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Post-release Success of Headstarted Green Iguanas (*Iguana iguana*) in Costa Rica

By

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A Thesis submitted in partial satisfaction
of the requirements for the degree of
Master of Science in Biology

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Each person whose signature appears below certifies that this thesis in his/her opinion is adequate, in scope and quality, as a thesis for the degree Master of Science.

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ABSTRACT OF THE THESIS

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Master of Science, Graduate Program in Biology
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Headstarting has become a popular tool employed by wildlife managers to help animal species offset extinction. However, many researchers challenge the conservation value of headstarting and urge proponents to monitor headstarted individuals following release into the wild to evaluate the success of headstart programs. As part of an experimental headstarting program managed by the Iguana Verde Foundation (IVF) in Costa Rica, I conducted a two-month radiotelemetry study of 11 headstarted two-year-old green iguanas (*Iguana iguana*) following their release into the wild. Headstarted iguanas were compared to their wild counterparts (two radiotelemetered and 18 opportunistically-encountered) with respect to changes in body condition, arboreal microhabitat use, social aggregation, movements, and activity ranges. Male and female headstarted iguanas exhibited similar behaviors for all variables measured. Collectively, the headstarted iguanas were also similar to wild iguanas for all variables measured. Thus, the headstarted green iguanas were clearly capable of short-term (two month) survival in the wild and their apparently normal behaviors reflected the suitable conditions under which they were raised. The results provide insight into the ecology of green

iguanas within the Gandoce-Manzanillo Wildlife Refuge (GMWR) and will help guide the ability to implement successful translocations of green iguanas at this location and elsewhere.

CHAPTER ONE

INTRODUCTION

Captive-breeding and Headstarting as Conservation Strategies

In the last 500 years, humans have accelerated the extinction process and forced at least 844 species to extinction in the wild, and an added 15,589 species of plants and animals are thought to face extinction in the near future (World Conservation Union [IUCN], 2004). Among the causes for this rapid depletion are habitat fragmentation and degradation, over-exploitation (extraction, hunting, fishing, etc.), pollution, invasive species, and global climate change (IUCN, 2004).

As a result of rapid worldwide species decline, wildlife managers have resorted to a variety of conservation strategies to help minimize species loss, including, but not limited to, translocation of captive-bred or captive-reared animals (Pelletier et al., 2002; Alberts et al., 2004; Knapp and Hudson, 2004; Wilson et al., 2004; Bell et al., 2005; White et al., 2005; King and Stanford, 2006). Translocation is defined by the IUCN (1987) as "the deliberate, human-mediated movement of living organisms from one area to another." Griffith et al. (1989) broadened this definition to "the intentional release of animals to the wild in an attempt to establish, reestablish, or augment a population." The IUCN (1987) recommends that captive-breeding programs be coordinated internationally and become established before species are reduced to critically low numbers or substantial genetic variability is lost. Captive-breeding or rearing programs aim largely to: (1) conserve genetically viable populations from threats faced by wild populations;

(2) generate founder populations for future release into the wild (Seal 1986; Kleiman, 1989); (3) supplement extant wild populations through an increase in the number of individuals (Griffith et al. 1989; White et al., 2005); and, as an ultimate goal, (4) to increase the number of breeding pairs in the wild (Beck et al., 1994).

Two types of captive-breeding programs, or a combination of both, are currently employed: *ex situ* and *in situ* conservation. The *ex situ* approach, used by most western zoos, occurs outside the species' natural range and is the most frequent approach. The *in situ* approach takes place within the species' natural range, having the added benefit of access to appropriate habitat and environmental conditions, and reducing exposure of the species to exotic diseases (Sillero-Zubiri et al., 1997).

Headstarting is a specific type of translocation technique in which captive-bred or juvenile wild animals are reared in captivity, usually until they reach a larger size or age, prior to release into the wild. Programs using this conservation approach operate under the assumption that animals are highly vulnerable to predation and/or starvation in the early stages of life, and hence, rearing may help increase survivorship and number of breeding pairs in the wild population (Mrosovsky, 1983). In its infancy, headstarting was employed in an effort to diminish nest predation and high levels of hatchling mortality in vanishing sea turtle populations (Pritchard, 1979), a strategy that flourished from the 1960's through the 1980's (Wilson et al., 2004). However**,** the conservation value of headstarting has been extensively criticized on the grounds of faulty theory, misguided application, and poor implementation (Dodd and Siegel, 1991; Reinert, 1991; Wilson et al., 2004). Critics argue, for example, that headstarting efforts in sea turtles did not address the initial cause of population declines, and no effort was conducted to

understand how removing neonatal turtles from their environment might affect marine ecosystems negatively (Alberts et al., 2004). Another main concern of critics is that headstarting will cause individuals to lose their fear of humans and other potential predators, lose the ability to adapt to natural food sources after extended periods in captivity, or expose wild populations to novel diseases and pathogens (Alberts et al., 2004). Lastly, critics argue that headstart-release programs usually lack adequate post-release monitoring, which is necessary to properly assess whether or not projects were successes or failures (Dodd and Siegel, 1991; Reinert, 1991; Wilson et al., 2004).

Historically, assessing the success or failure of translocation projects has been determined by whether or not releases yielded a self-sustaining or stable population (Griffith et al., 1989; Dodd and Siegel, 1991; Knapp and Hudson, 2004). However, this criterion has been challenged by Burke (1991) because of the difficulty of defining when a population can be deemed self-sustaining or stable; he argued that the longer a population is monitored the more it appears unstable. In addition, Wilson et al. (2004) pointed out that "definitive demonstration of a self-sustaining—much less stable—population may be unrealistic in many instances, especially for extremely rare, cryptic, and long-lived vertebrates." Knapp and Hudson (2004) defined self-sustaining as "the ability for sexually mature individuals to reproduce and increase or maintain population size without the necessity of additional translocations." However, they noted that using the "self-sustaining or stable" criterion to define success may be adequate for some species and not others because of differences in interspecific interactions and requirements (Knapp and Hudson, 2004).

Despite the criticisms and objections, headstarting is quickly becoming a prominent and promising tool for the conservation of endangered species, especially when carried out keeping in mind past criticism. Thus far, headstarting has been employed with success in the conservation of various species, including the Western Pond Turtle (*Emys marmorata*; Spinks et al., 2003), Plains Gartersnake (*Thamnophis radix*; King and Stanford, 2006), Puerto Rican Parrot (*Amazona vittata*; White et al., 2005), and California Condor (Utt et al., 2007). Headstarting has also been used with much success in iguana recovery efforts. Examples in the rock iguana genus *Cyclura* include the Anegada iguana (*C. pinguis*) in the British Islands, the Mona Island iguana (*C. cornuta stejnegeri*), the Grand Cayman iguana (*C. nubila lewisi*; Knapp and Hudson, 2004), the Cuban iguana (*C. nubila nubile*) in Guantanamo Bay, Cuba (Alberts et al., 2004), and the Jamaican iguana (*C. collie*; Wilson et al., 2004). In addition, success has been documented for Galapagos Island land iguanas (Cayot et al., 1994).

The success of iguana headstarting projects is attributed mainly to their hardy bodies and herbivorous diet that allows them to inhabit and endure harsh environments, and to an apparent innate natural and social behavior that allows for rapid re-adaptation (Knapp and Hudson, 2004). Herbivores are thought to experience less stress than either omnivores or carnivores upon long-distance translocations because herbivores have the ability to feed immediately after release, whereas animals with other diets may have to chase and capture prey before feeding (Knapp and Hudson, 2004). Translocated Exuma Island Iguanas (*C. cychlura figginsi*), for example, were observed immediately feeding on Ink Berry (*Scaevola plumieri*) leaves after being held in laundry bags for two days without food and after a 2-hr boat ride to the release site (Knapp and Hudson, 2004).

Hence, given the success of captive-release programs in iguanas of the genus *Cyclura* and the ability of these lizards to adapt quickly to their release environment, Alberts et al. (2004) proposed that iguanid lizards as a group appear good candidates for headstart-release programs.

