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GREEN IGUANAS (*IGUANA IGUANA*): THE UNINTENDED CONSEQUENCE OF SOUND WILDLIFE MANAGEMENT PRACTICES IN A SOUTH FLORIDA PARK

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***Abstract.*—We examined the demographic response of the Green Iguana (*Iguana iguana*) to the removal of Raccoons in an urban maritime state park in southern Florida. The rapid growth of iguanas to sexual maturity in an underexploited, if not vacant, niche contributed to the rapid recruitment of a large and growing population during the four and one half years since removal of its limiting predator. We proffer here that at sites where Green Iguanas and high density Raccoons are syntopic, future Raccoon removal programs should be concurrent with an equally concerted effort to remove resident Green Iguanas. In this fashion, by replacing one limiting predator with another, a population explosion can be prevented and an advantage can be maintained in the local control of this exotic species.**

Key Words.—exotic species; *Iguana iguana*; introduced species; invasive species; *Procyon lotor*; wildlife management

INTRODUCTION

The Green Iguana (*Iguana iguana*) is a ubiquitous exotic lizard in southern Florida (Townsend et al. 2003; Meshaka et al. 2004a,b) having an expanding geographic range (Meshaka et al. 2004b; Meshaka in press). Recently, investigations have been conducted concerning the biotic potential, limiting factors, and colonization patterns of the Green Iguana in Florida (e.g., Meshaka et al. 2004a,b; Smith et al. 2006, 2007a,b, in press a,b). Likewise, we are just beginning to understand the ecological impacts of the Green Iguana in Florida. For example, this species could impact the Florida Burrowing Owl (*Athene cunicularia floridana*) through its use of owl burrows (McKie et al. 2005), whereby the burrow is usurped, the nests are incidentally destroyed, or the eggs and chicks are eaten. The Green Iguana consumes the fruits of invasive plants and defecates the scarified seeds (HTS, pers. obs., SRS,. unpubl. data), thereby acting as a potential dispersal agent. At low frequencies, the snail *Drymaeus multilineatus* is eaten by the Green Iguana (Townsend et al. 2005). Regarding human dimensions, the growing populations in Puerto Rico are collision hazards on airport runways and have drawn concern at the Homestead Air Reserve Base Airport in Florida, and other airports around Miami and Tampa (Engeman et al. 2005b). Densely packed, Green Iguana burrows are also erosion hazards along drainage canals in Florida (Sementelli et al. in press).

This invasive exotic species, however, has predators in Florida, which include the Yellow-crowned Night-heron (*Nyctanassa violacea*; Engeman et al. 2005a), Florida Burrowing Owl (*Athene cunicularia floridana*; McKie et al. 2005), an unidentified species of hawk (*Buteo* sp.; Smith et al. 2006), domestic dog (*Canis familiaris*; Meshaka et al. 2004a), Gray Fox (*Urocyon cinereoargenteus*; Smith et al. in press-a,b), and Raccoon (*Procyon lotor;* Smith et al. 2006). Raccoons eat juveniles, attack adults, and have been suspected to prey upon nests (Smith et al. 2006). In this regard, Raccoons can be major nest predators of other lizards, such as the Black Spinytail Iguana (*Ctenosuara similis*) (Platt et al. 1999), turtles and tortoises (e.g., Ernst et al. 1994; Meylan 2006), including Gopher Tortoises (*Gopherus polyphemus*) (Douglass and Winegarner 1977; JAM, unpubl. data).

The Raccoon occurs at all southern Florida state parks, where its super-abundance and resulting negative impact on other native and endangered wildlife has warranted aggressive removal programs. For example, a trap and removal program conducted at the 70.9 ha urban Hugh Taylor Birch State Park (HTBSP) in Ft. Lauderdale, Florida, during November 2000, documented an absolute minimum density of 238 Raccoons/km^2 (Smith and

Engeman 2002). This is the third highest Raccoon density, 4-200 times greater, than others reported in North America (Smith and Engeman 2002). High numbers of the Green Iguana at HTBSP within a few years of Raccoon removal were suspected to be a direct result of sudden release from intense predation (Smith et al. 2006). At our other urban study site, Bill Baggs Cape Florida State Park (CFSP), Raccoon population densities were likewise considered high by park management personnel. Artificially high numbers of the mesopredator, and subsequent endangerment to sea turtle nests, warranted aggressive removal from CFSP. This occurred during 2001-2002; whereas, less aggressive trapping took place during 2004-2006.

