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Spatial Ecology of the Endangered Iguana, *Cyclura lewisi,* in a Disturbed Setting on Grand Cayman

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ABSTRACT.—**West Indian rock iguanas (genus *Cyclura*: Iguanidae) are among the most endangered lizards in the world, and many species will need to occupy human-modified and -occupied habitats to escape extinction. The Grand Cayman Blue Iguana, *Cyclura lewisi*, is critically endangered with fewer than 25 wild iguanas remaining. To aid the conservation of this and other iguanas, we investigated the spatial ecology of a captive-bred, released population of *C. lewisi* occupying a botanic park on Grand Cayman. Iguanas were monitored using transect walks and radio telemetry during the summer and fall of 2002. Males used larger areas and had greater movement distances than females during tracking periods in the summer but not in the fall. Overall home ranges for both seasons combined were larger in males than in females. Some home-range estimates were greater than any previously reported in *Cyclura*. Several iguanas, especially males during the breeding season, used areas outside the park where they are vulnerable to increased predation, death by vehicle, and hunting or collection by humans. This, combined with the large average home-range sizes for this species, indicate that future reserves for *C. lewisi* should be large and surrounded by buffer zones or fences.**

Rock iguanas of the genus *Cyclura* (Iguanidae, Frost and Ethridge, 1989; but see discussion of taxonomy in Hollingsworth, 2004) are a highly endangered group of lizards inhabiting islands throughout the West Indies (Alberts, 2000). These large, herbivorous iguanas are threatened by habitat loss and degradation (Alberts, 2000), competition with and predation by introduced species (Iverson, 1978; Mitchell, 1999), and hunting and collection by humans (Carey, 1966; Knapp et al., 1999; Alberts, 2000). Many populations are currently managed through captive breeding or head-starting programs, and some species will need to occupy human-modified and -occupied habitats to escape extinction.

The above circumstances apply to the endemic Grand Cayman Blue Iguana, *Cyclura lewisi*, which is critically endangered with only 7–25 individuals remaining in the wild (Burton, 2002). These iguanas remain as mostly isolated, non-reproductive individuals occupying disturbed

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habitat, thus revealing little about the natural population biology of *C. lewisi*. Because of the virtual extinction of the species in the wild, a captive breeding program for *C. lewisi* in 1990 by the National Trust was begun, and a small population of reintroduced iguanas was established in a protected area, the Queen Elizabeth II Botanic Park on Grand Cayman. Management of these released iguanas and planning of larger iguana reserves elsewhere on the island requires information on the basic ecology of the species, but little has been published and the opportunity to study natural populations in the wild no longer exists. Therefore, we studied the spatial ecology of this released, captive-bred, and only cohesive free-living population of *C. lewisi*.

We investigated two components of the spatial ecology of *C. lewisi*, home-range sizes and movement distances, by monitoring and radio-tracking adult male and female iguanas during the summer and fall of 2002. We compared space use and movements of adult males and females, although the two sexes were not tracked simultaneously. We also derived overall home-range size estimates for both sexes, which will be used in future reserve planning to determine how large a protected area is needed to support a self-sustaining population of *C. lewisi*.

MATERIALS AND METHODS

Study Area.—The Queen Elizabeth II Botanic Park is located in the eastern interior of Grand Cayman (19°19′N, 81°10′W) at approximately 2 m above sea level. Our 55-ha study site included the 24-ha botanic park and the surrounding land used by iguanas initially found in the park. Human-modified habitats, which make up less than 13% of the study site, include ornamental gardens containing native and nonnative plants, manicured grass lawns, buildings, sheds, roads, and trails (Goodman, 2004). Natural habitats include xeric forest and shrubland habitats, as well as seasonally flooded wetlands dominated by Logwood (*Haematoxylum campechianum*) and Buttonwood (*Conocarpus erectus*). For a more detailed description of the study site, see Goodman (2004).

