recommendations to the development of a recovery plan for the boa.

Habitat loss and landscape fragmentation have become another concern in the conservation of this species. Habitat destruction is increasing, and may disrupt natural population dispersal and gene flow. Due to its protected status, translocation (i.e., movement of wild individuals from one part of their range to another) has become a common practice when boas are found in human settlements. A study on how the translocation influences thermoregulation, movement and survivorship is in progress. Preliminary data show that translocated snakes expand their home ranges when compared to non-relocated individuals (Puente-Rolón, unpubl. data). Other conservation efforts include the development of mechanisms for the identification of potential habitat by local and federal agencies and the acquisition of forested areas in the northern karst region by a non-profit organization known as Ciudadanos del Karso. Preliminary landscape-level analysis of habitat fragmentation and potential habitat available for the boas in the northern karst area has been performed by the U.S. Fish and Wildlife Service to establish land conservation strategies.

Conservation of the Puerto Rican Freshwater Turtle (*Trachemys s. stejnegeri*)

We know almost nothing about the ecology of West Indian freshwater turtles (Schwartz and Henderson, 1991). Turtles of the genus *Trachemys* might be the least-studied vertebrates in the West Indies. *Trachemys s. stejnegeri* is the only freshwater turtle native to Puerto Rico. Although its population status is currently undetermined, early studies indicate potential threats to natural populations. For instance, Rivero (1998) suggested that both a limited distribution and possible small population sizes could warrant the protection of these turtles. However, environmental agencies (i.e., Department of Natural and Environmental Resources, and U.S. Fish and Wildlife Service) have been unable to provide legal protection for *T. s. stejnegeri* due to a lack of data on the status of populations. On the other hand, this species was classified as near-threatened in the Red List of the International Union for the Conservation of Nature and Natural Resources (IUCN) (Hilton-Taylor, 2000). Therefore, comprehensive studies are needed to characterize the nature and extent of the factors threatening the long-term persistence of the Puerto Rican freshwater turtle. Baseline data from such studies are necessary to direct effective management and conservation efforts.

Recent efforts for the conservation of the Puerto Rican freshwater turtle (León and Joglar, 2005) combined three main research approaches to clarify the status of local populations: (1) a medium-term mark-recapture-release study, (2) field-monitoring of reproductive activity (i.e., nocturnal patrolling to identify nesting activity) and (3) field-assessment of the potential impact of introduced species (i.e., field identification of predatory species and exotic turtles).

Research findings provided a comprehensive description of the population ecology and reproductive biology of the Puerto Rican freshwater turtle. Temporal patterns of sightings are proportional to reproductive activity. Specifically, relative abundance peaks during the nesting season from April to June. Presumably, females migrate to limited nesting areas during the reproductive season and are then more frequently sighted. Moreover, identified threats to reproductive success and recruitment of early life stages include, intense egg predation by the exotic Indian mongoose (*Herpestes javanicus*), habitat alteration and establishment of exotic freshwater turtles in natural ecosystems inhabited by the Puerto Rican freshwater turtle.

We recommend two management actions based on current research. First, eradicating *Herpestes javanicus* from nesting areas is an urgent need. Eradication will have a direct positive effect on the recruitment of early life stages. Second, enforcement of exotic trade laws by local agencies could help in phasing out illegal sales of the red-eared slider (*Trachemys scripta elegans*). The exotic red-eared slider has been released and is widespread in Puerto Rican wetlands inhabited by native turtles. This observation calls for stopping the introduction of exotic turtles in West Indian ecosystems due to potential detrimental effects of interspecific competition and hybridization in local turtle populations. For instance, recent massive introductions of *T. scripta elegans* into Europe have had negative impacts on the survival rates of the European pond turtle (Cadi and Joly, 2004).

Recovery Initiatives for the Mona Island Iguana (*Cyclura stejnegeri*)

Iguanas of the genus *Cyclura* are arguably the most endangered lizard in the world (Alberts, 1999, 2004). Their distribution is limited to the West Indies, with species or subspecies typically restricted to few or single islands or cays. *Cyclura stejnegeri* is found only on Mona Island, with estimated population densities ranging from

0.33 individuals/ha (Wiewandt, 1977) to 0.96 ± 0.47 individuals/ha (Pérez-Buitrago and Sabat, 2000). These densities are considered very low for this group (Iverson, 1977). Furthermore, a major concern has been the scarcity of immature iguanas (5-10%) in the wild population (Wiewandt, 1977; Pérez-Buitrago and Sabat, 2000).

