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Ecology of the Endangered Sandy Cay Rock Iguana, Cyclura rileyi cristata, in the Bahamas

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Ecology of the Endangered Sandy Cay Rock Iguana, *Cyclura rileyi cristata*, in the Bahamas

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 opinion is adequate, in scope and quality, as a thesis for the degree Master of Science.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT OF THE THESIS

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Master of Science, Graduate Program in Biology
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Dr. William K. Hayes, Chairman

In this thesis I present the results of a study on the population demographics and home range size of *Cyclura rileyi cristata*. There are eight species of West Indian rock iguanas, genus *Cyclura*. All are endangered, including *C. rileyi* which is endemic to the Bahamas. One of three recognized subspecies, *C. r. cristata* lives on a single cay in the Exumas chain and is among the most endangered lizards in the world. Various size measurements indicate that this taxon is among the smallest within the genus. Distance surveys and a Lincoln-Petersen estimate based on resightings of marked iguanas suggest that the total population is comprised of 134-204 animals. In contrast to other populations of *C. rileyi* sampled by similar means, the sex ratio was highly skewed toward male iguanas (95% of noose captures). Thus, as few as 10 female iguanas may remain in the population. Glue-traps set near burrows proved to be more effective than noosing for the selective capture of females. However, no females of reproductive size were captured. Three non-native mammals were found on Sandy Cay, including rats (*Rattus rattus*), mice (probably *Mus musculus*) and a single raccoon (*Procyon lotor*). Several estimates based on capture rates and resighting ratios suggested that the raccoon inflicted considerable mortality on adult iguanas (35-67% between 1996 and 1997). Comparisons of density among rat-infested versus rat-free populations and attacks observed on lizard models suggest that rats negatively impact *C. rileyi* populations. Home range estimates based on radio-tracking of iguanas showed highly variable home range sizes that, in males, may exceed those of other *C. rileyi* populations. Remarkably few social interactions were observed, which was probably a consequence of low population density. Based on these findings, I offer several recommendations for the conservation of this critically endangered lizard, including translocation and captive headstarting programs to begin a new population and formal protection of the island as a National Park.

INTRODUCTION

There are eight species of rock iguanas, genus *Cyclura*. These large lizards are important grazers and seed dispersers on many islands in the West Indies (Iverson, 1985). All of these species are designated as endangered and are listed on CITES (Convention on the International Trade of Endangered Species) Appendix I (Alberts, 2000). *Cyclura mattea, C. nigerrima, C. portoricensis* and others are entirely extinct (Carey, 1975). Human activities have been directly responsible for the endangerment of these animals (Alberts, 2000). In some areas the iguanas are eaten or hunted for sport and in others smugglers capture them for pets. However the chief threat has been habitat loss and the introduction of non-native animals such as hogs, goats, rats, mongooses, dogs and cats. The swift virtual extermination of *Cyclura carinata* from Pine Cay by feral cats and pet dogs was documented by (Iverson, 1978). The initial population was estimated at 5,500 adult animals before cats and dogs were introduced during a construction project. These animals spent large amounts of time preying on iguanas and within three years the iguana population estimate was 5 animals.

Three critically endangered taxa of *Cyclura* illustrate the problems these animals face. *Cyclura collei* is so rare that it was thought to be extinct for many years. It was decimated by mongooses preying on the juveniles and eggs (Woodley, 1980). It has survived in the Hellshire Hills due to the rugged terrain and lack of surface water in this area (Vogel, 2000). The Grand Cayman iguana (*C. nubila lewisi*), is losing habitat rapidly to real estate development and heavy grazing (Burton, 2000). It is being preyed on by cats and dogs and is shot by farmers who believe it threatens their crops. The third critically endangered taxa, (*C. pinguis*) is chiefly troubled by heavy grazing pressure from domestic animals (Mitchell, 2000). . Its current diet is composed largely of the plants that are rejected by domestic grazers. These plants may not have sufficient nutrition for the female iguanas to reach breeding condition. Feral dogs and cats also prey on these iguanas.

Rats have been introduced on islands in the range of several iguana species. Circumstantial evidence suggests that they prey on eggs and juveniles. Tuatara which are similar in size to iguanas have been extirpated on many islands where rats are present (Cree et al., 1995). The populations of tuatara that remain are nearing reproductive senescence suggesting lack of recruitment of juveniles to reproductive age.

Iguana populations on rat infested islands may be similarly composed of old animals due to lack of recruitment (Hayes et al., 1995). There are also fewer bird species on the cays infested by rats (Campbell, 1991).

There are three subspecies of *C. rileyi*, all of which are confined to the Bahamas (Fig. 1). This iguana is the smallest of the rock iguana species and is recognized as one of the most vulnerable to extinction. Small populations of the nominate subspecies, the San Salvador rock iguana (*C. r. rileyi*), are found on seven cays off of San Salvador and there are reports of a few animals still living on the main island of San Salvador. Hayes et al. (1995) estimated that fewer than 600 remain. The Acklins Iguana, (*C. r. nuchalis*) is found on two cays in the Acklins Bight. Hayes and Carter estimated that 10,000-15,000 remain in these very dense populations. The Sandy Cay rock iguana, (*C. r. cristata*) lives on a single small cay in the southern portion of the Exuma chain (Maclean et al., 1977; Blair, 1991; Hayes et al., 1995). Prior to my study no formal estimate of the population of *C. r. cristata* had been done. Rats and raccoon tracks were seen in June 1996 on the cay that *C. r. cristata* inhabits (Hayes, 1997). Raccoons are notorious egg predators that consume the eggs in a large percentage of the nests of certain turtle populations (Tuberville et al., 1994), and the presence of some adult iguana carcasses on Sandy Cay in 1996 suggested that the raccoon was preying on the iguana population (Hayes, 1997).

In this thesis I present the results of a study completed during the summer of 1997 on the population demographics and movements of *Cyclura rileyi cristata*. Preparatory work was done in 1996 and follow-up was done in 1998 and 1999 by W. K. Hayes and R L Carter. The purpose of this research was to gain information on the demography and apparent health of the population of *C. rileyi cristata* relative to other populations of *C. rileyi*. This research also provided information on its home range size and islandwide distribution. Because *C. r. cristata* was found to be at severe risk of extinction, the findings of this study are essential for development of a management plan to save this taxon.

MATERIALS AND METHODS

STUDY SITE

The study site was located on Sandy Cay in the southern Exuma islands, an extended chain of islands in the central portion of the Grand Bahamas Bank (Fig. 1). Sandy Cay is approximately 1 km long by 0.5 km wide (Fig. 2). It is the only location where *Cyclura rileyi cristata* may be found. Most of the cay is composed of a soft limestone rock with interspersed patches of sand. This rock forms wavelike ridges up to 5 m high. The highest point of the island, a ridge on the northwest point, is approximately 10 m above sea level. The elevation drops gradually toward sea level to the east and south. There are tidal flats that extend from the eastern and southern portions of the island to two large, vegetated sand dunes (3-5 m elevation) and two smaller protrusions of limestone rock. The north shore is rocky. There is a dense silver thatch palm (*Thrinax morrisii*) forest on the northwestern part of the cay that thins eastward and southward. A thick layer of dead fronds covers the ground in this area. Introduced Australian pine (*Casuarina* sp.) grows in a line along the south shore and on the sand dunes. These pines are up to 10 m tall and spread out extensively on the ground, where they mingle with a dense understory of shrubs. The eastern and central portions of the cay are more open with patches of *Strumphia* and *Coccoloba* being the dominant vegetation.

Study of the Sandy Cay iguanas began 7-9 June 1996, when W. K. Hayes, R. L. Carter, John Iverson and Sandra Buckner captured and marked 23 iguanas. During their visit they found a number of dead adult iguanas, they observed rats at their campsite during darkness, and they discovered the footprints of an adult raccoon on the island. My study began on 2 May 1997 and continued until I departed on 15 July 1997. During much of the first three weeks, I was assisted by W.K. Hayes, R. L. Carter and Carl Fuhrie. At this time most effort was directed toward the capture and processing of iguanas. A total of 74 iguanas were captured and marked in 1996 and 1997.

METHODS OF CAPTURE

Animals were captured using two methods. The first method was to stalk the animals and capture them using an extendable noose. This method appeared to be most effective when several people worked cooperatively. Tossing food to the iguanas was sometimes helpful, but the iguanas were skittish and easily

Figure 1. Map of the Bahamas showing the location of all known *Cyclura* populations in the Bahamas.