In response to the growing Green Iguana population in the park, existing Florida Park Service policy, and the park management's habitat maintenance and restoration interests, removal of the Green Iguana from CFSP began in earnest during the latter half of 2002. This was five years after the species was first seen in the park and one year after park personnel considered it to be more noticeable. Park personnel conducted aggressive removal during mid-2002-2004, followed thereafter by less intensive eradication.

Using the data from the removal program, we tested the hypothesis that Green Iguana abundance and population structure changed in response to Raccoon removal. We predicted that Raccoon removal would be accompanied by rapidly increasing numbers and more complex population age-class structure in Green Iguanas, as suspected at HTBSP (Smith et al. 2006).

MATERIALS AND METHODS

Study Site.—Bill Baggs Cape Florida State Park is a small, urban park located in Miami-Dade County, Florida, USA, on the southern end of Key Biscayne, approximately 11 km southeast of metropolitan Miami. It consists of 131.5 ha of uplands and 42.9 ha of tidal and freshwater wetlands for a combined total of 174.4 ha (Florida Department of Environmental Protection [FDEP]. 2001. Bill Baggs Cape Florida State Park Management Plan. Florida Park Service, Tallahassee, Florida. 166 p). The park is completely surrounded by urban high-rise infrastructure to the north, the Atlantic Ocean to the south and east, and Biscayne Bay to the west. The only terrestrial access to the park is at the northern interface.

Hurricane Andrew completely destroyed CFSP on 24 August 1992. Prior to the storm, the park had been dominated by a near monoculture of Australian pine trees (*Casuarina equisetifolia*), a large, invasive, exotic tree whose canopy rose to 30 m or more. Little if any native vegetation could grow in this forest as canopy, understory, or ground cover. The monoculture forest was destroyed by the hurricane, and the subsequent clearing of debris left the park almost barren of vegetation. An ecological restoration plan was developed for the park, with the goal of reestablishing, to the extent possible, the native plant communities that once existed on site. This plan was initiated in 1993, and multiple years of replanting followed.

As of 2007, the park consisted of 10 distinct natural communities in various stages of maturity (FDEP 2001, *ibid*). Principle habitats include 1.9 km of uplands, 2.4 ha of beach dune, 61.5 ha of coastal strand, 35.6 ha of maritime hammock, and 4.4 ha of coastal grassland (FDEP 2001, *ibid*). During the wet season, CFSP contains about 4.0 ha of freshwater in five interdunal swale ponds (FDEP 2001, *ibid*). There are 4.4 ha of ruderal habitat and 21.8 developed ha (FDEP 2001, *ibid*).

Green Iguana Removal Program.—Florida Park Service policy requires removal of non-native organisms when possible. Park personnel first detected the Green Iguana in the park in September 1997. In 2001, they suspected that the Green Iguana population size was growing at CFSP, perhaps in response to the habitat restoration efforts, and some park staff began to opportunistically and sporadically capture and remove them from the grounds. By the latter half of 2002, they intensified these efforts. Intensive eradication continued until March 2004, after which efforts remained ongoing, even if less intensively. Our analysis includes data collected through December 2006 for all but monthly distribution of body size and mean body size data, which include animals removed through April 2007.