Iguana Capture and Attachment of Transmitters.—We initially located iguanas by walking transects consisting of roads and trails in the park, often during related research conducted throughout the entire study area (see Goodman, 2004). Therefore, only iguanas that used the park regularly were included in this study. Iguanas were captured by hand, or with a landing net or Havahart® single door trap baited with fruit. We tagged all iguanas in the park with unique combinations of colored beads as described by Rodda et al. (1988), weighed them to the nearest 0.05 kg, measured snout–vent length (SVL) and total length (TL) to the nearest 1 mm, and probed them to determine sex. All iguanas in the released population had been captive-bred on site and released into the park at 2–3 years of age, when they are less vulnerable to predation (Alberts, 2000). We included only adult iguanas that were 3–7 years of age in the current study because iguanas of this age class were sexually mature and released at least one year prior to the initiation of this study.

We attached radio transmitters (Holohil Systems, Ltd. model AI-2, 45 × 15 mm with 23 cm whip antennae, < 40 g with plates or encapsulation described below) to males (SVL and mass of all study subjects in Table 1) by suturing them below the posterior dorsal crest with nylon-coated steel leader wire, along with a neoprene pad and aluminum backing plate. Transmitters were attached to females by encasing the transmitters in plastic and gluing the transmitter package to the posterior dorsum with cyanoacrylate gel. See Goodman (2005) for details on attachment methods and their reliability.

Population Monitoring and Tracking.—We monitored iguanas by walking a transect of park trails and roads from 9 May to 4 August (268 rounds) and 23 September to 10 November (198 rounds) in 2002. One researcher walked transects 1–8 times daily (mean = 3.5, SD = 2.8), with sampling spread over active hours of iguanas, 0700–1930. We also recorded incidental sightings of iguanas throughout the study site, including in natural habitats, while conducting focal animal observations and habitat surveys for related research (see Goodman, 2004). Locations of iguanas were recorded using GPS coordinates (Garmin GPS12XL) and, when possible, compass bearings to local landmarks.

During two separate periods, we tracked male and female iguanas using radio telemetry (Wildlife Materials, Inc., Carbondale, Illinois, model TRX-1000S tracking receiver and collapsible, hand-held yagi antenna). Males were tracked during 28 May to 13 June (summer; $N = 5$ iguanas) and during 5–20 October (fall; $N = 4$) 2002. Females were tracked during 19 July to 2 August (summer; $N = 5$) and during 23 October to 5 November (fall; $N = 6$) 2002. Females could not be radio-tracked during the mating season because of a limited number of radio transmitters and were, therefore, radio-tracked in the summer after all had nested. Males were tracked during the end of the mating season, based on the last observation of mating on 23 June and observations of peak courtship and mating in May.

We only conducted radio telemetry on days with mostly clear weather (no precipitation and less than 75% cloud cover estimated visually; 57 of 62 days during tracking periods), because iguanas typically did not move more than 5 m

TABLE 1. Estimated home ranges for 2002 and usage areas for each tracking periods therein are shown for adult iguanas, *Cyclura lewisi*, in the Queen Elizabeth II Botanic Park, Grand Cayman. Estimates are given in hectares for minimum convex polygons containing all locations (100% MCP) and 95% contours for fixed kernel use distributions (95% Kernel). Mass (kg) and SVL (cm) are shown for iguanas, with an average given when an iguana was measured more than once during the study. Number of locations per iguana in each period (*N*) is shown. Mean ± SD are shown for samples sizes and home-range and usage area estimates. Overall home-range size is estimated for radio telemetry data only and for radio telemetry and transect data combined (all data).