Factors that may influence the success of future translocations include the habitat quality of the release area (Griffith et al., 1989; Rout et al., 2007), the number of animals released, the duration of the translocation project, the location of the release site in relation to the historical range of the species, the type of source population (wild-caught vs. captive-reared) used, the diet and reproductive traits of the translocated species (Griffith et al., 1989), and whether the original cause of decline has been removed (Fischer and Lindenmayer, 2000). More importantly, Griffith et al. (1989) and Dodd and Siegel (1991) stress that future translocations need proper monitoring and dissemination of methodologies and results if they are to be successful. Knapp and Hudson (2004) add that, at the very minimum, methodologies and monitoring techniques (e.g., radiotelemetry, mark and recapture studies, individual and population growth-rate investigations) of successful and unsuccessful protocols should be actively discussed and shared with conservation managers to accelerate the ability to implement future translocations with confidence.

Green Iguana Biology and Conservation Status

The green iguana (*Iguana iguana*) is the most widely distributed lizard of the thirty species in the iguanine sub-family (Burghardt and Rand, 1985), occurring from Mexico southward to Brazil and Paraguay, but can also be found on many islands in the

Lesser Antilles, Isla de Maiz Grande in Nicaragua, and the Colombian islands of San Andres and Providencia (Censky et al., 1998; Savage, 2002; Townsend et al., 2003). They have also been introduced to southern Florida and Hawaii in the United States (Townsend et al., 2003), and have been reported as introduced pests in Puerto Rico (Engeman et al., 2005).

The green iguana is a large (male and females reaching up to 2,010 and 1,440 mm, respectively), diurnal, mostly arboreal lizard that is active year-long (Hirth, 1963; Dugan, 1982; Savage, 2002). Green iguanas are most easily recognized by the presence of a greatly enlarged (exceeds eye in diameter) smooth scale near the posterior margin of the head below the tympanum on the side of the throat (Distel and Veazey, 1982; Savage, 2002). Adults are exclusively herbivorous, spending most of their adult life high in trees (typically 6-25 m above ground), where they feed on leaves, flowers, and fruits (Hirth, 1963; Van Devender, 1982; Rand et al., 1990; Lichtenbelt, 1993; Hayes, 1995; Benitez-Malvido et al., 2003). The misconception that green iguanas eat insects derives from a single report by Hirth (1963), who observed a hatchling in Costa Rica feeding on a grasshopper in the late afternoon. However, other studies have never observed insect matter in the digestive tract (Hirth, 1963; Van Devender, 1982; Rand et al., 1990; Lichtenbelt, 1993; Hayes, 1995).

Along the northern Caribbean coast of Costa Rica, large males begin establishing territories and possibly begin mating in the beginning of the dry season (mid-October), following the summer rainy season (June-August), and carry out mating through the winter rainy season (December-January; Hirth, 1963). Females descend from trees and lay eggs in burrows from March to April, during the hottest and driest time of the year, in

open banks along rivers, beaches, or other forest-edge locations (Hirth, 1963; Van Devender, 1982). Burrows were described by Rand (1968) as being 1-2 m in length and 25-50 cm deep. Incubation takes between 65 and 115 days (Savage, 2002), with hatching occurring from April to June in the beginning of the summer rainy season (Hirth, 1963; Harris, 1982; Van Devender, 1982; Savage, 2002). The dry season (March-April) is advantageous for nesting because it reduces the risk of nest inundation from rain (Harris, 1982; Rand and Green, 1982) and hot sand may present optimal temperatures for incubation (Hirth, 1963; Dugan, 1982; Rand and Green, 1982). Additionally, the beginning of the summer rainy season (mid-June; Savage, 2002) is beneficial for young hatchlings because it coincides with the emergence of new foliage, which is most critical to hatchlings for feeding and allows for better concealment (Dugan, 1982; Harris, 1982; Rand and Green, 1982).

The eggs and young of Green Iguanas may be preyed upon by snakes of the genera *Loxocemus*, *Boa*, *Corallus*, and *Oxybelis*; Basilisk Lizards (*Basiliscus spp.*); raptors and other birds; and several carnivorous small mammals (Savage, 2002). The main predators of adult iguanas are Crocodiles (*Crocodylus acutus*), Coatis (*Nasua narica*), Tayras (*Eira Barbara*), King Vultures (*Sacroramphus papa*), and feral Cats (*Felis* spp.; Savage, 2002) and Dogs (Fitch et al., 1982). However, their large size, open habitat, and tendency to perch in conspicuous areas have also made green iguanas and other iguanine species particularly vulnerable to human exploitation (Fitch et al., 1982). Iguanas have been hunted and eaten throughout Central America for at least 7,000 years, earning the nickname “chicken of the trees” (Cohn, 1989). Consuming iguana is believed to aid in curing several human illnesses, including impotence; hence, in some cases

people are willing to pay higher prices for iguanas than they would for poultry, pork or beef (Fitch et al., 1982).

In the past, their high reproductive potential has helped green iguanas withstand exploitation, but a combination of over-hunting and habitat fragmentation has accelerated their disappearance in previously abundant areas (Fitch et al., 1982). Despite legislative protection of green iguanas in most, if not all, of the countries where they occur (Fitch et al., 1982), several wild green iguana populations are now endangered (Fitch et al., 1982; Cohn, 1989; listed in Appendix II of CITES, the Convention on International Trade in Endangered Species of Wild Fauna and Flora). Studies suggest that the repetitive browsing of herbivorous iguanas may strengthen plant communities by aiding seed survival and germination rate, providing nutrients to developing seedlings, and dispersing seeds into new microhabitats (Iverson, 1985; Benitez-Malvido et al., 2003). Therefore, the loss or reduction of iguana populations may have serious negative effects on the ecosystem to which they belong (Alberts et al., 2004).

The Iguana Verde Foundation

In Costa Rica, green iguanas occur mainly on the Caribbean lowlands (Fitch et al., 1982). Rangers at the Gandoca-Manzanillo Wildlife Refuge (GMWR), located on the south Caribbean coast of Costa Rica, have noticed sharp declines in the refuge's green iguana population, estimating a population between 500 and 2000 iguanas in an area approximately 5,011 ha. According to J. Cabrera (a biologist at the University of Costa Rica; pers. comm.), a minimum population size of 7,600 individuals is deemed necessary

for their long-term persistence within the GMWR. Rangers attribute this decline to over-hunting of pregnant females and other adult iguanas for egg and meat consumption.

In 2001, Edsart Besier (naturalist) established the Iguana Verde Foundation (IVF), a non-profit organization currently combining captive-breeding and headstart-releasing initiatives, with the goal of offsetting the green iguana decline in Costa Rica, especially in the GMWR. The IVF intends to accomplish this goal through the following objectives: 1) aiding the conservation and growth of the population of green iguanas along the Atlantic coast in Costa Rica; 2) stimulating involvement of the local inhabitants with a sustainable form of interaction with nature; 3) studying iguana populations in their natural habitat; 4) acquiring the needed funding; 5) supplying information about, and creating familiarity with, the activities of the foundation; 6) using all other legal means that are beneficial to the goals.

The IVF has already made considerable progress towards accomplishing their objectives. Since its establishment, the IVF has built an outdoor iguana enclosure approximately 0.19 ha. The IVF employs several local people in the daily management of the enclosure and care of the iguanas. Also, the IVF has had a great impact on the children of the local community. Edsart Besier has personally taught four day-long courses to children at the nearby Waldorf School in Playa Chiquita, where children get to interact with green iguanas in the classroom and in the field with the goal of allowing children to make a connection with the animals and become aware of the local decline of green iguanas. The IVF has also conducted week-long events in which they hand out flyers to tourists with information about green iguanas, the IVF, and what they can do to help (www.iguanaverde.com, 2007). Moreover, the IVF has successfully raised green

iguanas in captivity (approx. 175/year). In 2004, the IVF celebrated this accomplishment by releasing 18 headstarted iguanas into the wild in Gandoca (7 km from IVF), with the presence of the press and local community. They later released six more individuals in 2005 in Punta Uva (2 km from IVF; Edsart Besier, pers. comm.).

The IVF was prepared to release more adult (approximately 2-yr-old) iguanas into the wild in 2006; however, given the possible negative effects of headstarting on survival of iguanas in the wild, the IVF did not want to continue releasing iguanas without monitoring. At the request of the IVF, I used radiotelemetry to monitor (post-release) 11 green iguanas that were proposed for release and 2 wild counterparts for a period of two months within the GMWR in 2006. Radiotelemetry is one of the most valuable tools in wildlife biology, allowing researchers to repeatedly and consistently locate free-ranging individuals, particularly secretive animals, and reduce observational bias associated with sampling (Reinert, 1992, Cooke et al., 2004, Wikelski et al., 2006). Radiotelemetry proved to be an essential tool for this study because green iguanas spend much of the time high in trees in dense rainforest, making them hard to relocate on a daily basis.