Capture and Survey Methods.—Park staff used road cruising and opportunistic searching on sunny days along road edges, in picnic areas, and at other locations having partially open-canopies. Greater efforts took place on sunny days following cool and/or rainy weather. Park staff captured most Green Iguanas using a monofilament noose attached to the end of a fishing pole. Iguanas that were at

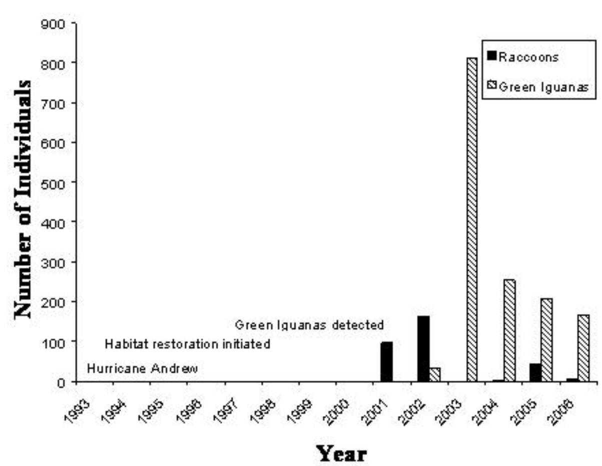

FIGURE 1. Time line: Annual totals of numbers of the Raccoon and Green Iguana (*Iguana iguana*) removed from Bill Baggs Cape Florida State Park in Miami-Dade County, Florida, USA, during 2002-2006.