The Mona Island iguana has been listed as threatened and a recovery plan approved (Diaz, 1984). Since then, we have implemented several recovery actions aimed at the management of invasive mammals, a headstart program for hatchling iguanas, and the assessment of the etiology of a condition causing blindness in several adult iguanas.

Feral goats and pigs have been controlled for decades on Mona Island using hunters, with a reported total of 314 goats and 49 pigs killed every hunting season from January to April (García et al., 2000). Since estimated population numbers of these animals are unknown, we cannot determine satisfactorily the efficacy of this management strategy. However, hunting success has not changed significantly throughout the years (García et al., 2000); this suggests a stable prey population since feral goat populations increase rapidly in island ecosystems (e.g., Rudge et al., 1970; Baker and Reeser, 1972). On the other hand, the most important iguana nesting sites found on the coastal terrace and in two of the interior forest depressions have been fenced to protect them from trampling and feral pig predation. From 1996 to 2005, intensive hunting and trapping of feral cats have been conducted on Mona Island (García et al., 2001; López and García, unpubl. data). Although we have eliminated a total of 118 cats, we seek to eradicate this predator. The feral cat diet was composed of insects, small mammals, birds and reptiles, including Mona Island iguana hatchlings. The eradication of feral cats in Mona Island is an attainable goal, but more efforts need to be devoted to the hunting activity and the introduction of a feline-specific virus may be necessary.

Headstarting is a conservation initiative aimed at increasing the survival of hatchlings and juveniles by keeping them in captivity until they reach a size at which they are protected from early age-class predators. The headstart program for the Mona Island iguana started in 1999 in response to Perez-Buitrago (2000) finding only 13% hatchling survival during the first five months. For the headstart program, hatchlings were collected and kept in captivity under natural conditions until they reach a target size of 25 cm and 950 g. To date, 132 headstarted iguanas have been released into the wild. They are showing adequate survival (40%) and adaptation. Although this is a conservative value because only individuals that are found are considered, it agrees with other headstarted iguana survival values (9–40%; Alberts et al., 2004; Wilson et al., 2004). Therefore, the implementation of the headstart program for the Mona Island iguanas seems to be an appropriate conservation strategy for augmenting the number of juveniles in the wild population.

Several blind iguanas had been observed in Mona Island (Haneke, 1995). Therefore, health screening to assess this condition was conducted in 1998 and 1999 by staff from the Toledo Zoo. Nine of 34 iguanas examined in the field (26%) were blind or partially blind in at least one eye, due mainly to cataracts (Hudson and Alberts, 2004), suggesting that the blindness was an age-related condition (Reichard, Tolson and García, unpubl. data). However, subsequent fieldwork (2000-2005) has determined that 28% of iguanas found ($n = 160$) were totally or partially blind (Pérez-Buitrago, unpubl. data). Therefore, a comprehensive and conclusive assessment of this condition is urgently needed.

In conclusion, we have in a relatively short period been able to address the major threats to this species. In addition, intensive ecological monitoring and research are being conducted (Pérez-Buitrago, unpubl. data). These data will be useful to assess the progress of the Mona Island Iguana Program. Thus, we are confident of the recovery of this species within a decade — if these management strategies are maintained or (preferably) intensified.

Recovery of the Herpetofauna in a Restored Karst Valley in Puerto Rico

The main goals of a habitat restoration project are to reestablish the original biota and natural ecological functions (Parker, 1997; Palmer et al., 1997; Zedler, 2001; Block et al., 2001). Studies that have monitored the recovery of animal communities in habitat-restoration projects, however, have focused mainly on birds, mammals, and macro- and microfauna in soils; the herpetofauna is rarely considered, particularly on tropical islands. On Caribbean islands, which lack the large mammals present in the mainland tropics, reptiles and amphibians constitute the top predators (Thomas and Kessler, 1996), and are the most abundant and conspicuous vertebrates (Reagan, 1996; Duellman, 1999b). Given the increased evidence of population declines in amphibians and reptiles worldwide (Pough et al., 2001), largely due to habitat destruction, we need to develop effective habitat restoration projects capable of recovering and maintaining the Caribbean herpetofauna.