Goal and Objectives

The main goal for this study was to determine if 2-yr-old headstarted green iguanas from the IVF are physically and behaviorally suited for successful release into the wild. I present the results of a two-month, post-release radiotelemetry study on 11 headstarted iguanas from the IVF and 2 wild iguanas in the GMWR. The objectives for this study were to: 1) conduct pre- and post-release general body and health examinations; 2) compare arboreal microhabitat use, such as tree species, tree height,

canopy cover density, and tree diameter in the wild between headstarted and wild green iguanas; 3) compare social behavior between headstarted and wild green iguanas; 4) compare activity ranges and daily movements between headstarted and wild green iguanas during the summer rainy-season.

To my knowledge this is the first study to monitor the release of captive-raised/headstarted green iguanas into the wild using radiotelemetry, and the first study of green iguanas within the GMWR in Costa Rica. Until now, studies on movements of green iguanas have been largely limited to female and hatchling dispersal during the nesting period in Panama (Montgomery et al., 1973; Bock, 1984; Bock et al., 1985; Bock et al., 1989). With the exception of studies by Dugan (1982) and Rand et al. (1989), no other studies (to my knowledge) have documented movements and activity ranges outside the nesting season. The results of this study provide important ecological information on green iguanas in the GMWR during a portion of the wet season (June-August). More importantly, this study also provides the IVF with initial insights into the efficacy of headstarting as a conservation tool for green iguanas in the GMWR. Data generated will guide future discussions concerning release protocols and advance the ability to implement successful future translocations of green iguanas within the GMWR. Data will also be used for educational programming by the IVF.

CHAPTER TWO

MATERIALS AND METHODS

Captive Management of Green Iguanas

The IVF is located on the Caribbean coast of Limon, Costa Rica, approximately 7 km south of Puerto Viejo, within the GMWR (Figure 1). After being issued permits from Ministerio del Ambiente y Energia (MINAE), the IVF initiated their headstarting program in 2001 with 12 adult wild green iguanas collected along the Sixaola River, within the GMWR, approximately 10 km away from the IVF. The iguana enclosure was situated in the center of the IVF property, ca. 150 m from the sea and 50 m from the road connecting Puerto Viejo with Manzanillo. Captive green iguanas initially were raised within a single 0.08 ha enclosure that was later expanded to 0.19 ha (Figure 2). The enclosure wall was made of 1.5-m-high wood framework covered with stainless steel sheets that prevented the iguanas from climbing over. Two hinged access doors, ca. 1.3 m wide and similarly constructed of wood and stainless steel, were placed at each end of the enclosure. Remnants of netting, formerly erected over a portion of the enclosure, still persisted (Figure 2). Several microhabitats that closely resemble the local jungle setting were present within the enclosure, including: two sand mounds for nesting with underground root systems for support, each approximately 15 x 3 x 0.5 m (L x W x H); various native shrubs and mature trees as sources of food, basking and sleeping sites; and two separate man-made ponds (6 x 3 m, 2 m deep).

Figure 1. Satellite: view of study area, depicting the location of the Iguana Verde Foundation and the study site. Inset: map of Costa Rica depicting the study region (yellow square) on the southern Caribbean coast of Costa Rica.

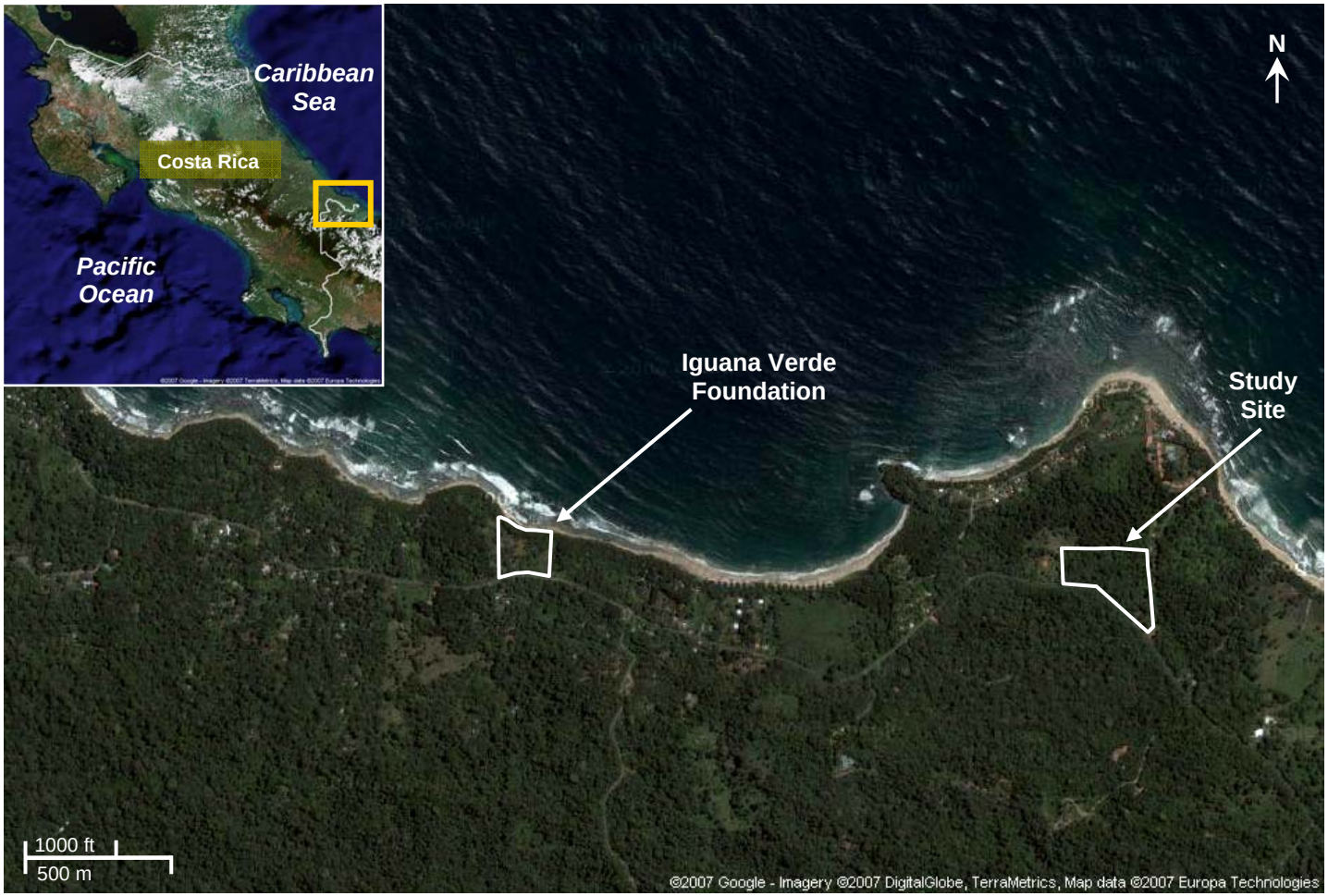
Caribbean Sea
Costa Rica
Pacific Ocean
N
Iguana Verde Foundation
Study Site
1000 ft
500 m
©2007 Google - Imagery ©2007 DigitalGlobe, TerraMetrics, Map data ©2007 Europa Technologies

Figure 2. Above: Southeastern corner of the Iguana Verde Foundation enclosure illustrating the enclosure wall and vegetation within the enclosure. Below: Interior of the enclosure, illustrating one of the water ponds and overhanging tree branches used by iguanas for perching, basking, eating, and sleeping.

The enclosure was designed by IVF such that iguanas would be self-sustaining, thereby enhancing survival in the wild upon release. Iguanas fed primarily on vegetation within the enclosure, though supplemental vegetation was supplied every week or two. Females have been observed excavating nest sites in the sand areas within the enclosure and guarding nest sites after egg-laying.