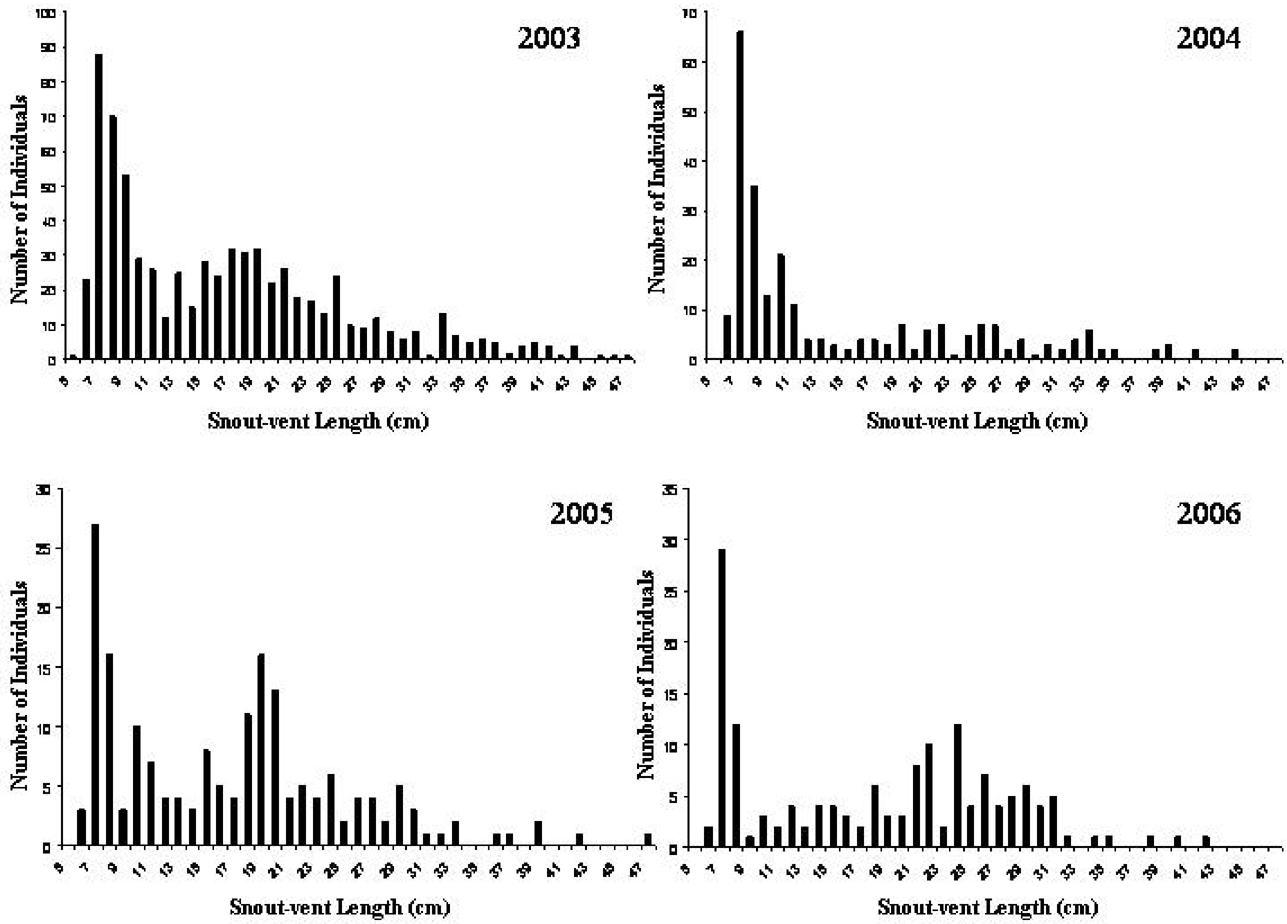

FIGURE 2. Distribution of body sizes of the Green Iguana (*Iguana iguana*) removed from Bill Baggs Cape Florida State Park in Miami-Dade County, Florida, USA 2003 - 2006.

first beyond reach in trees were pulled to the ground and then collected.

Park staff also used snare lines and nets to capture iguanas; they staked nets or heavy monofilament snares over the mouth of actively used burrows and waited for entering or exiting iguanas to get caught. CFSP Personnel then sexed and measured captures to the nearest 5 mm. We employed two measures of sexual maturity in males. Secondary sexual characteristics were most apparent in males of at least 18 cm SVL. We do not, however, discount the possibility of smaller sexually mature males. Likewise, we realize the greater potential for mating among larger males of this territorial species. With respect to the latter consideration, males have been considered sexually mature at 25 cm SVL (Fitch and Henderson 1977) and 27 cm SVL (Dugan 1982); consequently, we also incorporated the former value in the sample statistics. We tested differences in body sizes between sexes using the Student t-test ($\alpha = 0.05$). We based minimum female body size at reproduction on the smallest gravid female from this population (24.0 cm SVL). A representative sample of iguana voucher specimens was deposited in the Florida Museum of Natural History, Gainesville, Florida, USA.

RESULTS

The 2001-2002 Raccoon removal program evicted 263 animals; 97 were captured in 2001 and 165 in 2002 (Fig. 1). Numbers of Raccoons removed subsequent to the 2001-2002 efforts were few (Fig. 1). Park personnel removed more Green Iguanas during July-December 2002 (85%, 29/34) than earlier in their efforts (Fig. 1) but far less than what they removed during these same months in subsequent years (2003 = 487, 2004 = 178, 2005 = 113, 2006 = 79). Simultaneously, Green Iguanas first appeared in a road-kill study at CFSP (Smith et al. 2007b), which also correlates with the post-Raccoon removal increase in Green Iguanas. The numbers of removed Green Iguanas peaked in 2003 (N = 811; Fig. 1). Juvenile and young adults composed the majority of Green Iguanas that were removed subsequent to Raccoon removal (Fig. 2). Specifically, in 2003, juveniles, especially hatchlings,