As an attempt to recover a local Puerto Rican herpetofaunal assemblage, we reforested a limestone valley in Sabana Seca, Toa Baja, Puerto Rico. The study area is in the Subtropical Moist Forest life zone (Ewel and Whitmore, 1973). Average annual rainfall is 1700 mm. Rainfall is mildly seasonal, with most of the rain falling from May to November (Eusse and Aide, 1999). A similar annual pattern exists for temperature, with warmer months between May and November. In January 2000, a deforested valley (160×20 m) was reforested with 516 plants of 22 native woody species for a final density of 1666 plants/ha. In April 2002, plant survivorship was 93.6% and mean plant height was 1.78 m. We studied four reference sites, which were within 500 m of each other, and which consisted of a deforested valley that represented the pre-reforested conditions, another valley, which was reforested naturally approximately 30 to 40 years ago, and a karst hillside and hilltop, which have been forested for >65 years. At all sites, we sampled the species richness, monitored changes in community assemblages during a 12-month period, and collected data on vegetation structure and microclimate. Although the main objective for the reforestation of this valley was to create a forested habitat for the endangered Puerto Rican boa (*Epicrates inornatus*), we wanted to evaluate the success of this reforestation project in recovering an entire herpetofaunal assemblage.

We found a total of 17 species; the karst hillside had the highest number of species (12), whereas the deforested valley had the lowest (2). In the reforested valley, the herpetofaunal species richness increased rapidly from three to eleven species, but the herpetofaunal assemblage composition recovered more slowly when compared to the reference sites. In response to increases in the population sizes of colonizers (e.g., *Eleutherodactylus* spp. and *Anolis* spp.), forest interior and predatory species colonized the reforested valley by the end of the study. Among the predatory species were the Puerto Rican boa (*E. inornatus*), the racer (*Alsophis portoricensis*) and the arboreal giant anole (*Anolis cuvieri*). By planting native trees, we increased vegetation cover and heterogeneity. The increase in woody species changed the microclimate, specifically the variation in temperature and humidity, and conditions are converging on the conditions of references sites. These changes, along with the short distance to intact forest (species sources), have contributed to the rapid recovery of herpetofaunal species richness, assemblage composition and trophic structure.

Puerto Rican Marine Turtle Monitoring Programs

The first marine turtle studies in Puerto Rico started in 1974 on Mona Island (Pinto-Rodríguez, 1991). Since then several marine turtle monitoring programs have been developed or continued on Mona Island, Vieques, Culebra, Luquillo, Fajardo, Maunabo, Rincón and Piñones. One of these programs stands out because of its long time span, large turtle population and publication record: The hawksbill turtle monitoring program at Mona Island.

Marine turtles were studied on Mona Island by Jean Thurston and Thomas Weiwandt in 1974, Molly Olson in 1984 and Anastasia Kontos from 1985 to 1987. These studies concluded that beach erosion and nest predation by pigs were the major threats to *Eretmochelys imbricata* nesting on the island (Pinto-Rodríguez, 1991). These studies gave origin to management practices on Mona Island from 1989 to 1990 that included fencing the beach from Playa Mujeres to Sardinera to prevent nest predation by pigs. A second phase of marine turtle monitoring was initiated on Mona in 1989 by Carlos E. Diez (DNER) and Robert P. van Dam. Results of their wok have shown that: (1) Mona and Monito Islands are among the few known remaining locations in the Caribbean where hawksbill turtles exist in considerable densities; (2) the large juvenile population of hawksbill turtles around Mona and Monito consist of long-term residents that exhibit strong site fidelity for periods of at least several years; (3) Mona's hawksbill resident population is composed of individuals from multiple nesting populations in the Wider Caribbean (evidence from genetic data); (4) the conservation of the juvenile population of hawksbill turtles at Mona can contribute to sustaining healthy nesting populations throughout the Caribbean; and (5) Mona Island's hawksbill population is the largest under U.S. jurisdiction, and the second largest in the Caribbean, after Barbados (Bowen et al., 1996; Possardt et al., 2007; Diez and van Dam, 2002; van Dam and Diez, 1996, 1997a, 1997b, 1998a,b, 1999). Management practices such as beach fencing in Mona and other conservation measures in different areas of the Caribbean seem to be having a positive effect on nest numbers (Robert van Dam, pers. comm.). There has been a significant increase in the number of hawksbill nests in the last decade: 450 to 500 nests between 1997 and 2001; 850 to 925 nests between 2002 and 2004; and over 1000 nests between 2005 and 2006 (Carlos Diez, pers. comm.).

There are several additional marine turtle monitoring programs active in Puerto Rico. Unfortunately their results and findings have not been published in peer reviewed journals, making it difficult to review these studies. One of these programs is the leatherback turtle monitoring program in Luquillo and Fajardo which started in 1985. With more than 20 years of continuous monitoring, this is the longest marine turtle monitoring program in Puerto Rico. Hector Horta and other DNER personnel are responsible for this accomplishment. Luis Crespo directs another marine turtle monitoring program in Maunabo.