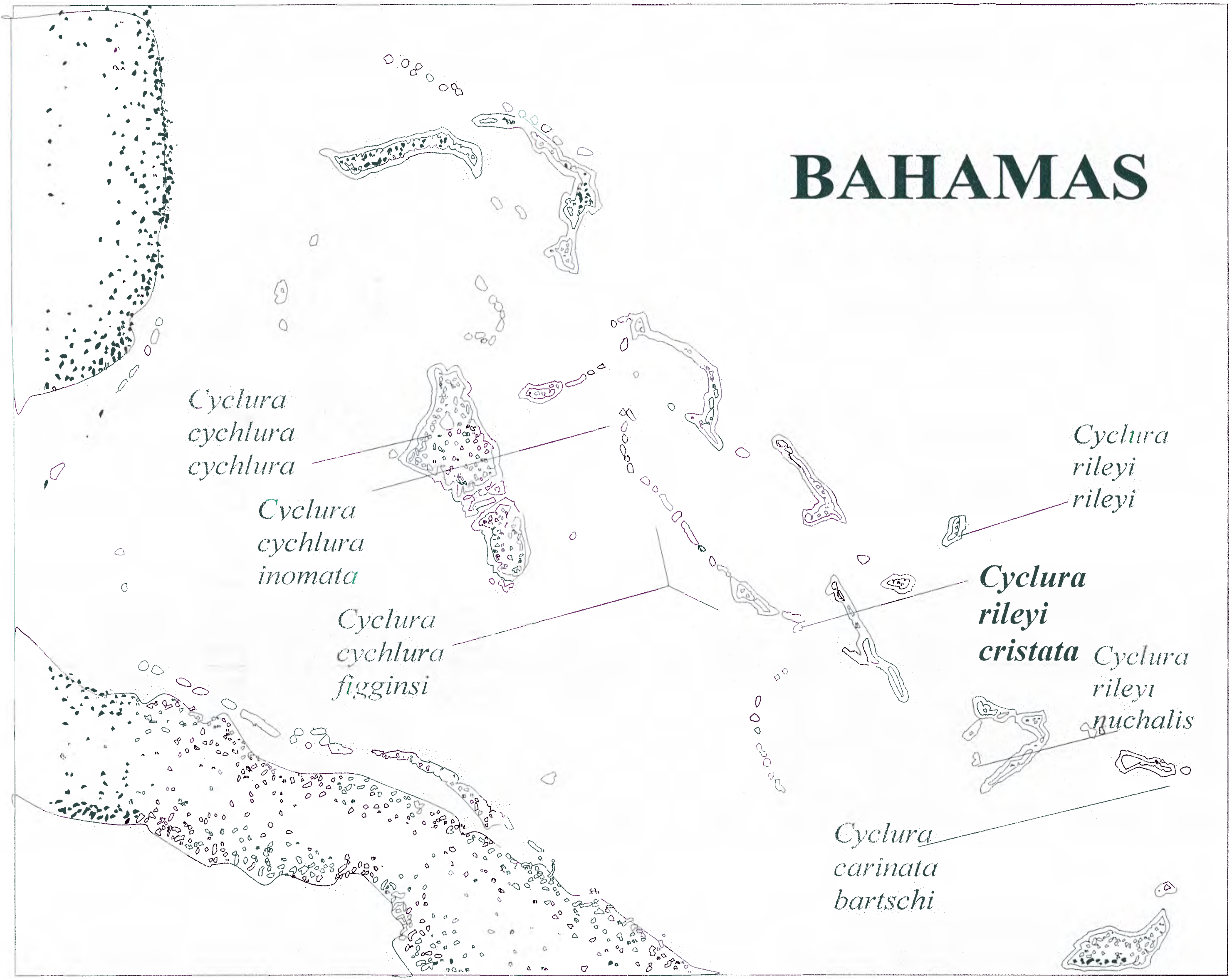
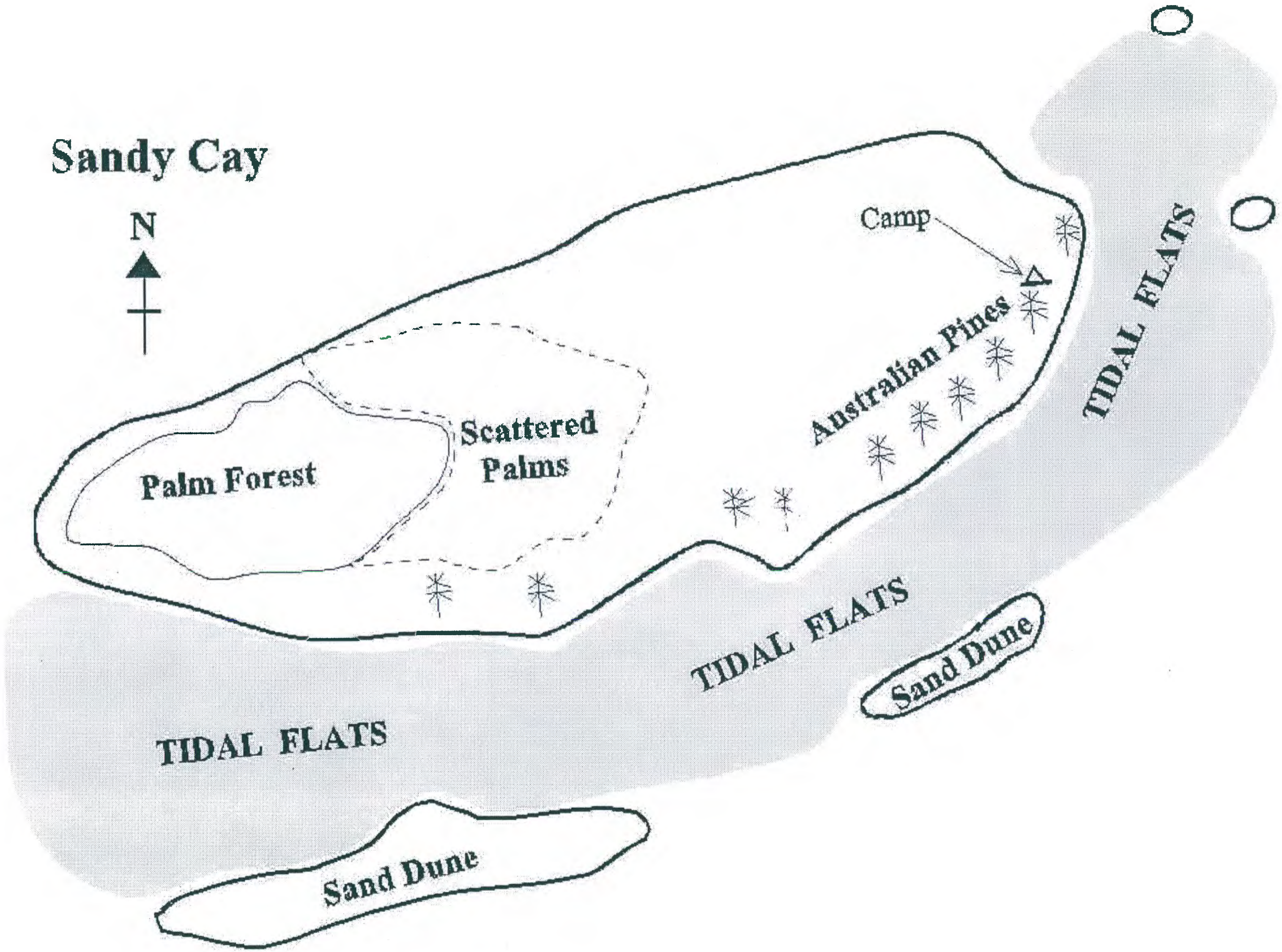

BAHAMAS
Cyclura cychlura cychlura
Cyclura cychlura inornata
Cyclura cychlura figginsi
Cyclura rileyi rileyi
Cyclura rileyi cristata
Cyclura rileyi nuchalis
Cyclura carinata bartschi

Figure 2. Map of the study site on Sandy Cay, Exumas, Bahamas.


Sandy Cay
N
Camp
Australian Pines
Scattered Palms
Palm Forest
TIDAL FLATS
TIDAL FLATS
TIDAL FLATS
Sand Dune
Sand Dune

frightened away. The second method was to set glue traps in the entrance of burrows with recent excavation activity. These glue traps were closely monitored so that captured animals were not exposed to excessive heat from sunlight. They were removed from the sticky substance by means of mineral oil. Both techniques were deemed safe and effective for capture, though minor injuries (e.g., lacerations) were occasionally seen. The number of males and females captured by each method was recorded and the proportion of each sex captured by these methods was compared using a chi-square test.

SIZE MEASUREMENTS AND INJURIES BASED ON CAPTURE DATA

The general location and date for each iguana captured was recorded. Each iguana was weighed with a Pesola spring scale and the following measurements were obtained: snout-vent length (SVL), head length, tail length, left foreleg length, left hindleg length and head width. The lengths of the longest nuchal spine and longest dorsal spine were recorded. Measurements were also obtained for largest femoral pore diameter, largest diameter of the opening in the center of the femoral pores, and number of femoral pores on the right and left legs. Many of these measurements were taken to compare differences between the sexes, but because so few females were captured, many of these measurements will not be reported in this thesis. However, they can be compared at a later time to the other subspecies of *C. rileyi*. Damage to the toes and any regeneration of the tail was recorded. A 1 ml sample of blood was drawn from the caudal vein for future genetic work.

The adult males were bluish gray with either red or yellow vermiculations on the head and sides. Females and juveniles were largely brown or gray and lacking in vermiculations. The color of the vermiculations, if present, was recorded for each animal. The larger adult males could be almost entirely red or yellow.

Iguanas greater than 12 cm SVL were sexed using a metal probe inserted into the cloacal pouches. Females probed less than 1.0 cm in depth, whereas even subadult males probed to 1.4 cm or more. Determination of sex for some animals, including nearly all juveniles, was deemed unreliable. Probing has been shown to be a reliable sexing technique although more inaccuracies occur than if more invasive methods such as cloacascopy are used (Dellinger et al., 1990). Finally, the animal was marked by inserting a piece of monofilament line (80#) through a needle hole in the nuchal crest. For identification purposes, colored glass beads (1-3) were threaded onto the line on each side of the nuchal crest and the ends of the monofilament were melted into a ball to secure the beads in place. A number was also painted on both sides of the animal using white enamel paint for short-term identification.

POPULATION SIZE

Population size was sampled during 9 and 11 May 1997 using distance transect techniques. It was sampled again on 18-19 June 1997 using the Lincoln-Petersen method. Finally, it was sampled again by Hayes and Carter on 24-25 October 1999 using classic strip transects.

May 1997 Survey.

For the distance surveys, 10 transects were conducted from north to south, separated by approximately 70 meters each. The length of each transect line was recorded. The pattern of transect lines can be seen in figure 3. One person moved along the transect line with a searcher on each side working outward to 18 meters (Hayes et al., 2000). The amount of effort directed toward the search for iguanas and burrows decreased outward from the transect line to comply with assumptions of distance models (Buckland, 1985; Buckland et al., 1992). The perpendicular distance from the researcher on the transect line to each iguana or burrow was determined by use of a laser rangefinder (Inteli Optics Laser 70). Each iguana seen well enough was recorded as marked or unmarked. The approximate size of the iguana (juvenile, subadult or adult) was also recorded. Based on capture data from throughout the range of *C. rileyi*, juveniles were considered to be <12 cm, subadults were 12.0-19.9 cm, and adults exceeded 20 cm. Burrows were recorded as active if there were tracks and/or whiter sand that appeared to be recently excavated at the entrance. Burrows were deemed inactive if there were no tracks or fresh sand present or if the entrance was blocked by debris. Each burrow was also noted as being constructed in rock or in sand. The program Distance was used to estimate the density of iguanas and burrows on each transect and for the entire population (Laake et al., 1989). Lincoln-Petersen surveys on other *C. rileyi* populations suggest that during a given survey only one-half to one-third of the iguanas present are actually seen (Hayes et al., 1995; Thornton, 2000; Cyril, 2001). Therefore the densities and population numbers were expressed as a range 2-3 times greater than the distance sampling estimates obtained by the program Distance. The distribution of iguanas and burrows were compared island-wide by regression analysis treating density as the dependent variable and transect number (Fig. 3) as the independent variable. The transect number corresponded to a west-east gradient from dense to less dense vegetation. The island-wide distribution of active burrows, inactive burrows and total burrows (active + inactive) was similarly evaluated by regression analysis.

June 1997 Survey.