	SVL (cm)	Mass (kg)	Summer (tracking only)			Fall (tracking only)			Overall (tracking only)			Overall (all data)	
			N	100% MCP	95% Kernel	*N*	100% MCP	95% Kernel	*N*	100% MCP	95% Kernel	*N*	100% MCP
Males:													
SLGR	46.0	4.55	84	0.862	0.186	87	0.470	0.431	171	1.144	0.398	358	1.180
PI	36.5	2.40	81	36.520	9.957	75	3.624	2.436	156	37.601	6.719	219	38.814
Y	43.1	3.58	82	5.151	3.938	82	2.260	0.331	164	5.217	1.326	334	5.385
SANT	42.1	3.28	76	6.667	3.741	83	0.046	0.018	159	7.243	0.538	220	7.477
TRAN	35.8	2.20	67	18.637	4.971				67			100	18.637
Mean	**40.7**	**3.20**	78	**13.567**	**4.559**	82	**1.600**	**0.804**	143	**12.801**	**2.245**	246	**14.298**
SD	4.4	1.0		14.426	3.517		1.656	1.102		16.727	3.010		15.148
Females:													
BITR	31.4	1.55	83	0.346	0.147	87	0.024	0.007	170	0.430	0.061	327	0.444
YB	34.3	1.93	87	0.251	0.048	79	0.225	0.100	166	0.594	0.217	273	0.614
RB	27.9	0.95	83	0.721	0.058	60	0.541	0.375	143	1.530	0.164	207	1.580
PIPB	37.3	2.29	86	0.818	0.458	79	1.094	0.185	165	1.381	0.351	259	1.425
PBX2	36.5	2.45	79	0.978	0.336	75	1.172	0.959	154	2.113	0.234	266	2.181
PU	29.6	1.23				87	2.079	1.178	87			122	8.423
Mean	**32.8**	**1.7**	84	**0.623**	**0.209**	78	**0.856**	**0.467**	148	**1.210**	**0.205**	242	**2.444**
SD	3.8	0.6		0.312	0.181		0.754	0.486		0.695	0.106		2.998

from their retreats on overcast or rainy days. All iguanas were radio-located 4–8 times daily, with hours of tracking standardized to ensure an even distribution over activity periods.

Iguanas were not pursued into vegetation if not seen within 20 m because they would flee the sound of an approaching researcher (although iguanas allowed close approach when in open areas). To estimate iguana locations when visual verification was not possible, 2–4 bearings were taken from known locations in the park with a 10-min maximum period between the first and last bearing. The majority of bearings (95.3 %, *N* = 1237) were taken from locations with GPS coordinates obtained multiple times and verified with aerial photography of the study site provided by the Cayman Islands Government's Land Information System (image date 1999). We triangulated iguana locations with TELEM88 (J. S. Coleman and B. I. Jones, Virginia Polytechnic Institute and State University, Blacksburg, VA, 1988) for only those locations with one set of bearings forming an angle of 30–165 degrees. Error of triangulation was estimated by tracking and estimating 36 dummy locations (unknown to the tracker) with the same methods as those used for tracking and triangulating real iguana locations. The 95% confidence intervals for triangulation error were 23–39 m and 20–34 m for two and three vectors, respectively.

Home Range and Movement Analyses.—In this study, home range refers to the area used by an individual during foraging, mating, and other regular activities over the course of a year (Burt, 1943). The term "usage area" is analogous to home range but applies to the area used by an individual in a shorter period, herein a tracking period (Powell, 2000). We estimated all home-ranges and usage areas using the Animal Movement extension (Hooge and Eichenlaub, 1997) in Arcview® GIS version 3.2. Two home-range estimators were used, the minimum convex polygon and the fixed kernel use distribution. The minimum convex polygon includes all animal locations for a given period (100% MCP) and is generally sensitive to sample size and easily influenced by outliers (Rose, 1982). However, MCPs are directly comparable to most other studies of space use. Probabilistic fixed kernel use distributions (Worton, 1989) were also used because they describe the area used most commonly by animals more accurately than MCPs (Rose, 1982; Powell, 2000). By convention, the area within 95% kernel contours was considered the home range or usage area (95% Kernel; Powell, 2000).