Since construction of the enclosures (2002 and 2003), iguanas have yielded close to 100-300 hatchlings each year. At the time of this study (July-August 2006), the enclosure was believed to house 100-200 iguanas over one year in age and an estimated 100 hatchlings. Years with lower hatching success rates were largely due to predation of eggs by raccoons (*Procyon lotor*; observed digging up nests during the present study) and possible predation of hatchlings by opossums (*Didelphis virginiana*; observed climbing trees within enclosure at night), common black-hawks (*Buteogallus anthracinus*; observed perching near enclosure surroundings), common basilisk (*Basiliscus vittatus*; several observed within enclosure), and vine snakes (*Leptophis* sp.; observed sleeping on tree branches within enclosure). Van Devender (1982) considered the common basilisk the major predator of juveniles on the west coast of Costa Rica. Enclosure caretakers frequently remove potential predators (sometime live-trapped) from the enclosure and maintain extra vigilance at night during the hatching period (April-July in enclosure). Black hawks are disturbed from nearby perching sites using sling shots aimed at nearby branches.

Study Site

I use the term study site to define the property where headstarted iguanas were released and studied, as well as the site where wild iguanas were captured and studied. The study site was located 1.6 km east of the IVF within the GMWR (09°38'N, 82°41'W; Figure 1). The GMWR occupies 9, 442 ha of sea and land in the southern Caribbean region of Costa Rica. The GMWR receives the least precipitation of the Caribbean region of Costa Rica, with a range of 2-2.5 m year-round, of which July-August and mid-November to mid-December are the rainiest periods. The mean annual temperature fluctuates between 22º and 27º C (www.armonianaturepreserve.com/wildliferefuge.html). The study site was approximately 250 m long (E-W) by 250 m wide (N-S), at its widest, totaling roughly 4.9 ha. The entire western boundary was limited by a one-way dirt road and a 2.5-m high cement wall. Beyond the wall were a 2-ha (approx.), mostly-cleared, private ranch, and thick mixed primary and secondary tropical moist forest beyond. A deep man-made turtle pond bordered three-fourths of the eastern boundary, with mixed primary and secondary tropical moist forest beyond. To the north, the site was bordered by a thin strip of private property having several cabins, with swamp (during rainy seasons) and mostly primary tropical moist forest beyond. The Caribbean Sea was approximately 500 m north of the study site. The southern boundary was bordered by a low-traffic, two-way paved road that joins Manzanillo with Puerto Viejo, and a medium-sloping mixed primary and secondary tropical moist forest beyond.

Vegetation within the study site was best described as mixed primary and secondary tropical moist forest (Savage, 2002) (Figure 3). Canopy trees reached 40-50 m tall, usually with wide crowns and 20-35 m of unbranched trunks. Shorter subcanopy

Figure 3. Above: Representative dense understory and moist leaf litter within the study site. Below: Representative view of tree height and canopy within the study site.

trees had narrower crowns and reached up to 30 m high. The understory was characterized by mixed broad-leaved herbs, small palms, and ferns. The forest floor was mostly covered by dense damp leaf litter, and a number of small depressions which were periodically flooded up to 25 cm deep during this study after strong rains. Representative trees included chilamate (*Ficus tonduzii*), javillo (*Hura crepitans*), guacimo colorado (*Luehea seemannii*), and jobo (*Spondias mombin*).

Like much of the property within the GMWR, the study site was privately owned; however the owner was acquainted with the IVF goals and expressed no intention of developing the property in the near future. The site was chosen because it was one of the known locations where wild green iguanas occurred in relatively high densities and allowed for daily monitoring of both wild and headstarted iguanas. Furthermore, it was adjacent to larger forested areas into which the iguanas could disperse. To avoid overcrowding, the IVF had no intention of releasing additional iguanas on their own property.

Capture and Marking

Iguanas were captured with the aid of IVF employees having considerable capture experience. Green iguanas within the IVF enclosure were captured early in the morning (July 3 and 4) using a thin, 6-m bamboo rod fitted with a noose at the tip. A total of six male and five two-year-old female iguanas (hatched in 2004) were captured randomly for telemetered release into the wild. Males were distinguished from females by relative femoral pore size or head size and determined to be mature based on their body size (all ≥ 265 mm SVL; see Dugan, 1982). Wild iguanas were captured at the study site on 5 July

and 13 July by climbing 20-25 m high into trees and using a 5 m aluminum collapsible noose. Despite 10 days of effort (20 person-days), only two wild iguanas, both males, were captured. For identification purposes, the captive-raised and wild iguanas were marked with a unique color combination of two ceramic beads (4 mm diameter) attached to the nuchal crest with Spectra 35-lb monofilament line (Hayes et al., 2000). To further facilitate identification of individuals in the field, an F (female) or M (male) and a single-digit number was painted on each dorsolateral side of the animal using white enamel paint (Hayes et al., 2000; Figure 4).

Body Size Measurements and General Health Assessment

Each iguana was weighed (± 0.01 kg) with a digital scale and, before release, the following measurements were obtained to the nearest millimeter by collapsible wooden ruler or digital calipers: snout-vent length (SVL), tail length, head length, head width, and longest nuchal and dorsal spines. The number of femoral pores was counted from the limb with the most femoral pores. Iguanas were then inspected for open wounds, infections, number of missing toes, tail condition, and number of ticks. Only iguanas with overall apparent good health were selected for release. The same measurements and general health assessment were conducted for recaptured iguanas at the end of the study to evaluate foraging success, growth, tick load, and injury in the wild.

Radiotelemetry

The 11 headstarted IVF iguanas and two wild iguanas were fitted with radio transmitters (model SOPB-2190, 6.0-7.0 g, 60-80 d battery life, Wildlife Materials Inc.,

Figure 4. Enamel paint marking used for identifying iguanas in trees and transmitter attachment using a loosely-fitted 20-lb monofilament line.

M5

Carbondale, Illinois) attached externally to the anterior and posterior of the hind limbs using a loosely-fitted 20-lb monofilament line (Figure 4). The line was tied off with a square knot using needle-nosed pliers and a drop of super glue was used to secure the knot from undoing. Similar transmitter attachment methods were used by Knapp and Owens (2005) on recently-hatched Andros Iguanas (*Cyclura cychlura cychlura*) during a study of natal dispersal, survival, and habitat preferences.

Headstarted iguanas from the IVF were processed within the enclosure and then placed in nylon sacs in the shade. Later the same day, the IVF iguanas were transported to the study site and randomly released at 50-m staggered intervals in the study area (Figure 5). Two of the 11 headstarted iguanas (M5 and F5) were released in swamp habitat. Wild iguanas were processed and fitted with transmitters in the field and released at their original capture site within the study site.

Radiotracking took place 4-6 times per week from 5 July - 25 August 2006. I located iguanas no more than once per day (with the exception of F1, which was tracked twice on July 10) using a Yaesu VR-500 receiver (100 kHz-1300MHz) and a two-element Yagi antenna. To minimize the possibility that iguanas could anticipate my approach, I randomized the time and approach direction for all fixes. Upon each fix (location of iguana with strong receiver signal), I visually located the iguana if possible and recorded date, time, and UTM coordinates with a handheld GPS unit (Garmin GPS 12XL) from a position directly beneath each iguana. Actual sightings were not achieved for every GPS fix, due to either the cryptic nature of green iguanas in trees or the visually-dense canopy. When an iguana could not be seen, the UTM coordinate was taken from the position with the strongest receiver signal. When iguanas remained in one

Figure 5. Approximate release locations of headstarted (white) and wild (orange) iguanas within the study site (shown as white dots). Nine headstarted iguanas were released within the study site and two outside of the study site within swamp habitat.

N
200 ft
100 m
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location between successive fixes, I assigned the UTM coordinates of the previous fix to minimize GPS measurement error.

Arboreal Microhabitat Use and Behaviors

For fixes resulting in actual sightings, I recorded the iguana's height in the tree using a laser range-finder by standing directly under the iguana and bouncing the laser off the iguana or a nearby tree branch. I also recorded the tree species and measured the tree diameter at breast height using a DBH (diameter at breast height) tape. I relied on common tree names used by the IVF and locals during the study to categorize tree species; however, some trees were unknown and categorized as such. Latin names were later assigned common names through photos on the internet. For each iguana, I recorded the activity (resting in sun, resting in shade, eating, fleeing, and fighting) in the tree. Iguanas were considered to be resting in sun if >50% of body was in the sun; resting in shade if <50% of body was in sun; eating if observed chewing on leaves or fruits; fleeing if moving rapidly away; and fighting if engaged in any ritualized agonistic behavior. I also counted the number of additional iguanas in the same tree to give some indication of social behavior in trees. The same data were collected when non-telemetered wild iguanas were incidentally encountered.