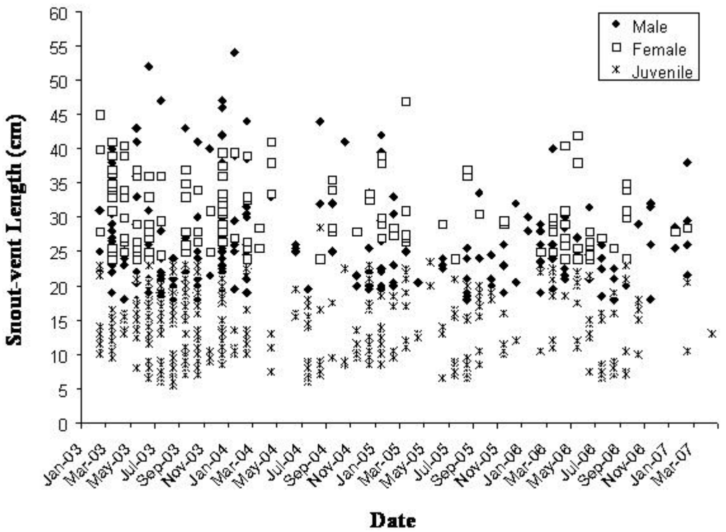

FIGURE 3. Monthly distribution of body sizes of the Green Iguana (*Iguana iguana*) removed from Bill Baggs Cape Florida State Park in Miami-Dade County, Florida, USA, during January 2003- April 2007.

dominated removal samples (Fig. 2). Following hatchlings through time, we estimated that males reach minimum SVL at sexual maturity (SVL = 18.0 cm) at approximately 16-17 months; whereas females reach maturity (SVL = 24.0 cm) at approximately 24-25 months of age (Fig. 3). Mean body size of males (25.2 $\pm$ 7.0 cm SVL; range = 18.0-54.0; n = 300) was significantly smaller (t = 8.796; df = 451; $P < 0.01$) than in females (30.8 $\pm$ 5.2 cm SVL; range = 24.0-47.0; n = 153), probably because males reach sexual maturity at smaller body sizes than females (Fig. 4), are more numerous than females, and there is restricted space for many large territorial males that exceed in body size the largest females. Males achieve mean body size and sexual maturity by 24-25 months of age, whereas females achieve this by 34-35 months. Minimum male body size at sexual maturity occurs at SVL = 25 cm as per Fitch and Henderson (1977). We found that mean body size of adult males (SVL = 31.5 $\pm$ 6.8 cm; range = 25.0-54.0; n = 122) was not significantly different from that of females (t = 1.076; df = 273; $P > 0.05$).

The high numbers of hatchlings and intermediate-sized Green Iguanas during 2003 corresponded to the release from Raccoon predation of the previous 1-2 years. Consequently, larger size-classes produced more hatchlings in 2001-2002 which grew to c.a. 18-25 cm SVL (Fig. 3) as young mature adults.

The flush of hatchlings from June-September (Figs. 3, 5, 6) correlates with the presence of gravid females and recently laid egg clutches during March-July, peaking in April. However, adult iguanas were still subject to attack and on 25 November 2003, on the CFSP Main Drive, a 40 cm SVL male faced off with a Raccoon before it was collected.

Thus, concomitant with Raccoon removal, and commensurate with more amenable habitat, the population size of the Green Iguana increased greatly, and its population structure reflected a growing population with annual spikes of hatchlings and a continuous wave of growing individuals.

DISCUSSION

Our findings illustrate how rapidly the size of a Green Iguana population can increase, and its population structure shift, following the removal of a limiting predator, in this case, the Raccoon. Conversely, our findings underscore the effectiveness of continuous predation by Raccoons in suppressing population growth of the Green Iguana and consequently hindering its colonization success. The small population of generally large Green Iguana's in this study benefited from habitat restoration activities that led to reduced predation pressure. This caused fast-growing juveniles to dominate the population and unusually high population densities. In this regard, even with a minimum estimate based only on removed animals from CFSP, Smith et al. (2007a) calculated an astonishingly high density estimate of 626 Green Iguanas/km^2. This is the same phenomenon reported for HTBSP (Smith et al. 2006).