We omitted from our radio telemetry data repeated locations of an iguana prior to the first movement of > 10 m within a day. However, autocorrelation still existed in the telemetry data for both radio-tracking periods (Schoener ratio

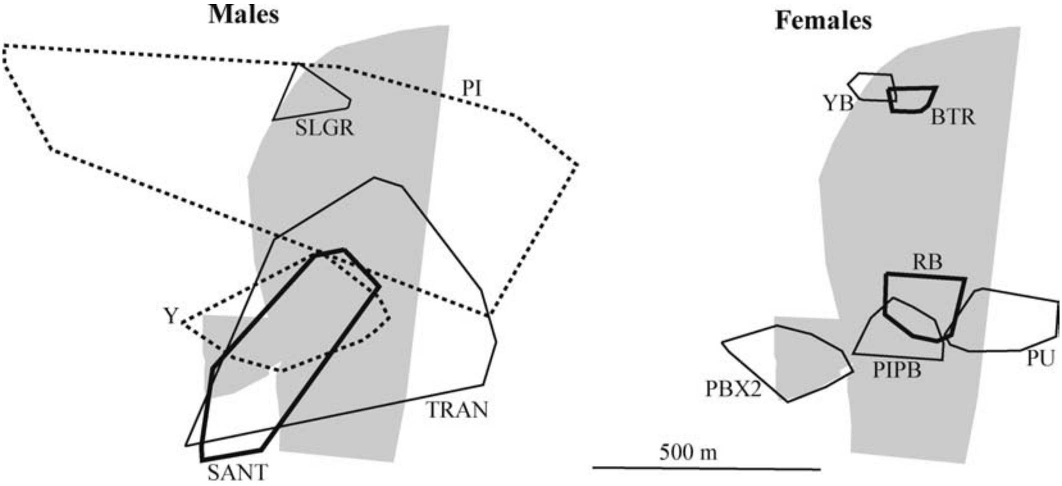

FIG. 1. Minimum convex polygon (100% MCP) home ranges for male and female *Cyclura lewisi* in the Queen Elizabeth II Botanic Park (grey shaded area) in Grand Cayman: Home ranges are constructed from five weeks of radio-telemetry data containing 67–171 (mean = 145.6) locations per iguana collected during May through November of 2002. Abbreviations next to home ranges refer to names assigned to iguanas.

t^2:r^2; mean = 1.030, SD = 0.401; Schoener, 1981). Previous studies have questioned the importance of autocorrelation in location data and its effects on kernel home range estimators (Swihart and Slade, 1985; Gese et al., 1990; Reynolds and Laundre, 1990; Rooney et al., 1998; de Solla et al., 1999; Otis and White, 1999), so we examined its effects on 95% Kernel estimates in our study. Subsampling every second and third location in our telemetry data resulted in a significant reduction in autocorrelation (i.e., increase in Schoener ratio; one-way ANOVA for summer tracking: $F = 5.51$, df = 2, 27, $P < 0.01$; fall tracking: $F = 5.49$, df = 2, 27, $P < 0.01$; both seasons combined: $F = 6.51$, df = 2, 24, $P < 0.01$) but had no effect on area of 95% Kernel usage areas or home ranges (Kruskal-Wallis One-way ANOVA on ranks was used because of violations of normality in the original data; for summer tracking: $H = 0.441$, df = 2, $P = 0.802$; fall tracking: $H = 0.452$, df = 2, $P = 0.798$; both seasons combined: $H = 0.596$, df = 2, $P = 0.742$). Therefore, the radio telemetry data was not subsampled but used in its entirety for all analyses.

Home-range areas were compared between sexes for the entire study period using radio telemetry data only (100% MCP and 95% Kernel) and radio-telemetry data plus transect data (100% MCP). Usage areas (100% MCP and 95% Kernel) were compared between sexes for both tracking periods from radio-telemetry data only.

Movement distances were estimated with radio-telemetry data from each tracking period using Animal Movement. The average distance between locations was calculated by averaging distances between consecutive locations within each day over a tracking period. Overall movement was the sum of all distances traveled, including those between days, in a tracking period. We compared movement distances between sexes in each tracking period. All above comparisons were performed using Mann-Whitney *U*-tests because data did not conform to normality assumptions required for parametric statistics. All statistical tests were performed in SAS version 9.0 (Statistical Analysis Systems Institute Inc., Cary, NC, 2002) with an alpha of 0.05.