Movement Analyses

I calculated the following movement variables: 1) mean distance moved per day over entire study = distance moved divided by number of days between successive fixes, averaged for all fixes (Gregory et al., 2001; Diffendorfer et al., 2005; Figueroa, 2006);

2) dispersal distance = distance from first to last location; and 3) total distance traveled = sum of all distances moved between successive fixes. I applied circular statistics to analyze movement directionality, using the Animal Movement Extension (AME; Hooge and Eichenlaub, 1997) in ArcView 3.3 (ESRI, Redlands, California) to compute mean bearing, angular concentration (*r*), and Rayleigh's *z* (Zar, 1996). Circular statistics were not computed for iguana M3 (headstarted) and M7 (wild) because they had only two unique fixes (fixes at different locations).

Activity Range Analyses

Similar to Figueroa (2006), I use the term "activity range" for headstarted iguanas instead of "home range," since they presumably have yet to establish or perceive a defined home range. I used the Animal Movement Extension (Hooge and Eichenlaub, 1997) in ArcView 3.3 (ESRI, Redlands, California) to estimate the seasonal (rainy season; Savage, 2002) activity range size using all fixes obtained from each iguana. I estimated the 100% minimum convex polygons (MCP: Jenrich and Turner, 1969) because they can be compared more readily to past conspecific studies (e.g. Montgomery et al., 1973; Bock et al., 1989; Rand et al., 1989). I also calculated 95% and core 50% fixed kernels (FK: Worton, 1995) because they are regarded as more accurate estimators of activity range size (Seaman and Powell, 1996; Diffendorfer et al., 2005). The 50% contours are reported, acknowledging their limitations (Powell, 2000), because they arbitrarily characterize the core area of use and provide potential insight into areas that may include important resources to the animal (e.g., Dixon and Chapman, 1980). Default least-squares cross-validation (lscv) was used to determine the smoothing factor for

individual FK activity range sizes (Seaman and Powell, 1996; Blundell et al., 2001; Diffendorfer et al., 2005; Knapp and Owens, 2005).

Minimum convex polygons use the outermost locations to construct a polygon to outline the maximum area used by the animal (Reinert, 1992; Powell, 2000) and often require more than 100 locations for accurate estimates (Powell, 2000). On the other hand, FK estimators place contours around different intensities of use and, when combined with least-squares cross-validation (lscv, the bandwidth with the least estimated error), allows for more accurate estimates with as few as 30 locations (Seaman et al., 1999; Figueroa, 2006).

I also used AME to compute autocorrelation for each iguana, represented by Schoener's ratio (t^2/r^2; Swihart and Slade, 1985). When autocorrelation exists ($t^2/r^2 < 2$), the distance moved between consecutive observations decreases, resulting in underestimates of activity range (Swihart and Slade, 1985). Because M3 (headstarted) and M7 (wild) had only two unique fixes (fixes at different locations), they were not analyzed for MCP areas or Schoener's ratio.

Statistical Analyses

I analyzed the data using SPSS 12.0 for Windows (Statistical Package for the Social Sciences, Inc., Chicago, Illinois, 2003) with alpha = 0.05. Because some radiotracked iguanas were not visually re-sighted, observational data were too limited to compare differences between males and females. Data on movements and activity ranges, however, were sufficient for sex comparisons. Because assumptions were virtually

always met, I relied on parametric tests (Zar, 1996) for most analyses. However, I also employed several nonparametric tests (Conover, 1999).

Body Size Measurements

Mass and SVL for headstarted iguanas at initial capture were $\log_{10}$-transformed for the regression of mass on SVL. To test for differences in body condition between sexes, the log-log residuals were analyzed using an independent-samples *t*-test. Differences between headstarted and wild iguanas in size at initial capture (SVL and mass) and change in mass between release and recapture were compared using independent-samples *t*-tests.

Arboreal Microhabitat Use and Behaviors

I used independent *t*-tests to compare differences between headstarted iguanas and wild iguanas for iguana height in tree, tree diameter, canopy density, and group size (number of iguanas in same tree). To avoid pseudoreplication, I used only one value from each iguana. Thus, if telemetered headstarted or wild iguanas were observed more than once during the study, I used the mean of all unique locations per iguana (0-6 per animal). Locations from wild iguanas included 16 non-telemetered animals (sex undetermined) in addition to the two telemetered males.

For species of tree and observed activity, the data were categorical and, therefore, mean values for individuals could not be computed. Accordingly, I pooled data from all individuals (thereby including pseudoreplication, >1 observation from some individuals)

and compared frequencies between headstarted and wild iguanas using tests of asymmetry (Phi for 2×2 and Cramer's *V* for 2×3 contingency tables; Conover, 1999).

Movements and Activity Range

I used independent-samples *t*-tests to evaluate differences in activity range and movements between sexes in headstarted iguanas, and between headstarted and wild iguanas. Pearson correlations (*r*) were computed among the measures of movement, activity range, and autocorrelation.

CHAPTER THREE

RESULTS

Recapture and Survival Success

Although the weariness of iguanas to humans was not experimentally tested, headstarted iguanas showed no signs of negative behavior associated with being raised in captivity. Iguanas exhibited violent flights when I attempted to capture them within the IVF enclosure, as well as in the wild at the conclusion of the study.

Recapture and survival data are summarized in Table 1. Seven iguanas, including five headstarted (three female and two male) and two wild, of the original 13 iguanas (11 headstarted and two wild) released with transmitters, were recaptured at the end of the study. Recapture success was 54% after a total effort of seven days (approx. 7-8 hours daily), averaging one recapture per day. However, no attempt was made to recapture iguanas F5 and M5 due to the inaccessible swampy conditions in which they were released. Iguanas and F2, M2, and M4 were intensely searched for by climbing trees near their last fix, but the iguanas were not observed the recapture effort. Iguana M6 was spotted on 24 August, but escaped repeatedly by switching trees as we attempted to capture it.

The total survival days for recaptured iguanas ranged between 43 and 51 days ($\bar{x}$ = 49) of a total 51 days of monitoring. Total survival days for non-recaptured iguanas (excluding F5 and M5) were estimated from date of the first GPS fix until the date of the last movement or visual (whichever totaled more days), and ranged from 29-51 days

Table 1. Summary of number of relocations (fixes), tracking dates (release, capture/last visual, and last movement; during the period July-August 2006), survival days and body size (initial snout-vent length, SVL in mm; mass excluding transmitter) before and after (with percent change) radiotracking of individual headstarted and wild green iguanas (*Iguana iguana*; M = male, F = female).

Iguana	Fixes	Release date	Capture/last sighting date	Last movement date	Survival days	SVL before[c]	Mass before (kg)	Mass after (kg)
F1	36	4 July	24 August		51[a]	320	1.26	1.48 (+ 17%)
F2	34	3 July		1 August	29[b]	320	1.27	n/a
F3	33	3 July	18 July		46[a]	295	0.95	0.87 (- 9%)
F4	33	3 July	20 July		48[a]	300	1.02	1.05 (+ 3%)
M1	35	3 July	22 July		50[a]	330	1.51	1.47 (- 3%)
M2	34	3 July	1 August	4 August	32[b]	335	1.39	n/a
M3	36	4 July	24 August		51[a]	335	1.47	1.39 (- 6%)
M4	34	4 July	10 August	18 August	45[b]	265	0.90	n/a
M6	35	4 July	24 August		51[a]	319	1.28	n/a
M7 (wild)	34	5 July	25 August		51[a]	480	4.86	4.57 (- 6%)
M8 (wild)	28	13 July	25 August		43[a]	445	3.33	3.72 (+ 12%)

[a] Estimated from date of release to date of capture or last sighting
[b] Estimated from date of release to date of last change of location
[c] SVL after were not calculated because growth during the two-month period was less than the measurement error.

($\bar{x}$ = 39). Iguanas were recaptured at an average height in a tree (before disturbing) of 22 m (N = 6; data missing for F4). There was no direct evidence of iguana mortality.