The Lincoln-Petersen method was done in the following way I walked eight east-to-west transect lines separated by approximately 40 m. During these surveys, all iguanas seen were recorded. For those seen well enough, the size class (juvenile, subadult or adult) and presence of beads and/or paint was also recorded. The proportion of iguanas seen during the survey that were marked (N marked / N seen) was assumed to be equal to the ratio of marked iguanas believed present on the cay (animals marked in 1996 and seen again in 1997 and all iguanas marked in 1997 prior to the survey) to the total number of iguanas in the population (N total marked / N total). Thus, the number of iguanas in the population was estimated algebraically in a manner that made no assumptions about the proportion of iguanas that could be detected during surveys (see Hayes and Carter, 2000).

October 1999 Survey.

Hayes and Carter visited Sandy Cay in October 1999, shortly after the hatching season to reassess the iguana population. Due to limited time and manpower they did not conduct distance surveys. However, they did classical "strip" surveys along transects similar to those of the distance surveys in May 1997. They recorded all iguanas observed within nine north-south transects 36 m wide separated by approximately 80 meters. The area covered during the surveys was close that of the 10 transects in May 1997. Well-seen iguanas were categorized within the three size classes (juvenile, subadult and adult) and marked iguanas were identified by their bead colors.

AGE STRUCTURE AND SEX RATIO

Age structure was evaluated both by survey data and by capture data. Captured iguanas were divided into three size classes by SVL (juveniles, subadults, adults) as described above. The age class ratios obtained by capture data (1996, 1997) and by the distance survey (May 1997) were compared by chi-square test. Nearly all iguanas (including both years) were captured between early May and early-June, and the May 1997 survey data were considered most representative of this period. The sex ratio was obtained solely from capture data.

COMPARATIVE POPULATION DEMOGRAPHY

Hayes, Carter and their collaborators have collected data on all known populations (10 cays total) of the two other subspecies of *C. rileyi* using classical surveys (counts on entirety of small cays: Gaulin, Guana, Goulding, Low, Pigeon Cays), distance surveys (on large cays: Fish, North Cays) and Lincoln-Petersen estimates (on cays with sufficient marked animals present: Green, Manhead, Unnamed). These data, all obtained between 1994 and 1997, were compared with those obtained by the distance surveys (May 1997) for *C. r. cristata* on Sandy Cay. These investigators have learned that during surveys they see approximately one-third to one-half of the iguanas that are present. Thus, they have adopted an approach of expressing population size as a range that is two to three times the estimates based on numbers of iguanas seen during classical and distance surveys (Hayes et al., 1995; Thornton, 2000; Cyril, 2001). For the purpose of comparison, population size (N) of all cays where estimates were based on classical and distance surveys was considered to be the lowest end of that range (i.e., two times the estimate based on numbers of iguanas seen during the surveys). Density (number of iguanas per hectare) and biomass (density multiplied by average mass of iguanas on each cay, determined from capture data) were also calculated for each cay. To evaluate the potential impact of rats on iguana populations, density and biomass were compared for cays with rats documented to be present (Guana, Low, Sandy, Pigeon Cays) and cays where rats are believed to be absent (the remaining seven cays).

Sex ratio was compared for all populations based on captures during the months of May and June only. Age structure was also compared for all populations. On some of the cays, adults larger than 28 cm SVL can be found, and these were classified as a fourth category (large adults) in addition to those of juveniles, subadults and adults. The largest iguana on Sandy Cay measured 28.0 cm SVL, and this was assigned to the smaller adult category (i.e., no “large” iguanas were captured on Sandy Cay).

MORTALITY

There was an apparent decline in iguanas between visits to Sandy Cay in 1996 and 1997. Three species of feral animals were found to be present, which could be potential causes of iguana mortality.

These included rats (*Rattus rattus*), mice (probably *Mus musculus*, which were not a likely source of mortality) and a single raccoon (*Procyon lotor*). The rats were first seen at camp during the nights in 1996, and both rats and mice were live-trapped in 1997. The raccoon was never seen but its footprints, first discovered in 1996, were observed daily and throughout the island. This animal appeared to be largely if not entirely active at night. The raccoon presumably arrived by one of three means: By jumping ship at sea, by deliberate release on Sandy Cay, or by swimming on its own from nearby Hog Cay where a pair of raccoons formerly was introduced (Roy Albury, pers. com.)

The apparent impact of feral animals on the Sandy Cay iguanas was evaluated in several ways. Capture rates of iguanas (numbers of iguanas captured and processed per person-day) were compared in 1996 and 1997 to assess the decline of iguanas. Mortality was also estimated by comparing the proportion of iguanas marked in 1996 that were resighted in 1997 to the proportion of animals marked in 1997 that were resighted a second time in 1997. Capture and marking of animals in 1997 began on May 2. Then starting on May 15, the first resighting for each of the animals marked in 1997 was recorded.

The causes of mortality were evaluated by several means. The number of adult iguana carcasses found in 1996, 1997, 1998 and 1999 was recorded. These numbers were standardized for the first 12 person-days on the island in 1996, 1997 and 1998. The data in 1998 were collected by Hayes and the team from Flora and Fauna International that eradicated rats on the cay during the months of April and May. Additional data were collected in October 1999 by Hayes and Carter, who spent only 4 person-days on the cay. During 1997, raccoon feces were examined for iguana remains, iguana carcases were scrutinized for cause of death, and radio-transmitters recovered from dead iguanas (or from those that shed them) were investigated for bite marks.

The relative abundance of Black Rats, *Rattus rattus* and House Mice, *Mus musculus* was investigated by live-trapping in several areas on Sandy Cay. Size measurements were taken from the dead rats, which were also dissected so that the stomachs could be examined for iguana remains.

Potential predation on hatchling iguanas was evaluated with ten rubber lizard models which were somewhat similar in size to that of hatchling iguanas (SVL 6-7cm). Four of these lizards were placed in open areas to test for attacks by predatory birds and the remaining six were placed under the cover of bushes to test for attacks by rats. These models were left in place for two weeks and evidence of attempted predation in the form of physical damage such as chew marks, peck marks or missing individuals was recorded once each morning and once each evening.

HOME RANGES

Radio transmitters (model SOPB 2190, 5 g, 220 day battery life, Wildlife Materials Inc., Carbondale, IL) were glued with silicone cement to the posterior hip of 5 adult male iguanas (SVL 21.8-27.0 cm, mass 490-720 g) and 5 subadult female (SVL 15.5-18.4 cm, mass 145-235 g) iguanas. Based on more recent work with *C. r. nuchalis* from North Cay, which attains a maximum size comparable to *C. r. cristata* (Thornton, 2000), all of the female iguanas were probably subadults because sexual maturity is attained at close to 20 cm SVL and 300 g. Since the glue was slow to cure (with negligible heat production), each iguana was held for an hour or more and then kept it in a cloth bag at camp overnight before being released at the site of capture. Subsequent radiotelemetry by (Thornton, 2000) suggests that handling and radiotelemetry of gravid females does not affect reproductive success. The animals in the present study were located at random times and a flag was placed at their location. Several animals were relocated twice within the same day, with a minimum of 3 hr between sightings. Type of habitat and behavior of the animal were recorded for each resighting. Once the animals shed their transmitters the position of each flag relative to the next closest flag for that animal was recorded by using a compass and a laser rangefinder. These positions were drawn on a grid and converted to x-y coordinates.

Home range size was calculated by adaptive kernels and minimum convex polygons (MCP) calculated by the Calhome program (Kie, 1994). The adaptive kernel approach is preferred to other estimators of home range size (Worton, 1989; Seaman et al., 1996), but the minimum sample size for reliability should be close to 30 resightings (Seaman et al., 1999). The MCP method, though less reliable, is widely used (even for small sample sizes) and is reported because it can be compared more readily to other studies.

The maximum distance between any two location points for each iguana was recorded and compared to the maximum distances reported for *C. r. nuchalis* telemetered by (Thornton, 2000) on North Cay and for *C. r. rileyi* observed on Green Cay (but not telemetered on this small island) by (Cyril, 2001).

Finally the telemetry data were tested statistically for independence between locations by use of t^2/r^2 statistic (Swihart et al., 1985) calculated by the Home Ranger software program (Hovey, 1998).

SOCIAL INTERACTIONS

Due to the scarcity of iguanas in 1997 and their skittish behavior, social interactions (two or more iguanas seen within 2 meters of each other or heard in conflict) were rarely observed. To illustrate this, the total number of social interactions observed was related to the sum of total hours for capture effort (walking throughout the island), ethological observations (standing near a single iguana) and radiotelemetry tracking (walking throughout the island in search of transmittered iguanas)

RESULTS

METHOD OF CAPTURE

Sixty-nine animals were captured by noose including 23 in 1996 and 46 in 1997. Of these 59 (85.5%) were male, three (4.3%) were female and seven (10.1%) were of uncertain sex. Five animals were trapped by setting glue traps in the entrance of freshly-dug burrows (late June). Four (80%) of these were female and one (20%) was male. A chi-square test that excluded animals of uncertain sex showed that the two techniques differed significantly in the sex ratio of iguanas captured ($\chi^2 = 27.94$, df = 1, $P < 0.0001$). The glue trap technique was more likely than noosing to capture females.

SIZE MEASUREMENTS AND INJURIES BASED ON CAPTURE DATA

The number of iguanas captured for each size class and sex, regardless of capture method, is provided in Table 1. Overall, females represented 9.5% of the total captures. Prior to the use of glue traps, females represented only 4.3% of noose captures, which is the method used on all others cays on which *C. rileyi* has been studied. The females captured were within a narrow size range (15.5-18.4 cm), and all were considered subadults. Some juveniles of uncertain sex were likely female. Males averaged much larger in size.

The majority of iguanas captured were adults (59.5%), while fewer were sub-adults (32.4%) and juveniles (8.1%) were captured. Thirty-six of the 74 iguanas (48.6%) showed damage to either toes or the tail. Amongst all iguanas, tail injuries were three-fold more common than toe injuries. The frequency and proportion of toe and tail injuries was similar for the three age classes ($\chi^2 = 0.45$, df =6, $P => 0.2$).

POPULATION SIZE

The numbers of iguanas seen during each of the three population surveys is summarized in Table 2. From the distance surveys of May 1997, the density of iguanas calculated by the program Distance was 4.56 iguanas per hectare for the entire cay, and the iguana population was estimated at 68 before multiplying by the correction factor of 2 to 3. Approximately 61% of the 14.9 ha cay was covered in the transects. As mentioned previously, it was assumed that only one-third to one-half of the iguanas present were detected. Thus, the estimated density of iguanas is between 9.12 and 13.67 iguanas per hectare and the estimated population is between 134 and 204 animals.