RESULTS

Male usage areas were larger than those of females during the summer tracking periods (100% MCP: $N = 10$, $S = 39.0$, $P = 0.016$; 95% Kernel: $N = 10$, $S = 38.0$, $P = 0.032$; see Table 1 for all usage and home-range sizes) but not during the fall tracking periods (100% MCP: $N = 10$, $S = 25.0$, $P = 0.610$; 95% Kernel: $N = 10$, $S = 24.0$, $P = 0.762$). Males generally had larger 100% MCP home ranges than females during both tracking periods combined, but this was not statistically significant ($N = 9$, $S = 27.0$, $P = 0.111$; Fig. 1). However, males had significantly larger 95% Kernel home ranges during both tracking periods combined ($N = 9$, $S = 30.0$, $P = 0.016$; Fig. 2). Results were similar when home ranges were constructed for the entire study period from both transect and radio-telemetry data (100% MCP: $N = 11$, $S = 39.0$, $P = 0.126$).

In 2002, MCPs constructed from radio telemetry data revealed that several iguanas used area outside the boundaries of the park (Fig. 1). In some cases, kernel usage areas constructed from

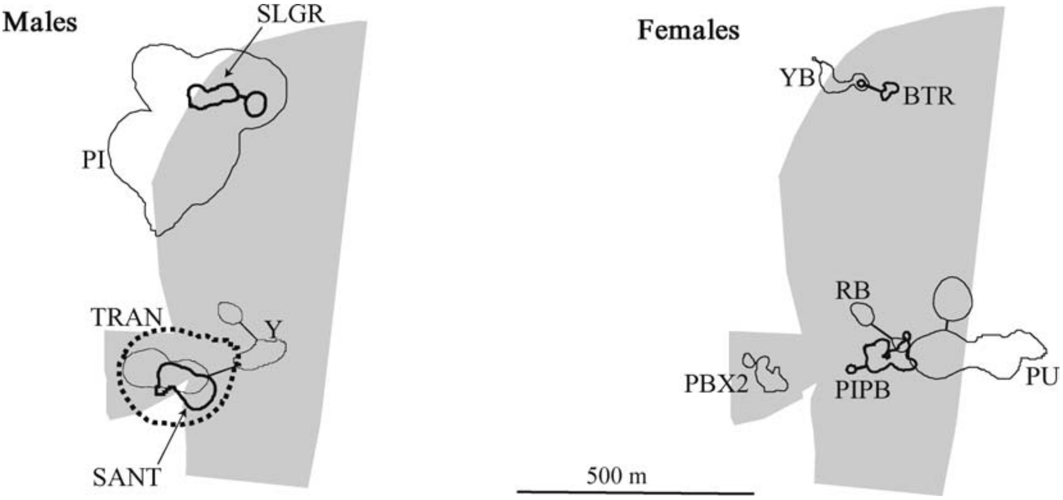

FIG. 2. Probabilistic fixed kernel (95% Kernel) home ranges for male and female *Cyclura lewisi* in the Queen Elizabeth II Botanic Park (grey shaded area) in Grand Cayman: Home ranges are constructed from five weeks of radio-telemetry data containing 67–171 (mean = 145.6) locations per iguana collected during May through November 2002. Abbreviations next to home ranges refer to names assigned to iguanas.

radio-telemetry data also identified area used by iguanas outside of the park but not to the extent indicated by MCP usage areas (Fig. 2).

Males had significantly greater total and between-location movement distances than females during the summer (total movements: average difference = 3580 m, Mann-Whitney *U*-test, $N = 10$, $S = 16.0$, $P = 0.016$; between-location movements: average difference = 45 m, $N = 10$, $S = 15.0$, $P = 0.008$). Sexes did not exhibit significantly different movement distances during the fall tracking period (total movements: Mann-Whitney *U*-test, $N = 10$, $S = 21.0$, $P = 0.914$; between-location movements: $N = 10$, $S = 18.0$, $P = 0.476$).