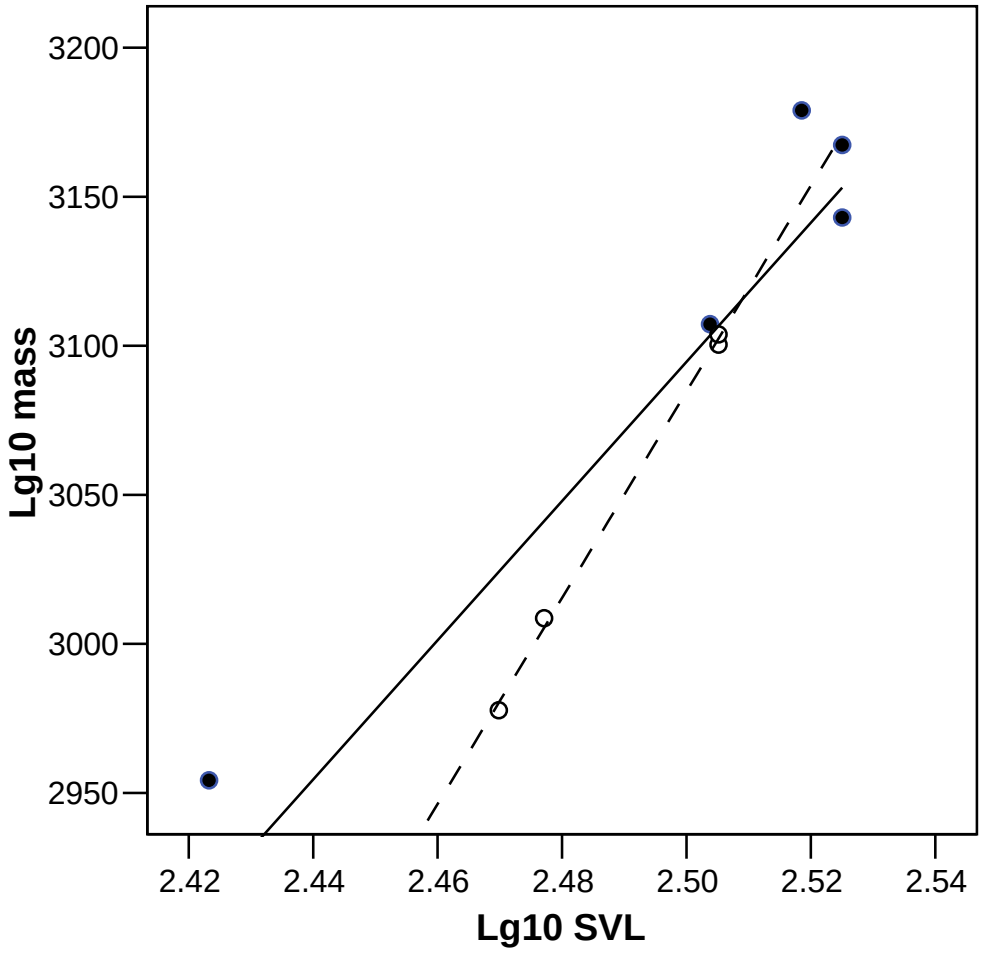
Transmitter Attachment

The monofilament used to attach transmitters to the body caused shallow to deep abrasions on the tail and inner hind thighs of all five recaptured headstarted iguanas. Both wild iguanas lacked abrasions upon recapture; their larger size and thicker skin may have afforded more protection from the monofilament. With the exception of iguana F3, iguanas were treated in the field with an antiseptic spray and released. Iguana F3 was taken back to the IVF (due to deep abrasions) and similarly treated before release into the IVF enclosure. This iguana was confirmed to be recovering adequately in the enclosure shortly after transmitter removal; hence, other headstarted iguanas with minor abrasions returned to the wild were expected to recover as well.

Body Size Differences

Each headstarted iguana released (N =11) showed normal weight and body size (Table 1) for their estimated two years of age, when compared to Van Devender's (1982) growth models for green iguanas on the west coast of Costa Rica. There were no significant differences in SVL (t (9) = 0.50, P = 0.63) or mass (t (9) = 1.29, P = 0.24) between males and females (Table 1) collected from the IVF. However, a t-test of residuals from the log-log regression of mass on SVL showed that body condition was better in males than in females (t (9) = 2.72, P = 0.03), though this resulted largely from the smallest male's condition (Figure 6). Both male wild iguanas (Table 1) captured

Figure 6. Log-log regression plot of mass (grams) on snout-vent length (mm SVL) of headstarted male (●) and female (○) iguanas before transmitter attachment and release in the wild.


3200
3150
3100
3050
3000
2950
Lg10 mass
2.42
2.44
2.46
2.48
2.50
2.52
2.54
Lg10 SVL

within the study site were larger and heavier than any of the headstarted iguanas (SVL, t (11) = -8.27, $P < 0.001$; mass, t (11) = -8.79, $P < 0.001$).

Two of the three recaptured headstarted females increased in weight (17% and 3%) during the two months between release and recapture, whereas the third female lost body mass (-9%). Both male headstarted iguanas lost mass (-6% and -3%). However, mass was statistically similar for headstarted female and male iguanas at the end of the study (t (3) = 1.26, $P = 0.30$). One wild male (M7) lost weight (-6%) and the other gained weight (12%) during the two months of this study. Changes in mass of the headstarted and wild iguanas were statistically similar (t (5) = 0.20, $P = 0.85$; Table 1). Comparisons of SVL were not calculated because growth during the two-month period was less than the measurement error.

Arboreal Microhabitat Use and Behaviors

Independent t-tests revealed no significant differences between headstarted ($N = 7$ with adequate data) and wild ($N = 18$) iguanas with respect to iguana height in tree (t (23) = -1.69, $P = 0.10$), tree diameter (t (23) = 0.41, $P = 0.69$), and canopy cover (t (23) = -0.62, $P = 0.54$). The mean (± 1 S.E.) height of iguanas when observed in trees was 22 m (± 2) for headstarted and 25 m (± 1) for wild iguanas. Iguanas were observed as high as 33 m (M7; wild) in a tree and as low as 15 m (M1; headstarted). With the exception of M2 (one sighting), all iguanas were found 100% of the time in trees. Preferred tree diameter during the study averaged 55 cm (± 9) and 46 cm (± 4) for headstarted and wild iguanas, respectively. An average canopy density of 78% and 82% was recorded directly

under headstarted and wild iguanas, respectively, probably explaining the difficulty of spotting iguanas in the trees during the study.

To compare use of tree species by headstarted (N = 7 individuals) and wild iguanas (N = 18 individuals, including two telemetered), I analyzed a sample of 56 observations (N = 13 headstarted and 43 wild) from these 25 individuals. This sample included pseudoreplication (>1 observation for some individuals). Iguanas were observed the majority of time (66%) in the Chilamate tree (wild fig, *Ficus tonduzii*) and (27%) in Javillo (sandbox tree, *Hura crepitans*). Iguanas were only observed once in each of the remaining trees: Guacimo Negro (*Guazuma ulmifolia*), Jobo (*Spondias mombin*), Sarua (unknown latin name), and Guavo (unknown latin name). In spite of pseudoreplication, which would increase the likelihood of detecting a difference, headstarted and wild iguanas were similarly distributed between the two most frequently used tree species (Phi = 0.01, P = 0.93, N = 52). Because I did not measure relative abundance of tree species present at the study site, I could not test whether iguanas preferentially used specific tree species.

To examine behaviors, I analyzed 68 observations from the 25 individuals (N = 18 headstarted and 50 wild), thus including pseudoreplication. The majority of activity sightings involved iguanas resting in the sun (73.5%), with only 13% resting in the shade. Iguanas were observed feeding only on Javillo, and Chilamate tree, totaling 11.8% of activity observations. Neither wild nor headstarted iguanas were observed exhibiting fighting behavior during study. Headstarted and wild iguanas exhibited similar frequencies of the three most commonly observed behaviors (Cramer's V = 0.17, P = 0.36, N = 67).

Both headstarted and wild iguanas were more often found in groups than singly. An independent *t*-test revealed no significant difference between headstarted ($\bar{x}$ = 1.8 ± 0.49; N = 7 with adequate data) and wild ($\bar{x}$ = 1.2 ± 0.10; N = 18) iguanas in group size (t (23) = 1.76, P = 0.09). The largest group number observed totaled 10 iguanas in a single tree. Iguana F4 was recaptured within this group of 10 iguanas at the end of the study.