Table 1. Frequency data for sex and size class (based on snout-vent length, SVL) of captured iguanas, with measurements of body size and frequency of injuries.

		SVL (cm)			Mass (g)		
Sex	N	Mean	S.E.	Range	Mean	S.E.	Range
Male	60	21.4	0.5	10.6-28.0	439	25	41-760
Female	7	17.1	0.5	15.5-18.4	180	16	130-235
Uncertain	7	13.9	1.2	10.2-17.2	103.6	24.4	37-170

			Number with Injuries		
Age Class	SVL (cm)	N	Toes	Tail	Either
Juvenile	< 12	6	1	2	2
Sub-adult	12.0-19.9	24	4	11	12
Adult	> 20.0	44	6	20	22
Totals	–	74	11	33	36

Table 2. Summary of population surveys with breakdown by size and by presence or absence of markings.

Sightings by Size Class

Date	Juvenile	Subadult	Adult	Uncertain	Total
May 1997[a]	5	5	19	5	34
June 1997[b]	9	7	6	11	33
October 1999[c]	10	5	17	4	36

Sightings of Marked vs. Unmarked

Date	Marked	Unmarked	Uncertain	Total
May 199[a]	5	10	19	34
June 1997[b]	6	15	12	33
October 1999[c]	2	6	28	36

[a] 10 North-South transects (36 m wide); covered 61% of the island's area

[b] 8 East-West transects of Lincoln-Peterson survey (no defined width)

[c] 9 North-South transects (36 m wide); covered 48% of island's area; includes juveniles which could not have been marked

At the time of the Lincoln-Petersen surveys of June 1997, there were 51 marked animals believed to be alive (including iguanas marked in 1996 that had been resighted in 1997 and all iguanas marked up to this time in 1997). Six of the 21 iguanas seen well (28.6%) were marked (Table 2). Due to their skittish behavior, a large portion of the iguanas encountered (36.4%) were not seen well. Based on the Lincoln-Petersen ratio, the total population was estimated to be 179 iguanas.

Thirty-six iguanas were seen during the classic strip surveys in October 1999 (Table 2), which covered 48% of the island. This total was not significantly different than that of May 1997. The intent was to compare total numbers and age structure between 1997 and 1999 rather than to estimate total population size.

The island-wide distribution of iguanas and burrows is summarized in Table 3, with the sequence of transects numbered 1-10 corresponding to a west-east orientation (Figure 3). Regression analyses showed that densities of iguanas, active burrows, inactive burrows and all burrows (active + inactive) was homogenous across all 10 transects (range for r values was 0.0 - 0 58; all p's > 0.078). Less than half of the burrows encountered appeared to be actively used (47.2%). The distribution of iguanas in May 1997 and October 1999 appeared to be similar (Table 3).

AGE STRUCTURE AND SEX RATIO

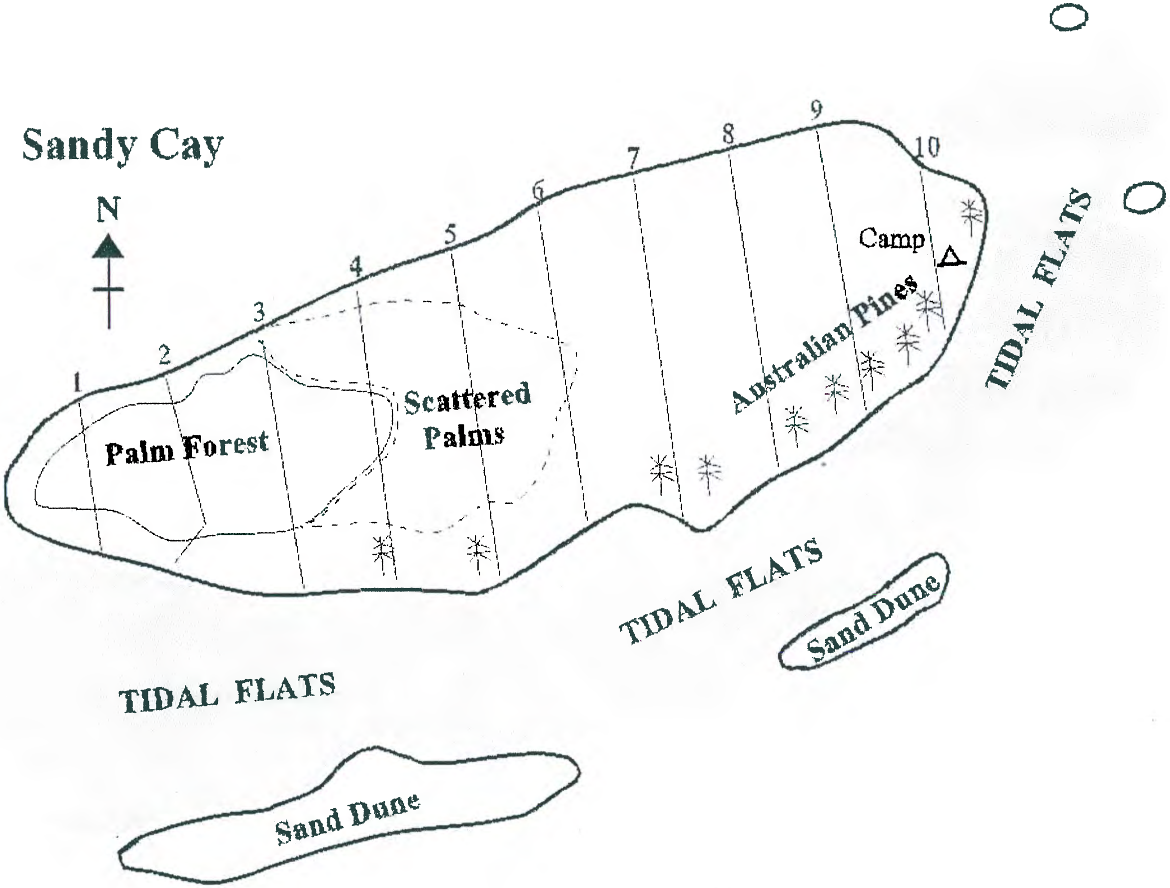
The number of iguanas in each size class, based on population surveys, is shown in Table 2. The majority of iguanas seen well enough to be assigned to a size class during the distance surveys (May 1997) were adults (66%), with juveniles and subadults in less abundance (17% each). A higher proportion of iguanas of uncertain size was seen during the Lincoln-Petersen surveys (June 1997), and many of these were probably adults that could not observed as readily by the single investigator. In October 1999, shortly after the hatching of young iguanas, a greater number of juveniles was found compared to May 1997. However, the proportion of iguanas in each size class did not differ significantly between the two surveys ($\chi^2 = 1.63$, df = 2, P = 0.44). The proportion of iguanas in each size class based on capture data (mostly from the months of May and June 1996 and 1997: 6 juveniles, 24 subadults, 44 adults) was similar to that of the May 1997 distance surveys on iguana size ($\chi^2 = 3.46$, df = 2, P > 0.1). Thus, data obtained during population surveys and by capture data were congruent.

Table 3. Numbers and density (per hectare) of iguanas and burrows for each of the distance survey transects (May 1997) corresponding to a west-east orientation of Sandy Cay. Numbers of iguanas seen per transect in October 1999 are also given.

Transect	Iguanas	Active burrows	Inactive burrows	All burrows	1999 Iguanas
1	0	2	5	7	---
2	3	6	1	7	0
3	2	5	4	9	1
4	3	5	7	12	4
5	4	5	7	12	7
6	9	11	16	27	7
7	4	13	17	30	5
8	4	17	15	32	5
9	3	10	6	16	4
10	2	3	8	11	3
Total	34	77	86	163	36

Transect	Iguana density	Active burrows density	Inactive burrows density	All burrows density	Transect length (m)
1	0.00	10.28	12.02	20.7	120
2	5.82	28.24	2.89	30.23	153
3	2.53	6.67	5.07	11.4	216
4	3.22	21.79	9.2	22.8	255
5	10.41	5.59	9.07	16.19	278
6	8.43	11.79	20.97	32.48	331
7	6.19	35.38	13.09	48.21	300
8	6.34	14.08	24.23	35.38	330
9	6.34	16.43	5.64	19.51	291
10	5.47	10.12	24.84	40.32	206
Total	4.56	14.44	12.35	27.35	2479

Figure 3. The approximate position of transects during distance surveys in May 1997. Line 2 had to be bent at a 45° angle due to impenetrable undergrowth.


Sandy Cay
N
1
2
3
4
5
6
7
8
9
10
Palm Forest
Scattered Palms
Australian Pines
Camp
TIDAL FLATS
TIDAL FLATS
TIDAL FLATS
Sand Dune
Sand Dune

The animals captured by noose are most appropriate for comparisons of sex ratio with other cays where nooses were relied on exclusively. Therefore, if the uncertain animals are excluded, approximately 95% of the population (59 of 62 noose captures) is comprised of male iguanas.

COMPARATIVE POPULATION DEMOGRAPHY

Table 4 compares the population size, population density and biomass of iguanas on Sandy Cay with other populations of *C. rileyi*. Sandy Cay has a low iguana density compared to most of the other cays. Three other populations have low iguana density. These include Gaulin Cay, where iguanas are probably now extirpated subsequent to the storm surge of Hurricane Floyd in 1999 (Hayes and Carter, unpublished data), Low Cay, where recruitment of juveniles to the adult population appears to be negligible on this rat-infested island and Pigeon Cay, where few iguanas live in the dense mangrove interior of the island (Hayes and Carter, unpubl. data). The biomass of iguanas on Sandy Cay is also much lower than on any other cay except Gaulin Cay.

The sex ratio of iguanas on Sandy Cay is compared to that of other populations of *C. rileyi* in Fig. 4. In contrast to other cays where the sex ratio is close to 1:1 (50% male), the sex ratio on Sandy Cay is highly skewed toward male iguanas.

The age structure of iguanas on Sandy Cay as compared to other populations of *C. rileyi* is the subject of Table 5. The relatively high number of juvenile iguanas on Sandy Cay compared to other cays may reflect high adult mortality caused by the raccoon (see next section). The only cay having a higher proportion of juvenile iguanas is Guana Cay, which is experiencing an apparent recovery from the unexplained deaths of many adults in 1994 (Hayes et al , 1995).