DISCUSSION

Among iguanid lizards, males typically have larger home ranges than females (reviewed in Perry and Garland, 2002), and this is true of most species of *Cyclura* that have been studied (Carey, 1975; Iverson, 1979; Goodyear and Lazell, 1994; Mitchell, 1999; Knapp, 2000; but see Alberts et al., 2002). Similarly, male *C. lewisi* in this study had larger home ranges than females during the entire study period. Males also had larger usage areas and moved greater distances than did females during the summer tracking period. However, interpretation of the latter result is difficult because the two sexes were not tracked simultaneously. Polygyny is common in the genus *Cyclura*, and males typically travel to, court, and defend several females during the mating season (Carey, 1975; Iverson, 1979; Dugan and Wiewandt, 1982). We observed male *C. lewisi* traveling to distinct areas that contained different females, particularly during May and June when males courted multiple females. Females, however, did not appear to travel outside of their normal usage areas to visit males during this time.

Our estimates of overall home-range sizes varied considerably among individuals. Past studies of *Cyclura* populations have reported home-range sizes varying by one order of magnitude among individuals (Carey, 1975; Iverson, 1979; Goodyear and Lazell, 1994; Mitchell, 1999; Knapp, 2000), rather than the two orders of magnitude reported here. Our minimum overall home-range sizes for iguanas are not attributable to inadequate sampling as the two smallest home ranges for 2002 (100% MCPs with all data of < 0.7 ha; both females) were based on 273 and 327 locations collected over a 185-day period, which are large sample sizes compared to most studies in *Cyclura*.

MCP home-range sizes of iguanas in this study had a higher maximum (38.8 ha) than previously reported for any species of *Cyclura* (reviewed in Goodman, 2004). The closest maximum value of home-range size previously reported in this genus, 9.0 ha, was found in a male *Cyclura pinguis* occupying disturbed habitat on Anegada (Mitchell, 1999). Population density has been demonstrated to be negatively related to home-range size in other lizards (Schoener and Schoener, 1980; Alberts, 1993). The estimated population density of iguanas in the botanic park was 0.64 iguanas per hectare (iguana/ha) in 2001–2002 (Goodman, 2004). Goodman (2004) reviewed 24 sources containing surveys of 41 populations representing 11 subspecies of *Cyclura* and found that our study population had a very low population density when compared to most populations (range 0.3–128.3 iguana/ha) in both natural and disturbed settings. Thus, the large home ranges may be explained by low population density in our study population, or alternatively, a low density of resources in the park. Another possibility is that large home ranges may have been detected in this study and not in others because of differences in methods between researchers.

The large home ranges used by *C. lewisi* indicate that large reserves are needed with buffer zones or fences to keep iguanas from moving out of protected areas. Fences could serve the additional role of keeping feral cats and dogs out of reserves, which is important because they are known to devastate rock iguana populations (Iverson, 1978; Alberts, 2000; Alberts et al., 2004). Because only a few scattered wild individuals of *C. lewisi* exist on Grand Cayman at present, eliminating gene flow by erecting fences will not be problematic in the near future.

Home-range sizes may have been influenced by supplemental feeding of iguanas discovered during the course of this study (Simon, 1975; Stamps and Tanaka, 1981; but see Waldschmidt,1983; Guyer, 1988). However, supplemental feeding is predicted to decrease home-range size (Simon, 1975; Eifler, 1996), whereas home-range sizes in this population were large compared to those of other species of *Cyclura*. Further studies, possibly conducted with controlled supplemental resources and variable densities of iguanas, are needed to determine which factors ultimately determine home-range size in *C. lewisi*.

In the park, iguanas occupy anthropogenically modified habitats, come into contact with humans on a regular basis, and are heavily habituated. One might argue that these circumstances may limit the application of our findings to iguanas in more natural settings. In fact, few pristine settings remain for rock iguanas, and knowledge of their ecology in unnatural settings will be crucial to their management in the future. Many populations of *Cyclura* are faced with frequent human interaction and habitat disturbance and are increasingly managed with headstarting and captive breeding programs. *Cyclura lewisi* is unlikely to ever occupy pristine settings, and this prediction applies to many other animals as well. Therefore, the study of the spatial distribution and movements of captive-bred, released *C. lewisi* is important to preserving populations of this and other species of iguanas.

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