Concluding Remarks

Conservation of the world's natural resources and biodiversity is one of the greatest challenges humanity faces at present. The obstacles encountered by conservation biologists and environmentalists in Puerto Rico are not very different from those elsewhere. However, among our Caribbean neighbors, we may be distinguished by having the highest population density, level of industrialization, and rate of urban development. Thus, the threats of habitat loss and contamination are of more immediate concern. Unfortunately, an abysmal difference remains between the funds and efforts allocated to 'economic development' and those dedicated to the conservation of nature. Finding a balance that will allow for true sustainable yield is the key to preserving our planet. However, this will entail major changes at all levels of our societies (politics, economy, environmental policy, etc.), but most importantly, such changes will require modifications of human conduct. The latter, we can only achieve through education. Teaching the general public the value of our biodiversity is imperative, for people will only strive to conserve that which they consider significant.

Author contributions. All authors after the first are listed alphabetically. RLJ conceived and designed the manuscript. Specific topics were written by the following authors: (1) Introduction, Puerto Rican herpetofauna, conservation, Puerto Rican marine turtle monitoring programs and appendices — RLJ; (2) Amphibians, pathogens and climate change — PAB, RLJ and AVL; (3) Puerto Rican crested toad — DB; (4) Puerto Rican Boa — AP; (5) Puerto Rican freshwater turtle —

ALC and RLJ; (6) Mona Island iguana — MAG, NPB, AOA and PJT; and (7) herpetofaunal community — NRL and TMA. RLJ and PAB edited the manuscript.

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Accepted: August 29, 2007 (BSW).

Appendix. Amphibians and reptiles in Puerto Rico (#: introduced species in Puerto Rico).

Bufonidae		
Peltophryne lemur	*Bufo marinus #*	
Leptodactylidae		
Eleutherodactylus antillensis	*E. brittoni*	*E. cochranae*
E. cooki	*E. coqui*	*E. eneidae*
E. gryllus	*E. hedricki*	*E. jasperi*
E. karlschmidti	*E. locustus*	*E. monensis*
E. portoricensis	*E. richmondi*	*E. unicolor*
E. wightmanae	*E. juanriveroi*	*Leptodactylus albilabris*
Ranidae		
Rana catesbeiana #	*Rana grylio #*	
Hylidae		
Hyla cinerea #	*Osteopilus septentrionalis #*	*Scinax rubra #*

Testudines

Caretta caretta	*Chelonia mydas*	*Dermochelys coriacea*
Eretmochelys imbricate	*Lepidochelys olivacea*	*Trachemys scripta #*
Trachemys s. stejnegeri		

Gekkonidae

Hemidactylus brookii	*Hemidactylus mabouia*	*Phyllodactylus wirshingi*
Sphaerodactylus gaigeae	*S. klauberi*	*S. levinsi*
S. macrolepis	*S. micropithecus*	*S. monensis*
S. nicholsi	*S. roosevelti*	*S. townsendi*

Teiidae

Ameiva alboguttata	*A. desechensis*	*A. exsul*
A. wetmorei		

Scincidae

Mabuya mabouya

Anguidae

Diploglossus pleei

Polychrotidae

Anolis cooki	*A. cristatellus*	*A. cuvieri*
A. desechensis	*A. evermanni*	*A. gundlachi*
A. krugi	*A. monensis*	*A. occultus*
A. poncensis	*A. pulchellus*	*A. roosevelti*
A. stratulus		

Iguanidae

Cyclura nubila #	*C. stejnegeri*	*Iguana iguana #*

Amphisbaenia

Amphisbaena bakeri	*A. caeca*	*A. schmidti*
A. xera		

Typhlopidae

Typhlops granti	*T. hypomethes*	*T. monensis*
T. platycephalus	*T. richardi*	*T. rostellatus*

Boidae

Epicrates inornatus	*E. monensis*

Colubridae

Alsophis portoricensis	*Arrhyton exiguum*

Crocodylia

Caiman crocodilus #

Extinct reptiles

Anolis rooselvelti	extinction circa 1930
Cyclura pinguis	old extinction (>500 years) in Puerto Rico; extant populations in the BVI
Leiocephelus etheridgei	old extinction (>500 years)
Leiocephelus partitus	old extinction (>500 years)
Monachelys monensis	old extinction (>500 years)