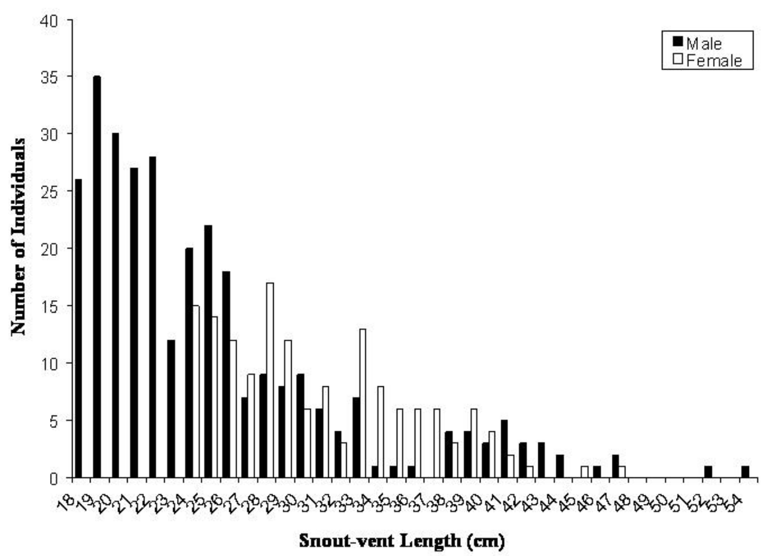

FIGURE 4. Body size histograms of mature Green Iguanas (*Iguana iguana*) removed from Bill Baggs Cape Florida State Park in Miami-Dade County, Florida, USA, during the combined years of 2003 - 2006.

Our results corroborate the importance of local recruitment in this post-predator scenario. We do not discount dispersal of animals into CFSP from adjacent private property (Townsend et al. 2003). In light of what appears to be suboptimal surrounding habitat, its restricted connection with CFSP, and our inability to find Green Iguana road-kills in these areas before or during our study (Smith et al. 2007b); we conclude that local recruitment, not dispersal, best explains the population explosion of Green Iguanas at CFSP.

That the Green Iguana was severely limited by its predator at CFSP appears also to have been the case in Belize, where an insular population consists exclusively of large adults, presumably the result of age-class restructuring by rat (*Rattus* sp.) predation (Meerman unpublished report). Likewise, the population size and structure of sympatric Black Spinytail Iguanas responded similarly to the Green Iguana population (Meerman unpublished report to Audubon). At a nearby atoll, where rats are present but not numerous, the size distribution of the Black Spinytail Iguana appears to be normally distributed (Platt et al. 1999). Furthermore, Raccoons were a major nest predator of the Black Spinytail Iguana on another atoll in Belize (Platt et al. 1999).

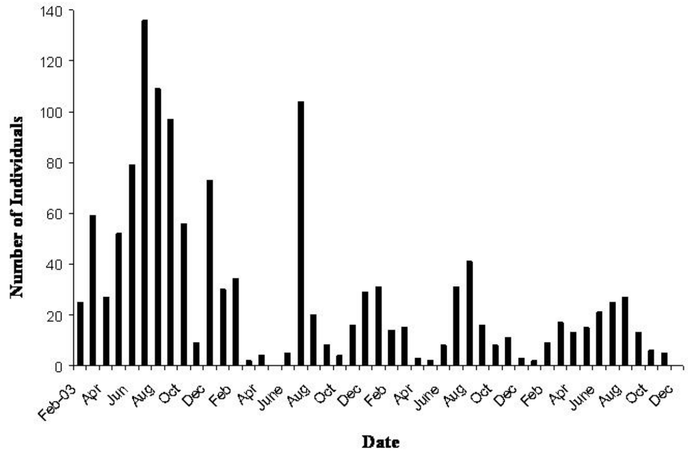

FIGURE 5. Numbers of Green Iguanas (*Iguana iguana*) removed from Bill Baggs Cape Florida State Park in Miami-Dade County, Florida, USA, for each month during 2003 - 2006.

The Green Iguana is a successful colonizing species in Florida as measured by its geographic range and its ubiquity (e.g., Meshaka et al. 2004a,b). A suite of biological traits are associated with successful colonization (Drake et al. 1989), and several of these traits are evident in the Green Iguana in southern Florida: (1) close association with humans (Brown 1989); (2) open niche space (Brown 1989); and (3) high fecundity (Baker 1965). To the latter biological trait, we note a nesting season for Green Iguanas that peaks in April (March-May) and that conforms to predictions of a later nesting season in northern latitudes (Rand and Greene 1982).