MORTALITY

A dramatic decline in iguanas between 1996 and 1997 was evident in our capture success. In 1996, 5.33 iguanas were caught and marked per person-day (number of observers multiplied by days of capture effort), whereas only 1.75 iguanas were caught and marked per person-day of effort in 1997. This suggests a 67.2% reduction in the iguana population between 1996 and 1997 but the iguanas appeared to be somewhat more wary in 1997.

Table 4. Demographic comparisons of all known *Cyclura rileyi* populations, based on data collected 1994-1997. See text for explanation.

Taxon	Cay	Area (ha)	N	Density (N/ha)	Mass[a] (kg)	Biomass (kg/ha)
C. r. cristata	Sandy[b]	14.9	136	9	.403	3.7
C. r. nuchalis	Fish[b]	73.9	9484	129	.459	59.1
	North[b]	51.7	3036	59	.404	23.7
	Unnamed[c]	3.3	299	91	1.097	99.4
C. r. rileyi	Gaulin[d]	1.6	9	6	.650	3.6
	Goulding[d]	2.9	90	31	.562	17.4
	Green[d]	5.1	252	49	.608	30.0
	Guana[d]	1.6	24	15	.665	10.0
	Low[d]	10.8	75	7	1.481	10.2
	Manhead[d]	3.3	74	22	.268	6.0
	Pigeon[d]	7.8	75	10	.665	6.4

[a] Mean mass of iguanas based on capture data
[b] Based on distance surveys, assuming that 50% of iguanas were detected during surveys
[c] Based on Lincoln-Peterson estimates
[d] Hayes et al., 1995

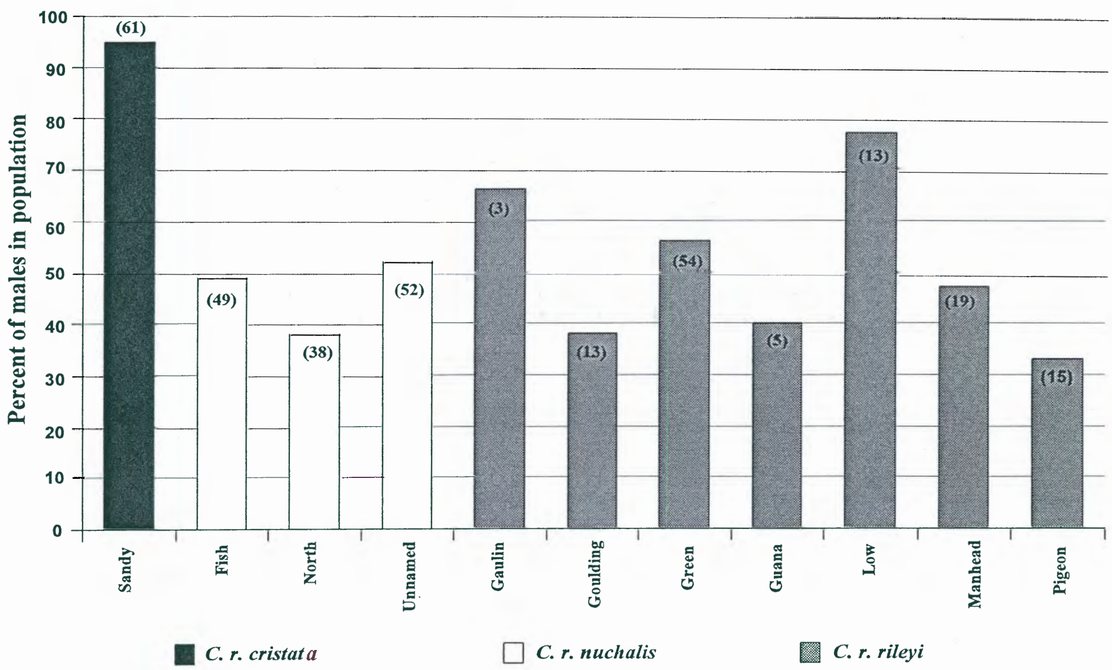


Figure 4. Sex ratio (percent of males) for each known population of *C. rileyi*, based on noose capture data during months of May and June. (Number of captures is indicated in parentheses.)

Table 5. The percentage of individuals represented by each age class for all populations of the three subspecies of *Cyclura rileyi* (Hayes and Carter, unpublished data)

Subspecies	Population	Juveniles (< 12 cm)	Subadults (12-19.9 cm)	Adults (20-27.9 cm)	Large adults (> 28 cm)
C. r. cristata[a]	Sandy Cay	17	17	66	0
C. r. nuchalis[a]	Fish Cay	10	15	45	29
	North Cay	7	16	76	0
	Unnamed Cay	1	5	8	80
C. r. rileyi[b]	Gaulin Cay	0	0	100	0
	Goulding Cay	5	26	61	7
	Green Cay	6	16	60	18
	Guana Cay	20	27	33	20
	Low Cay	0	0	7	93
	Manhead Cay	14	43	43	0
	Pigeon Cay	3	6	77	14

[a] Populations sampled in 1997
[b] Gaulin Cay population sampled in 1995 (only 3 animals found); all other populations sampled in 1998

The proportion of marked iguanas resighted also suggested substantial mortality between 1996 and 1997. Fifty iguanas were marked in 1997 beginning on May 2 and continuing to July. Twenty-three of these were resighted between May 15, 1997 and July 15, 1997. Thus 46.0% of the animals marked in 1997 were seen a second time. Only 7 of 23 iguanas (30.4%) that were marked in 1996 were resighted between May 1 and July 15 in 1997. A chi-square test revealed that the proportion of marked iguanas resighted from 1996 vs.1997 captures was similar ($\chi^2 = 1.58$, df = 1, P = 0.21). However, if it is assumed that these 7 iguanas marked in 1996 and resighted in 1997 represented 46% of the marked iguanas that were alive and sightable in 1997, then approximately 15 of the 23 marked in 1996 remained alive in 1997. Since 8 out of the original 23 were presumably dead, mortality would have been approximately 34.8% between 1996 and 1997.

These two estimates of mortality, although indirect, suggest an annual rate of mortality in the vicinity of 35-67%. Given the Lincoln-Petersen estimate of approximately 179 iguanas present in 1997, this would suggest that the iguana population numbered somewhere in the vicinity of 275-542 individuals in 1996.

Figure 5 illustrates the change in number of iguana carcasses found before and after the removal of the raccoon. In the first 12 person-days in 1996 five iguana carcasses were found and in the first 12 person-days of 1997 six iguana carcasses were found. The raccoon was euthanized by anaesthesia overdose in Mid-July of 1997. In the first 12 person-days of 1998 no carcasses were found. The rats were eradicated from Sandy Cay in 1998. No iguana carcasses were found in 1999 but there were only 4 person-days of effort.

Altogether, fourteen iguana carcasses were found in 1997 and for two of these the skin had been split open near the head and was peeled back past the abdomen. The anterior portion of the body had been consumed. I concluded that the raccoon was likely responsible for these deaths, but it was not possible to determine cause of death for these and other iguanas. One sample of raccoon feces had iguana remains in it. Three of the radio transmitters were badly chewed when recovered. Bits of iguana jaw and skin were found around one of these transmitters, which suggests predation had occurred.

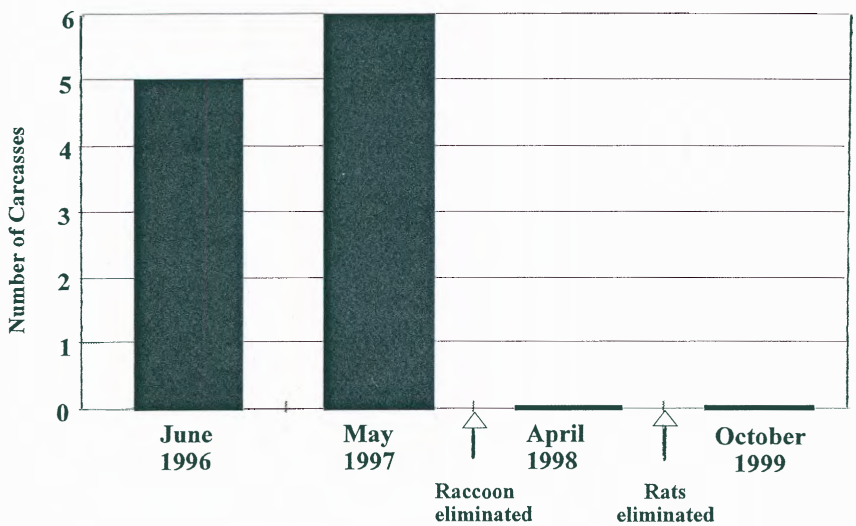


Figure 5. Number of adult iguana carcasses found on Sandy Cay during the first 12 person-days (number of people X days on the island) for each year that research was done Only 4 person-days were spent on the island in 1999. The arrows indicate the times at which the raccoon and the rats were eradicated.

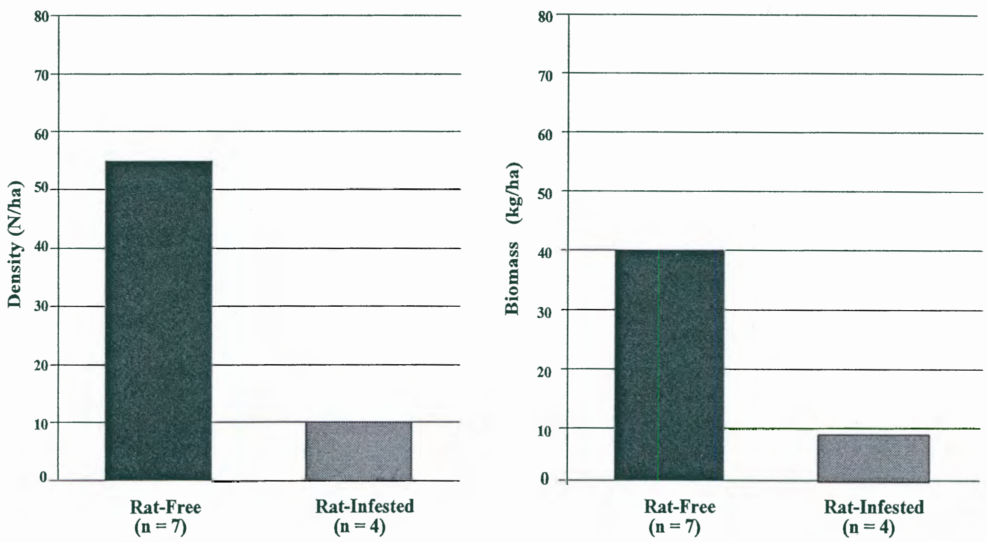


Figure 6. Comparison of population attributes of *Cyclura rileyi* for cays believed to be rat-free versus those known to be occupied by rats. Data are from Table 4.