Movements and Activity Range

The movement and activity range data are summarized in Table 2. Each of the 11 iguanas analyzed (9 headstarted; 2 wild) provided 28-36 fixes ($\bar{x}$ = 34), with 2-11 ($\bar{x}$ = 6) actual moves (number of fixes wherein the animal changed location). Iguanas were visually detected 26 occasions of 372 fixes (7%). Among headstarted iguanas, independent *t*-tests showed no significant differences (all $P > 0.20$) between sexes for any of the movement variables (m/day, dispersal distance, and total distance), circular statistics (mean bearing, angular concentration, and Rayleigh's Z), autocorrelation values (t^2/r^2), or activity range estimators (100% MCP, 95% FK, and 50% FK). Similarly, no significant differences were found between headstarted and wild iguanas (all $P > 0.15$).

Headstarted iguanas averaged a mean distance moved per day over entire study (distance moved divided by number of days between successive fixes, averaged for all fixes) of 33 ± 5 m/day compared to the 37 ± 18 m/day averaged for the two wild iguanas. Total distance traveled (sum of all distances moved between successive fixes) by headstarted iguanas (both sexes pooled) ranged from 36-458 m versus total distances of 40 m (M7) and 176 m (M8) for the two wild iguanas. Wild iguana M7 was the largest iguana (4.86 kg), but traveled one of the shortest distances, second only to headstarted

Table 2. Estimated activity ranges and movement data for individual green iguanas, *Iguana iguana*. Moves = number of fixes wherein the animal changed location. MCP = 100% minimum convex polygon; FK = fixed kernel (LSCV = least squares cross-validation bandwidth; 95%, and 50% areas used). All estimated activity range values are given in hectares (ha). Mean m/d = distance moved (meters) divided by number of days between successive fixes, averaged for all fixes. Dispersal distance = distance from first to last location. Total distance = sum of all distances moved between successive fixes. t^2/ r^2 = Schoener's autocorrelation value. Mean bearing = average compass bearing for movements; r = angular concentration. Rayleigh's *z* = test for directionality (all $P > 0.05$). Group means ($\bar{x} \pm 1$ SE) are provided for headstarted (HS), wild, and all iguanas.

Iguana	Fixes	Moves	MCP100	FK95	FK50	$\bar{x}$ m/d	Dispersal distance	Total distance	t^2/ r^2	Bearing	r	Rayleigh's *z*
F1	36	7	0.17	0.29	0.03	25	75	159	0.15	222	0.50	1.51
F2	34	7	0.93	3.00	0.43	50	238	401	0.08	134	0.53	1.69
F3	33	5	0.09	0.13	0.02	26	17	114	0.23	237	0.34	0.46
F4	33	5	0.32	0.63	0.11	34	121	262	0.22	58	0.04	0.01
M1	35	8	0.14	0.08	0.009	25	28	270	0.94	165	0.09	0.06
M2	34	11	1.06	1.93	0.15	41	138	434	0.14	140	0.27	0.74
M3	36	2	---	.003	0.001	19	37	36	---	---	---	---
M4	34	9	0.46	0.53	0.06	62	154	458	0.44	133	0.20	0.29
M6	35	10	0.19	0.29	0.03	14	24	232	0.24	298	0.28	0.85
M7 (wild)	34	2	---	0.0008	0.0003	19	0	40	---	---	---	---
M8 (wild)	28	4	0.14	.57	0.08	55	94	176	0.20	303	0.22	0.15
HS ♀♀	34 ± 1	6 ± 1	0.38 ± 0.19	1.00 ± 0.67	0.15 ± 0.09	34 ± 6	113 ± 47	234 ± 64	0.17 ± 0.03	163 ± 42	0.35 ± 0.11	0.92 ± 0.41
HS ♂♂	35 ± 0	8 ± 2	0.46 ± 0.21	0.57 ± 0.35	0.05 ± 0.03	32 ± 9	76 ± 29	286 ± 77	0.44 ± 0.18	184 ± 36	0.21 ± 0.04	0.49 ± 0.19
Wild ♂♂	31 ± 3	3 ± 1	0.14	0.29 ± 0.29	0.04 ± 0.04	37 ± 18	47 ± 47	108 ± 68	0.20	303	0.22	0.15
All iguanas	34 ± 1	6 ± 1	0.39 ± 0.12	0.68 ± 0.28	0.08 ± 0.04	34 ± 5	84 ± 22	235 ± 45	0.29 ± 0.09	188 ±28	0.28 ± 0.05	0.64 ± 0.21

--- Calculation not possible because of small sample size

iguana M3. The short distances traveled by iguanas M7 and M3 are reflected in their 95% FK activity range estimates (0.0008 ha and 0.003 ha). The largest 95% FK activity range estimate (3 ha) corresponded to headstarted iguana F2, which also had the longest dispersal distance of 238 m. Headstarted and wild iguanas dispersed an average of 92 m ± 25 and 47 m ± 47, respectively. Movements were considered to be random in compass bearing rather than directional, since all Rayleigh's *z* values were non-significant (all $P > 0.05$). Autocorrelation values were all well below 2.0, ranging from 0.08 - 0.94 ($\bar{x} = 0.29$), indicating strong time-dependence between successive observations and likely underestimation of activity ranges (Swihart and Slade, 1985; Figueroa, 2006).

Pearson correlations revealed significant positive correlations among all of the activity range estimators (all r (7-9) ≥ 0.75, $P \leq 0.02$). Furthermore, 100% MCP and 95% FK were positively correlated with all three movement variables (r (7-9) ≥ 0.68, $P \leq 0.02$). The 50% FK was positively correlated with dispersal distance (r (9) = 0.87, $P < 0.001$), and positively correlated, but not significantly, with m/day and total distance (r (9) = 0.58, $P = 0.059$ and r (9) = 0.598, $P = 0.052$, respectively). In addition, all movement variables were also positively correlated with each other (all r (9) ≥ 0.78, $P \leq 0.004$). All movement and activity range variables were independent of body size (SVL and mass; all $P > 0.11$) and number of fixes (all $P > 0.19$). Circular statistics and autocorrelation values were independent of all activity range estimators and any of the movement variables (all $P > 0.05$).

CHAPTER FOUR

DISCUSSION

In this study, I relied on radiotelemetry to evaluate the success of 2-yr-old headstarted green iguanas released into the wild by comparing their behaviors and habitat use to those of non-captive-reared iguanas. Because all of the behavioral and ecological variables analyzed were similar for the male and female headstarted iguanas, I felt justified in pooling the two sexes for comparison to the two radiotelemetered wild iguanas and other wild iguanas observed incidentally. My analyses revealed no differences between the headstarted and wild iguanas, suggesting that the headstarting approach used by the Iguanaverde Foundation (IVF) will succeed in augmenting wild iguana populations. In the sections that follow, I address the dependent measures that support my conclusion.

Transmitter Effects

Researchers often assume that radiotelemetry studies do not affect normal movement and behavior of animals (Knapp and Owens, 2005). Researchers generally agree that the weight of transmitters should not exceed 5% of the animals' weight, which we adhered to (e.g., Reinert, 1992). Compared to the wild iguanas, movements and behavior of the headstarted iguanas might have been more affected by the transmitters for two reasons: the ratio of transmitter mass to body mass was greater for headstarted

iguanas and, unlike the wild iguanas, they suffered abrasions from the monofilament attachment of the transmitters to the body. However, we found no differences in any measures of behavior or survival between the headstarted and wild iguanas.

Unfortunately, the headstarted iguanas we failed to recapture (6 of 13 individuals) may not survive in the long-term unless the monofilament degrades, allowing the transmitter to fall off. Knapp and Owens (2005) found that hatchlings (12%) in their 2003 study also developed abrasions. To reduce abrasions, Knapp and Owens (2005) recommended several refinements to their original technique (see Knapp and Owens, 2005), including re-positioning the transmitter to the ventral surface (directly posterior to cloaca) instead of the dorsal side of the pelvic girdle, or removing the posterior monofilament line (line around tail). In the future, I recommend against methods that will affect green iguanas on a long-term basis if they are not recaptured. Goodman et al. (2007), for example, suggest suturing transmitters to the dorsal crest, similar to the attachment of glass beads (see Capture and Marking section above).