We propose that Green Iguanas from South Florida possess two more traits associated with a successful colonizing species. First, achievement of sexual maturity within just over two years suggests to us rapid maturity that conforms to the colonizing trait of short generation times (Ehrlich 1989), and is in the high end of the range of other early-maturing successful colonizing amphibians and reptiles in Florida (e.g., Meshaka 2001; Meshaka and Layne 2005; Meshaka et al. 2006a,b). These values are also within the range of other native populations of the Green Iguana (Dugan 1982; Harris 1982; Van Devender 1982; Wiewandt 1982).

Second, the matter of predator-free space (Pimm 1989) also comes into play. In some instances, the potentially severe impact of a large number of predators can be offset by interguild predation, as in the case of the Cuban Treefrog (*Osteopilus septentrionalis*) in southern Florida (Meshaka 2001). On the other hand, a single predator species that is also keenly adapted to the predation of one or more life stages of an organism, as in the case of the Raccoon, can quickly limit the colonization by a species, exotic and native alike. Even though removal of Raccoons did not create a predator-free situation for iguanas, our results corroborate the importance of predation pressure as a powerful obstacle to colonization, and approximate the predator-free space scenario associated with successful colonization.

The connection between the removal of a limiting mesopredator and a population boom of its prey is, therefore, not surprising. The relationship between these two species introduces a profound management consideration for public land managers. The Raccoon is a native meso-predator that was released from its natural predators long ago. This caused its egg-foraging behavior to severely impact the nesting success of sea turtles (Stancyk 1982; Engeman et al. 2002, 2005c, 2006) and sea

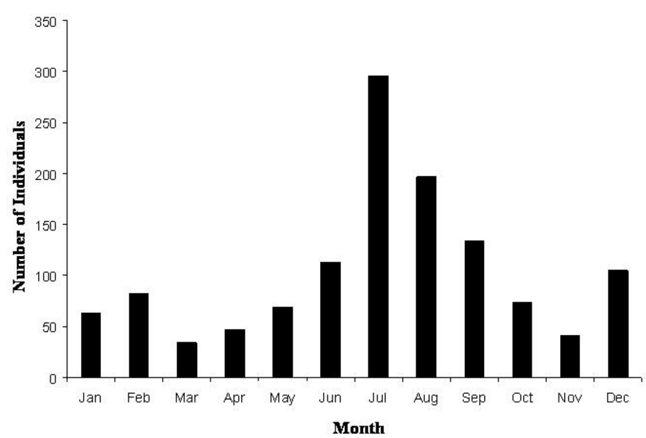

FIGURE 6. Numbers of Green Iguanas (*Iguana iguana*) removed from Bill Baggs Cape Florida State Park in Miami-Dade County, Florida, USA, for each month during the combined years of 2003 - 2006.

birds (Rodgers et al. 1996). It also increased the health risk to humans, domesticated animals, and wildlife because of its function as a reservoir and vector of rabies, distemper, and other epizootic contagions (Smith and Engeman 2002). In this predator-prey relationship, the prey species is an exotic capable of rapid colonization and population growth.

The management practice of Raccoon removal provides a well-proven, sound, and effective wildlife management technique as a means to conserve indigenous systems and their wildlife components (Smith and Engeman 2002; Engeman et al. 2002, 2005c), but, likewise can bring with it the quick and unintended consequence of Green Iguana population growth (Smith et al. 2006; this study). We submit here that, at sites where Green Iguanas and high-density Raccoons are syntopic, future Raccoon removal programs should be concurrent with an equally concerted effort to remove Green Iguanas. Removal of Green Iguanas should be continued for several years thereafter at isolated sites, and should continue perennially at sites that are closely connected to other Green Iguana demes. This objective can be accomplished both by removing individuals; as well as, removal of colonial nests in May after the completion of most nesting. Such an approach, whereby one limiting predator, the Raccoon, is replaced by another, humans, would at the same time prevent a potential population explosion of the Green Iguana as seen at CFSP and elsewhere (Smith et al. 2006) and maintain an advantage in its local control.