Figure 6 shows the difference in iguana density on cays where rats are absent compared to cays where rats are present. Iguana biomass is lower on rat-infested cays than it is on rat-free cays. Density also decreases on the rat-infested cays. Iguana density was significantly reduced on rat-infested cays (one-tailed Kolmogorov-Smirnov Z = 1.37, P = 0.024). The difference in biomass approached significance (one-tailed Kolmogorov-Smirnov Z = 1.14, P = 0.075).

Live trapping yielded 14 rats (*Rattus rattus*) and 3 mice (species uncertain, probably *Mus musculus*). One rat and one mouse escaped before I could obtain measurements and determine sex. Table 6 shows the capture rate for each week that trapping was done. The trapping rate during the first two weeks (3-17 May) was 9.1% (10 captures in 110 trap-nights). The majority of rodents were caught when the moon was less than half full. Six (46%) of the rats were female and 7 (54%) were male. Table 7 provides the mean measurements for both rats and mice. The males had a mean mass of 133 g and a mean total length of 37.7 cm. The females had a mean mass of 124 g and a mean total length of 38.3 cm. The mice had a mean mass of 22 g and a mean total length of 21.75 cm. All rats had stomachs filled with worms of an unidentified species which made identification of stomach contents difficult. The worms were not present in the mice. No identifiable iguana remains were found in any rodent stomachs.

Figure 7 shows the difference in model lizard attacks under cover and in the open. There were 4 lizard models in the open and 6 under cover. Five of the 6 lizards placed under cover were attacked and some were attacked repeatedly during the 2 week period. An attack consisted of fresh damage to or disappearance of a lizard model. All damage was clearly identifiable as bite marks that matched rat incisors. Figure 8 is a photo of one of the bitten models. The mean number of attacks per lizard was 1.5. All attacks on lizards under cover occurred at night. One of the lizard models that had been placed under cover disappeared. It had already suffered from rat attack. One of the lizard models from an open area disappeared. This was the only attack on a model lizard in an open area making the mean number of attacks on lizards in the open 0.25.

HOME RANGES

Table 8 shows the home ranges of telemetered iguanas calculated by minimum convex polygon (100%) and by adaptive kernel at 85%, 90% and 95%. The adaptive kernel method creates a kernel around each data point with boundaries set by the surrounding data points. This means that a data point that is far

Table 6. The number of traps set and rodents (black rats, *Rattus rattus*, and presumably house mice, *Mus musculus*) captured each week. The location of traps and nearest phase of the moon (with its date) is included.

Week	Site	Traps	Rats	Mice	Moon phase (date)
May 3	East point	11	0	0	Last quarter (April 29)
May 4-10	East point	52	6	0	New (May 6)
May 11-17	East point	47	4	3	First quarter (May 14)
May 18-24	East point	45	1	0	Full (May 22)
May 25-31	East point	22	0	0	Last quarter (May 29)
	South shore	18	0	0	
June 1-7	South shore	22	0	0	New (June 5)
June 8-14	Central	44	0	0	First quarter (June 12)
June 15-21	West end	66	0	0	Full (June 20)
June 22-28	West end	11	0	0	Last Quarter (June 27)
	E, W, S	44	1	0	
June 29 - July 5	E, W, S	55	2	0	New (July 4)
July 6-12	E, W, S	55	0	0	First quarter (July 12)
July 13-14	E, W, S	0	0	0	Full (July 19)
Totals		492	14	3	

Table 7. Sizes of black rats, *Rattus rattus*, and presumably house mice, *Mus musculus*, captured on Sandy Cay.

	Mice (n = 2)			Rats (n = 13)		
Dependent measure	Mean	S. E.	Range	Mean	S.E.	Range
Mass (g)	22	0	22-22	128.8	4.8	105-175
Total Length (cm)	21.8	1.1	20.7-22.8	38.0	0.4	35.9-40.6
Tail Length (cm)	12.4	0.5	11.8-12.9	21.0	0.3	19.0-22.5
Hind foot Length (cm)	2.7	0.1	2.6-2.7	3.4	0.1	3.1-3.9
Ear Length (cm)	1.3	0.0	1.3-1.3	1.7	0.0	1.4-1.9

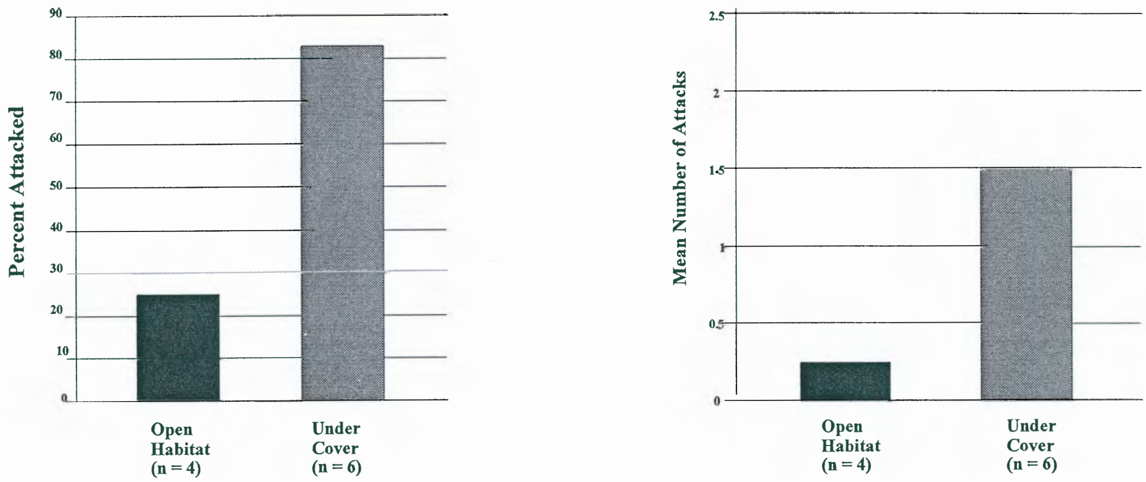


Figure 7. Rat attacks on rubber models of juvenile-sized iguanas, as detected by incisor gnaw marks. Models were placed beneath vegetation or left on open gound.

Figure 8. Photo of a model lizard with gnaw marks inflicted by rat incisors.

Table 8. Home range size (m^2) of iguanas on Sandy Cay calculated by minimum convex polygon (MCP at 100%) and adaptive kernels (AK at 85%, 90% and 95%). The number of sightings, maximum distance (m) between any two locations (m) and duration of time iguanas were tracked are also provided.

Animal	Sex	Sightings (N)	Max dist (m)	MCP 100%	AK 85%	AK 90%	AK 95%	Duration (days)
42	M	11	139	5600	5600	8100	–	45
54	M	7	104	3100	6700	–	–	40
36	M	4	126	760	3600	–	–	31
23	M	9	99	1200	1400	1700	1900	45
35	M	8	39	390	630	–	–	45
51	F	4	69	640	–	–	–	31
46	F	4	38	96	460	570	750	31
70	F	4	24	94	200	250	330	8
65	F	2	19	–	–	–	–	3
73	F	2	29	–	–	–	–	4

from the others may create an unbounded or infinite kernel making it impossible to calculate an area. Therefore a percentage of the data is rejected in order to eliminate such points and create a calculable area. The standard percentage of data that is used in calculating adaptive kernels is 95%. This was a small data set which had the unfortunate affect of putting more data points on the boundary and making it necessary to use smaller percentages of the data to obtain calculable areas. This is why the adaptive kernels were done at 85% and 90% as well as 95%. Figure 9 shows each of the calculated areas graphically for iguanas number 42 and 54. The position of each iguana's range on the island can be seen in figure 10.

Swihart and Slade's (1985) method for calculating independence of radio telemetry location points over time was used to analyze the data for each iguana. A t^2/r^2 close to 2.0 indicates that sequential points are not linked by time. If the t^2/r^2 is less than 2.0 it shows time-linked data and if it is greater than 2.0 it shows overdivergence in the data which might happen if the animal was moving its territory or migrating (Swihart et al., 1985). The location points for iguanas # 23, 35, 42 and 54 were tested to see if consecutive data points were linked by time but no other iguanas could be tested. Two iguanas (#23, 35) had indices of 2.6, and one (#42) had an index of 2.4. Both of these showed overdivergence, indicative of substantial movement. Iguana #54 had an index of 2.0, showing near complete independence of sequential locations..

Table 9 compares the maximum distance moved for the Sandy Cay, North Cay and Green Cay iguanas relative to the size of each cay and the population density of iguanas on the cay. Male iguanas on Sandy Cay appeared to move further than any other group of iguanas. The females on Sandy Cay seemed to move less than on any other cay but they were located the fewest times. The young females on North Cay appeared to move nearly as much as did the adult males on Sandy Cay. However, due to differences in techniques and sample sizes, no statistical comparisons were made between the three studies.

SOCIAL INTERACTIONS

A total of 17 social interactions (two or more iguanas seen within 2 meters of each other or heard in conflict) were observed. These were spaced out across 43 days, which included 187 hrs. capture effort, 26 hrs. ethological observation, and 37 hrs. radiotelemetry tracking; social interactions were observed at a rate of approximately 1 occurrence every 14.7 hrs. in the field. During observation, iguanas were sighted on 342 occasions. Hence, only 5.0% of iguana observations involved more than one individual.