Body Condition

Past studies in Jamaican iguanas (*Cyclura* collie) suggested that the type of diet given to iguanas in captivity may have serious implications for survival of headstarted iguanas when released into the wild (Hudson, 2000). Hudson (2000) proposed that feeding commercially grown fruits and vegetables to iguanas in captivity may predispose them to substantial water weight loss immediately upon release in the wild, due to the high moisture content of the diet. Hudson (2000) further argued that using such highly palatable diets in captivity may slow down the ability of iguanas to adapt to feeding on

native vegetation. Although some headstarted iguanas in the present study lost weight, it was minimal compared to weight losses observed in Jamaican iguanas (see Hudson, 2000). The iguanas headstarted within the in-situ enclosure at the IVF benefited from being able to actively search and choose from a diet strictly composed of a variety of native plant choices. Hence, any possible weight losses related to diet may have been considerably reduced due to the husbandry methods used by the IVF.

Arboreal Microhabitat Use and Behaviors

Both headstarted and wild telemetered iguanas remained high in trees during this study. None of the telemetered study animals (9 headstarted, 2 wild), nor any other incidentally-encountered wild iguanas, were observed on the ground during this study. However, telemetered iguanas likely descended to the ground for some of their longer movements, and at least one (M2) was presumed to be fleeing from me on the ground and then up a tree on one occasion. Green iguanas have been known to remain in tree tops from one day to several weeks, apparently because a single tree could meet all of an iguana's short term requirements (food, thermoregulatory sites, and sleeping perches), with the iguana only rarely descending for basking, tree-to-tree movement, or escape from predators (Dugan, 1982).

Iguana height preferences in this study (15-33 m) were similar to heights reported by Hirth (1963), at 6-25 m above the ground. However, adult iguanas within my study site probably used higher perches, on average (22 m headstarted, 25 m wild), than those reported in other studies, since many of the trees in my study site were unbranched for at least 20 m. Large iguanas tended to occupy higher perches than smaller ones, but this was

not the rule since on several occasions I observed smaller unmarked adult iguanas on higher perches. Dugan (1982) found that outside of the breeding season, medium males usually avoid large males, and that large males may share conspicuous perching sites with females but not other males. Hence, it is likely that within my study site, medium iguanas that were observed using higher perches than large males were female iguanas rather than medium males.

Although headstarted iguanas were raised within an enclosure where the tallest trees reached approximately 15 m, when released into the wild they seem to have had little problem adjusting to taller tree heights. Hence, headstarted iguanas showed normal height distribution when compared to iguanas in past studies and to their wild counterparts in this study. This is important because the ability to remain high in trees, limiting their time on or near the ground, protects them from dogs on nearby properties and easy detection by human poachers.

Green iguanas are commonly found in groups during the non-breeding season; however, they can also be found alone (Hirth, 1963; Dugan, 1982). Hirth (1963) reported a maximum of four adult iguanas in a single group, and Dugan (1982) reported groups of up to 10 iguanas of various ages in a single tree. In my study, although sometimes telemetered iguanas were observed alone (assuming I did not miss other iguanas in the tree), both headstarted and wild iguanas were more often found in groups ($\overline{x} = 2$ individuals per group) than singly, and on one occasion in a group as large as ten individuals. More importantly, headstarted iguanas were observed on several occasions in the same tree with other wild iguanas, showing signs of proper social integration into the

local population, and hence, allowing them to take advantage of group benefits (see below).

Among the reasons suggested for group behavior in iguanas are exploitation of a food source site and better avoidance of predators (Rand and Burghardt, 1985). Dugan (1982) noticed green iguanas feeding in groups of 10-15 on *Spondias mombin* fruit trees during the fruiting period in the wet season (August-September), and in large numbers feeding on an abundant vine (*Cardiospermum grandifolium*) during the dry season. Data from Auffenberg (1982) suggest that iguanas feed in groups because exploiting a known food site may be more efficient than searching for new food items, specific food items may be preferred over others, and seasonal or daily constraints may impede access to preferred food items; hence, the effort appears coordinated. In regard to predator avoidance, animals are suspected to group because the probability of detecting a predator increases with the number of vigilant individuals (Rivas and Levin, 2004). Sociality may also help against individual predation through the selfish-herd effect (Hamilton, 1971), active deterrence of predators (Gross and MacMillan, 1981), and confusion of predators through perceived bottlenecks by predators which lead to lower capture efficiencies (Krakauer, 1995). I suspect that iguanas within the GMWR tend to occur more likely in groups to avoid predators, rather than to exploit a food source, since suitable, non-utilized food trees were abundant within the study site. However, I cannot rule out having missed other groups of iguanas within apparently vacant trees suitable for food.

Movements and Activity Range

Dugan (1982) and Rand et al. (1989) found that mature iguanas (> 260 mm) lead relatively sedentary lifestyles outside of the nesting season, restricting their movements to small home ranges ($\bar{x}$ 100% MCP = 0.18 ha [Dugan, 1982] and 0.98 ha [Rand et al., 1989]). The average 100% MCP activity range calculated for all telemetered iguanas in my study was also relatively small (0.39 ha ± 0.12), and similar to those reported in earlier studies (Dugan, 1982; and Rand et al., 1989) outside of the breeding season. Among iguanas, scarcer food sources typically translate into larger home range sizes since they have to travel longer distances to find food (Iverson, 1979; Rand et al., 1989). Hence, the small home range sizes observed in this study are most likely explained by the apparent abundance of food sources within the study site at the time of my study which allows for smaller home range sizes. It may also help explain why telemetered iguanas did not wander outside of the study site boundaries. Results for the current study showed that headstarted females and males did not differ in activity range size, similar to findings of similar sized animals from Dugan (1982).

Although I cannot say for sure that there were no significant differences in movements and activity ranges between headstarted and wild iguanas within the GMWR, due to the small sample size of wild iguanas ($N = 2$), the headstarted iguanas exhibited normal movement behaviors and activity range sizes when compared to past conspecific studies (see Dugan, 1982 and Rand et al., 1989). The lack of differences between headstarted and wild iguanas for microhabitat and behavioral variables lends confidence to my conclusion that headstarted iguanas rapidly adjusted to their new environments following release.

Recommendations

The IVF has almost single-handedly changed local public opinion regarding the importance of green iguanas for the local environment, thereby enhancing the iguana's future prospects. The following suggestions should increase the knowledge of iguana ecology and likelihood of continued survival within the GMWR. First, the IVF should make a conscious effort to estimate yearly survival rate of iguanas of all age classes within the enclosure, including those lost to predators and disease. Once identified, any significant causes of mortality can hopefully be ameliorated. Second, more sand mounds could be added for nesting, thereby decreasing damage to eggs by late-nesting females (see Iverson, 2004). Third, more frequent releases of headstarted iguanas would reduce the number of iguanas within the enclosure, thereby decreasing the potential for disease and increasing food, sleep, and basking opportunities for each iguana. Radiotelemetry could be used to compare the post-release success of different age classes of headstarted iguanas. Perhaps 1-yr-old iguanas fare as well as 2-yr-old iguanas. Finally, effort should be taken to obtain population estimates within release sites prior to and for several years following releases. The ultimate measure of headstarting success would be to increase the number of breeding individuals within the wild population (Griffith et al., 1989; Beck et al., 1994). Although radiotelemtry studies may not always be feasible, simpler methods, such as mark-resighting, may suffice to estimate population size, reproductive success, and even the survival and normal behaviors of individual headstarted iguanas released in the wild.

Some of the above recommendations may apply to other iguana headstarting programs. Other aspects contributing to the success of the IVF headstarting program

should also be considered, such as educating the public of the species in danger (see Knapp and Hudson, 2004, and Carter et al., 2005) and raising iguanas on a natural food source (Hudson, 2000). More importantly, an in-situ approach should be strongly considered in any headstarting attempt, because it reduces the potential of introducing exotic pathogens to local environments, eliminates the stress posed to animals due to extended transportation periods, and presumably increases survival since iguanas should develop immunity to most local pathogens (Knapp and Hudson, 2004).

Headstarting will no doubt continue to be used as more species become threatened by human activities. Critics will continue to give reasons for discontinuing such efforts (Dodd and Siegel, 1991; Reinert, 1991), and proponents will continue to advocate the many positive outcomes of such aggressive tools (Cayot et al., 1994; Stanford and King, 2006). However, this type of debate should encourage the development of new and better headstarting methods and monitoring techniques, and hence provide wildlife managers with more options for helping species in peril.

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