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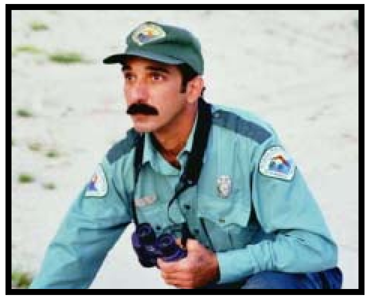
WALTER E. MESHAKA, JR. (above) is the Senior Curator of Zoology and Botany at the State Museum in Harrisburg, Pennsylvania. His research interests in herpetology combine field and museum techniques that center around the ecology of native and exotic eastern North American amphibians and reptiles. Photographed by Robert Mulvihill of Powdermill Nature Reserve (Carnegie Museum of Natural History).



HANK SMITH (above) is the District Biologist for wildlife resources with the Florida Park Service in Hobe Sound; his region encompasses 25 state parks extending from Fort Pierce to Key West. He is an Affiliate Research Assistant Professor of Biology and Environmental Studies at Florida Atlantic University, Wilkes Honors College where he supervises student research, internships, and theses. His publications include the ecology of colonial waterbirds, the effects of human disturbance on wildlife, bioeconomics of wildlife management, and exotic herpetofauna colonization dynamics in Florida.

LIZ GOLDEN (above, holding an exotic juvenile Green Iguana) is the Park Biologist at Bill Baggs Cape Florida State Park (site of this study) located on Key Biscayne in Miami-Dade County, Florida. After Hurricane Andrew completely devastated the park on 24 August 1992, and the debris was finally cleared, she was hired in 1994 to work on the upland and wetland ecological restoration plan. In addition to the on-going plant community restoration work, Liz stays extremely busy with the park's nesting Loggerhead Turtles, environmental education programs, and of course Green Iguanas.

STEPH FITCHETT (left) is an Associate Professor of Mathematics at Florida Atlantic University, Wilkes Honors College, in Jupiter, Florida. Her research interests are in the areas of algebraic geometry and commutative algebra. She is also interested in undergraduate curriculum reform efforts in mathematics. A great deal of her time likewise is spent with students in the biology and environmental studies programs helping them design statistical methodologies for their field research projects and theses.

ERNIE COWAN (above) is a District Biologist with the Florida Park Service in Hobe Sound; his region encompasses 25 state parks extending from Fort Pierce to Key West and he also manages these operations and staff for the entire district. Ernie's research interests include ecology and demography of the endangered Florida Scrub-jay, marine turtle nesting ecology, and exotic herpetofauna in Florida. He has published in all three subject areas and his compelling wildlife photos have graced various articles.

JON MOORE (not pictured) is an Associate Professor of Biology at Florida Atlantic University, Wilkes Honors College, in Jupiter, Florida. His areas of research include the ecology, evolution, and distribution of fishes, the biology of deep-sea animals, and biological oceanography. He also has interests in fisheries and marine conservation, systematics, and vertebrate paleontology. Since moving to South Florida, Jon also has added Gopher Tortoises and Green Iguanas to his list of research priorities.

RICK ENGEMAN (not pictured) is a research biometrician at the National Wildlife Research Center in Fort Collins, Colorado, the only U.S. federal facility dedicated entirely to researching practical and environmentally responsible solutions to human-wildlife conflicts. His research interests include developing practical, yet quantitatively valid wildlife indexing and ecological sampling methods. He also has authored numerous papers on invasive species, conservation of rare species and habitats, and the bioeconomics of human-wildlife conflicts.

STACEY SEKSCIENSKI (not pictured) is a graduate student at Florida Atlantic University working on her MS thesis regarding Green Iguana activity patterns and habitat use in Hugh Taylor Birch State Park in Broward County, Florida. Jon Moore, Hank Smith, and Walt Meshaka sit on her thesis research committee.

HEATHER CRESS (not pictured) recently completed her BS in Environmental Studies at Florida International University and previously, an internship with the Florida Park Service "Parknership" Research Program studying hemidactyline gecko colonization dynamics.