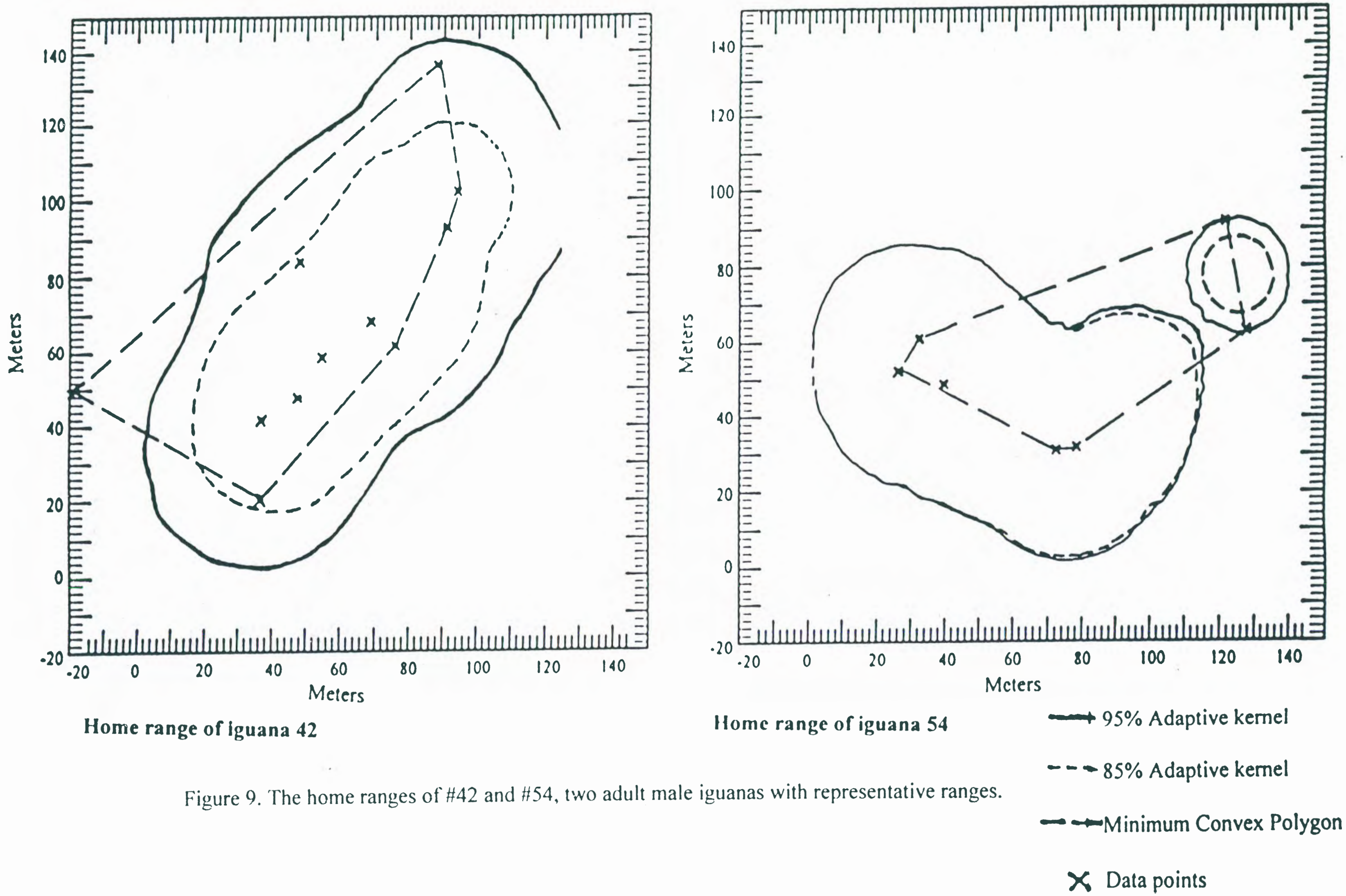
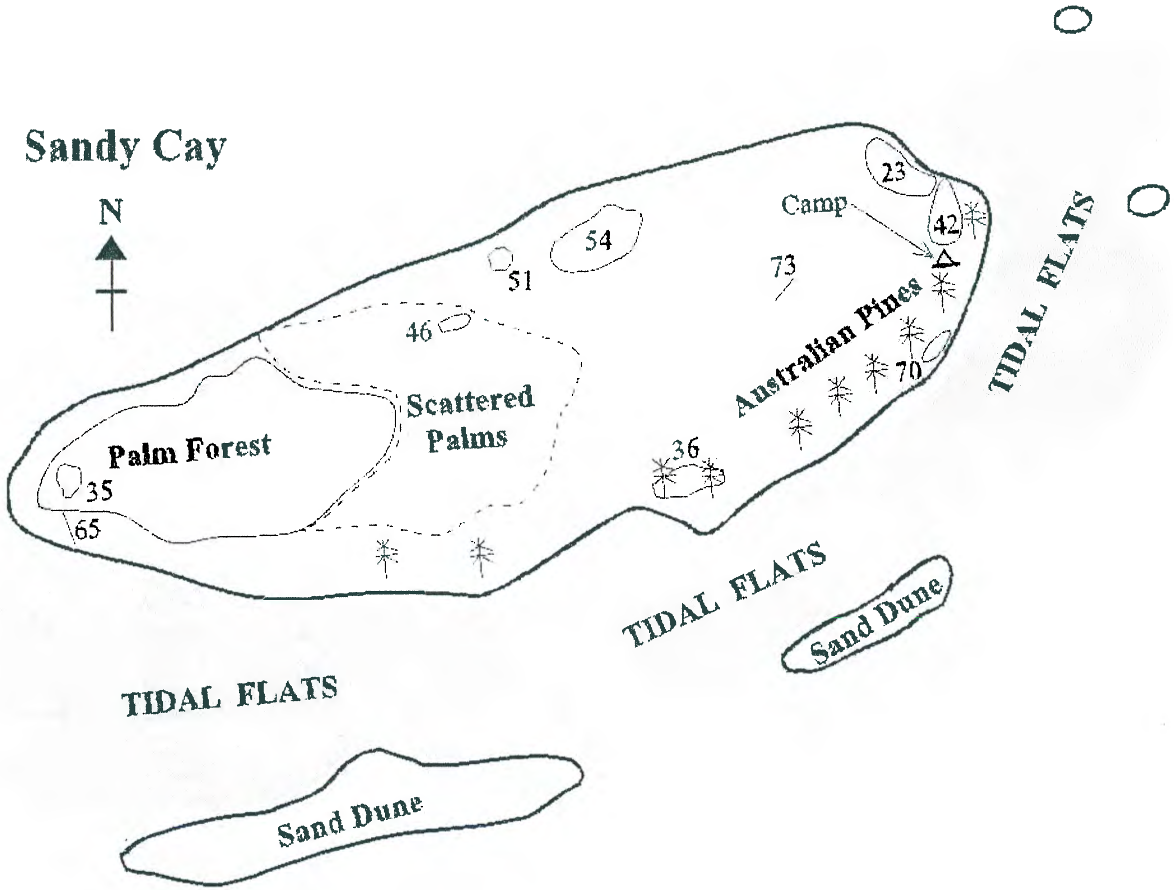


Figure 9. The home ranges of #42 and #54, two adult male iguanas with representative ranges.

Figure 10. The position of each iguana's home range on Sandy Cay.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Scattered Palms
Palm Forest
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TIDAL FLATS
TIDAL FLATS
Sand Dune
TIDAL FLATS
Sand Dune

Table 9. Comparison of maximum distances (m) between any two points in studies of home range size of iguanas (*Cyclura* species) at different localities. The mean and range for the number of relocations in each study is provided. There appears to be no obvious relationship between home range size and size or population density of the cay.

Taxon	Location	Area (ha)	Density	Biomass
C. r. cristata	Sandy Cay	14.9	9	3.7
C. r. nuchalis	North Cay	51.7	59	23.7
C. r. rileyi	Green Cay	5.1	49	30.0

		Relocations (N)		Mean	
Population	Iguanas (N)	(mean)	(range)	Maximum Distance (m)	Source
Sandy Cay:					
adult male	5	8	4-11	101	this study
subadult female	5	3	2-4	36	
North Cay:					
adult male	15	10	–	62	Thornton, 2000
subadult female	7	17	–	95	
adult female	13	17	–	55	
Green Cay:					
adult male	14	19	10-26	53	Cyril, 2001
adult female	24	19	10-24	69	

DISCUSSION

METHOD OF CAPTURE

Most iguanas caught by noosing were male, whereas most iguanas caught by glue trap were female. This difference was highly significant. Noosing was the only method used to capture iguanas on other cays. It is possible that juveniles are under-represented by this method of capture, but the percentages of the sexes and the other age classes should be representative. The high percentage of females caught by setting glue traps in burrows with indications of recent sand removal suggests that the digging activities in late June had something to do with the breeding season. The other subspecies of *C. rileyi* begin nesting activities in late June (*C. r. nuchalis*; Thornton, 2000) or early July (*C. r. rileyi*; Cyril, 2001). However, none of the females that I captured appeared to be of reproductive size (see below).

SIZE MEASUREMENTS AND INJURIES BASED ON CAPTURE DATA

If the minimum reproductive size of *C. r. nuchalis* on North Cay (Thornton, 2000) can be applied to this subspecies, then no females of breeding age were captured and the average male had barely reached adulthood. The data from North Cay indicated that the minimum size for a breeding female is 20 cm SVL and 300 g in mass. The largest female captured in this study was 18.4 cm SVL, with a mass of 235 g. This female was apparently killed by the raccoon during the study.

The similarity in frequency of injuries across all age classes seems to show that most injuries are inflicted on juvenile animals which survive to adulthood with the damage from those injuries. The large number of injuries to the tail suggest that most injuries are inflicted during the iguana's escape attempt. There is no evidence available that could be used to identify the causes of these injuries. They may be caused by agonistic behavior of conspecifics, by rat or raccoon attack, by collapsing burrows that trap animals, or by a combination of these and other sources of injury. Although cannibalism is exceptionally rare, Auffenberg (1982) reported one incident in his detailed study of the diet of *C. carinata* in the Turks and Caicos, and Iverson (1979) witnessed a near-fatal attack on a hatchling by a male of the same species.

POPULATION SIZE

The Lincoln-Petersen population estimate gave a population in the same range as the line transects and classic transects. It seems fairly certain that the population of iguanas on Sandy Cay was less than 200 animals at the time of these estimates. Fortunately, the most recent estimate (October 1999) suggests that the iguana population has stabilized and that successful reproduction is occuring. However, senescence and mortality of currently reproductive females could outpace the low recruitment rate of hatchlings to the breeding population. Iverson (1979) concluded that only about 5% of *C. carinata* hatchlings survive to reproductive age. If a captive headstarting program was initiated, a substantially higher percentage of young should survive (assuming successful reintroduction) and this would accelerate population recovery.

The regression analysis done on Table 3 demonstrated that the density of iguanas and their burrows are homogeneously distributed in 1997, and this appeared to be true also in 1999. This is interesting because it suggests that most of the animals were territorial and that microhabitat variables such as type of vegetation and percent of cover were less important then maintaining sufficient space between neighbors. The scarcity of iguanas on this cay would make it interesting to examine questions of territoriality and social spacing in greater detail. Statistical methods are available to evaluate the spatial independence of individual iguanas (e.g., Powell, 2000). The locations and number of active burrows within a territory could also be examined. There is a paucity of research on microhabitat selection by iguanas, but the black iguana is known to make its burrows in areas with less vegetation than most of the surroundings (Burger et al., 1991).

AGE STRUCTURE AND SEX RATIO

The age structure of the population did not appear to change significantly between 1997 and 1999. Since the strongest threats to the population have been removed the population would be expected to begin recovery. Nevertheless, population recovery will proceed slowly because of the limited reproductive capacity of this iguana. Clutch size in *Cyclura* (and other iguanids) is highly correlated with body size (Iverson, 1979; Alberts, 1995; Thornton, 2000; Cyril, 2001 see also Rauch, 1984 and Lichtenbelt et al., 1993), and *C. r. cristata* is among the smallest of any taxon within the genus. Although larger species can produce clutches in excess of 20 eggs, *C. r. nuchalis* on North Cay, which attains a size similar to that of *C. r. cristata*, is limited to a clutch of 5 eggs (Thornton, 2000).

The extremely small number of females on Sandy Cay places the animals in imminent danger of extinction. A further problem is that there is a study that suggests that reptile growth may slow when an animal first breeds rather then when it reaches adult size (Halliday et al., 1988). If this is true then the small females on Sandy might be permanently stunted if aggressive males induce them to breed early. If so they would always produce small clutches and future recruitment would be slowed even more.

COMPARATIVE POPULATION DEMOGRAPHY

It has been argued that low densities of iguanas such as that found on Sandy Cay actually approach the carrying capacity of the cay due to its small size (Gicca, 1980). The evidence indicates that this is not true. A look at Table 4 shows that the density of iguanas on Sandy Cay is much lower than the densities seen in other populations of *Cyclura rileyi*. This is the case even though many of the other populations of *C. rileyi* are subject to disturbance (Hayes et al., 1995) and (Hayes et al., 1998). In addition to the population estimates in Table 4 a viable population of *C. carinata* had a density of 31.1 iguanas/ha (Iverson, 1979).

On Sandy Cay, a high proportion of the iguana population was comprised of juveniles (Table 5). Low Cay is similarly rat-infested (Hayes et al., 1995), but juveniles are scarce and recruitment appears to be limited. Thus, the high proportion of juveniles on Sandy Cay may seem surprising for a rat-infested island. However, it likely reflects the remarkably high level of adult mortality caused by the raccoon.

The severe adult mortality on Sandy Cay appears to have been selective, as there are far fewer females than males present in the population. The most likely explanation is that the feral raccoon preyed selectively on the females during the nesting season, when they were presumably more conspicuous and more readily captured. Other explanations can be considered. For example, it is possible that smugglers visited the cay during a recent nesting season and captured many of the female iguanas.

MORTALITY

Although tenuous and lacking in precision, several estimates of mortality revealed a substantial decline in the number of iguanas between visits to Sandy Cay in 1996 and 1997. The single raccoon that was present on Sandy Cay before being killed in 1997 was likely the primary cause of iguana mortality. There are several lines of evidence for this. The strongest evidence that the raccoon was a major cause of iguana mortality can be seen in figure 3. It shows that iguana carcasses were found in 1996 and 1997 but I killed the raccoon at the end 1997 and no carcases were found in 1998 or 1999. Also two carcasses had the skin peeled back and most of the animal eaten, there were iguana remains in the raccoon feces and 3 of the transmitters were badly chewed when recovered. One transmitter had iguana remains near it. There is no way of knowing how long the raccoon had been on the island but it is likely that this predator killed hundreds of iguanas and nearly caused complete extirpation of the population.

There were undoubtedly other sources of mortality on the cay, such as disease, rats and predatory birds. Regarding disease, one male iguana was captured that was swollen and blowing mucus from its nose. This iguana was kept overnight and was found dead in the morning. Circumstantial evidence suggests that rats negatively impact iguana populations. For example, density and biomass of iguanas is significantly reduced on rat-infested cays (figure 5). The lizard models that I set out were clearly vulnerable to rat attack (figure 6). Juvenile iguanas may also be vulnerable to attack when sleeping at night. Fortunately, the rats were eradicated in 1998. Hopefully, the island will remain rat-free until the population can recover, but rats are plentiful on Leaf Cay, an adjacent island which, at low tide, is less than 1 km distant. Several species of birds on Sandy Cay are potential predators of iguanas. Osprey (*Pandion haliaetus*) nest on the cay and have been observed feeding on an occasional adult *C. r. nuchalis* on North Cay (R. L. Carter, unpublished data). Merlins (*Falco columbarius*) and peregrine falcons (*Falco peregrinus*) are common visitors during migration and winter, and are capable of killing even large iguanas. Laughing gulls (*Larus atricilla*) nests in small numbers on the cay, and these are capable of killing small iguanas.

Both rats and mice were captured in live traps. The mice, by virtue of their small size, were much less likely than rats to impact the iguana population. From their relative abundance compared to rats, they also were less likely to affect the habitat. The initial capture rate of rats near the campsite was relatively high. It soon dropped off and no rodents were captured for approximately a month. After this a few rats were captured in other areas of the island followed by another drop-off after which no further rodents were captured. The capture rate of rodents may be affected by several factors, including local depletion of rodents resulting from trap removal (which was likely at the campsite), accumulation of rodent odors in the traps, and variation in moonlight. Any or all of these may have contributed to variation in trap success in my study. The capture rates (9.1% in the first 14 days) should be meaningful for those who wish to survey rats on Sandy Cay and other cays in the future Trimm, (2001) found that on San Salvador Island, capture rates for rats were 14.3% on Low Cay and 13.6% on the main island; his samples, however, were quite small. The rodent measurements are provided so that comparisons can be made with other island populations.

HOME RANGES

The home ranges are calculated from very small data sets and are of questionable reliability. However, asymptotes for sea snake home ranges could be obtained with only 10 or 11 data points (Burns et al., 1998). The autocorrelation measures from four iguanas suggested that three exhibited a degree of overdivergence between successive relocations. The fourth had no autocorrelation whatsoever. Some degree of autocorrelation reflects biological reality, as temporal independence can seldom be achieved in studies of home range size (Powell, 2000). Some research suggests that autocorrelation is of little importance in home range calculations (De-Solla et al., 1999).

There appears to be a difference in male and female home range size, which can be seen in Table 6. However, the female ranges were calculated from the smallest data sets and the difference may be reflected largely in sample size differences. My personal impression, however, is that the difference between male and female ranges was real.

Iguana density may be an important factor influencing home range size. Compared to a prior study by Carey (1975), Mitchell (2000) showed that mean home range size of *C. pinguis* on Anegada increased subsequent to a long-term reduction in density. Despite the smaller sample sizes, the mean maximum distance across the range of adult males on Sandy Cay was greater than that of *C. r. nuchalis* on North Cay (Thornton, 2000) and *C. r. rileyi* on Green Cay (Cyril, 2001). This may be a density-dependent effect. In contrast, the maximum distances between any two points for females on Sandy Cay were smaller than those of the other taxa. This may be a simple consequence of the small sample size on Sandy Cay. However, predation by the raccoon may have selected for females that remain near refugia at their centers of activity.

SOCIAL INTERACTIONS

The scarcity of social interactions was surprising. Even though a loose definition of social interaction was used, only 5% of the iguana observations were classified as social. On average, a social event was witnessed only once every 14.7 hrs in the field. Although comparable data have not been collected elsewhere for comparison, social interactions are abundantly observed in other populations of *C. r. rileyi*. The virtual absence of social interactions and the homogeneous distribution of these animals suggest that the iguanas on this cay are territorial. Given ample space to spread out under conditions of low population density, they probably avoid each other to minimize conflict.

A large number of freshly dug burrows began appearing shortly after a period of heavy rain. Most of these burrows were dug between 10 and 22 June. Glue traps set in these burrows captured almost exclusively females. However, these females fell well below the minimum reproductive size of *C. r. nuchalis* on North Cay (Thornton, 2000). While the digging behavior was most likely a response to substantial rainfall, it is possible that female iguanas on Sandy Cay mature at a smaller size, or that they have begun to breed at an earlier age in response to low population density and the male-skewed sex ratio. Female iguanas begin nesting in late June on North Cay (Thornton, 2000) and in early July on Green Cay (Cyril, 2001), and the nesting period is preceded by a period of exploratory digging. At the time, I surveyed the cay and counted 99 burrows with recent excavation activity. However, many of these burrows had entrances that were too small for iguanas and may have been dug by rats or mice.

Several studies have shown a link in timing between the breeding season and the onset of the rainy season in iguanas (Carey, 1975; Iverson, 1979; Snell et al., 1985; Alberts, 1996). The evidence from these studies is circumstantial, and there is some evidence to dismiss the possibility of a link (Blair, 1991). In one population studied on Curacao by Lichtenbelt et al. (1993), the Green iguana (*Iguana iguana*) nested in the midst of the dry season, and hatching occured near the onset of the rainy season when the plants were producing new growth. The possibility that rainfall is a trigger for breeding in rock iguanas should be investigated in future work.

CONSERVATION RECCOMENDATIONS

The Sandy Cay Iguana is in serious trouble. Its prospects are brighter now that some of the worst threats have been eliminated. The raccoon has been removed and the rats eradicated. There is increased awareness among the islands of smugglers and the need to refrain from bringing non-native animals to shore. Based on the findings of this study, I would like to make some recommendations for the management of this iguana. These include the following. 1) A small number of iguanas should be translocated to a suitable nearby cay to establish a second population. 2) A captive breeding program should be initiated as a further safeguard against extinction. A facility for this program should be constructed in the Bahamas, preferably in the Exumas, perhaps at the Exumas Educational Resource Center in George Town. Headstarted iguanas can be repatriated to augment the existing population on Sandy Cay, or translocated to a new population. Excellent guidelines have been developed for implementing relocation, repatriation and translocation studies (Burke, 1991; Dodd et al., 1991; Reinert, 1991). 3) DNA studies of all *C. rileyi* populations should be completed to improve our understanding of biosystematic relationships, genetic variance (heterozygosity), and the possibility of inbreeding depression. 4) Basic research on this iguana and closely related taxa should continue. Because so few females remain on Sandy Cay, studies of reproduction, such as those conducted by Thornton (2000) and Cyril (2001), should be conducted elsewhere. 5) Sandy Cay should be protected as a National Park under the auspices of the Bahamas National Trust. Signs should be posted to warn visitors that pets taken ashore and the feeding of iguanas are not permitted.

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