AN ANALYSIS OF THE DEMOGRAPHY AND HABITAT USAGE OF ROATÁN'S SPINY-TAILED IGUANA, *CTENOSAURA OEDIRHINA*

by

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This dissertation was prepared under the direction of the candidate's dissertation co-advisors, Dr. Terry L. Maple, Department of Psychology, and Dr. Dale E. Gawlik, Department of Biology, and has been approved by the members of her supervisory committee. It was submitted to the faculty of the Charles E. Schmidt College of Science and was accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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ABSTRACT

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The Roatán Spiny-tailed Iguana (*Ctenosaura oedirhina*) is endemic to the 146-km^2 island of Roatán, Honduras. Harvesting for consumption, fragmentation of habitat, and predation by domestic animals threaten this lizard. It is currently listed as Endangered by the International Union for Conservation of Nature (IUCN), as threatened by the Honduran government, and is on Appendix II of the Convention on International Trade in Endangered Species (CITES). This species has been geographically fragmented and genetically isolated into small subpopulations that are declining in density. With data gathered from use/availability surveys, resource selection functions were used to identify habitats and environmental variables associated with their presence. Results indicate that protection from harvesting is the most important factor in determining their distribution. These high-density populations are currently restricted to ~0.6 km^2. Organisms living in small, isolated populations with very restricted ranges are at higher risk of extirpation due to various direct and indirect forces. Mark-recapture-resight surveys and distance sampling have been used to monitor the populations since 2010 and 2012 respectively. The data show that the high-density populations are declining. The current population size is estimated to be 4130-4860 individuals in 2015. A population viability analysis (PVA) was conducted to identify the most pressing threats and specific life history traits that are affecting this decline. The analysis estimates that if current trends persist, the species will be extinct in the wild in less than ten years. Adult mortality is a main factor and female mortality specifically characterizes this decline. In order for this species to persist over the next fifty years, adult mortality needs to be reduced by more than 50%. A lack of enforcement of the current laws results in the persistence of the main threat, poaching for consumption, thus altering the species distribution and causing high adult mortality. This is complicated by social customs and a lack of post primary education. Management changes could mitigate this threat and slow the population decline. Recommendations include an education campaign on the island, increased enforcement of the current laws, and breeding of *C. oedirhina in situ* and *ex situ* for release into the wild.

DEDICATION

For Mom, Dad, and Matt.

AN ANALYSIS OF THE DEMOGRAPHY AND HABITAT USAGE OF ROATÁN'S SPINY-TAILED IGUANA, *CTENOSAURA OEDIRHINA*

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1. HABITAT UTILIZATION OF ROATÁN SPINY-TAILED IGUANAS (*CTENOSAURA OEDIRHINA)* AND ITS IMPLICATIONS FOR CONSERVATION

Introduction

Prioritization of habitat protection is an important aspect of in situ species conservation. This is especially true when dealing with limited resources, as is often the case in conservation (Murdoch et al. 2007; Bottrill et al. 2008). Biodiversity hotspots are areas of high diversity that may be undergoing severe habitat degradation. These hotspots harbor high numbers of endemic species within small areas, such that the conservation of these areas protects a large proportion of global biodiversity (Myers et al. 2000). This same concept can be applied to smaller scale situations, such as the range of a single threatened species. Not all habitats are equal in their value to a species and some taxa may use habitat disproportionately to its availability. Species can actively select for a certain attribute, such as vegetation type or distance to water, or modify their niche preference based on dietary needs, thermoregulation, competition, and/or predation (Manly et al. 1992). In turn, conservationists can prioritize habitats for protection by identifying the environmental variables a species selects (Boyce and MacDonald 1999).

Use/availability surveys are used to determine what habitat a species uses and is able to access. These data can then be used to describe the habitat, or habitat variables, a species utilizes within a landscape (i.e., Resource Selection Functions (RSFs); Boyce and MacDonald 1999). Many studies use RSFs to focus resources for conservation initiatives. For example, using these methods Smith et al. (2004) found that current pastoral management techniques of the European Hare (*Lepus europeaus*) were not in fact helping to increase the hare population because the hares were selecting for different habitats than previously assumed. Changing management practices to increase heterogeneous pastoral habitat is thus more efficient for the farmers and also benefits the hares and the biodiversity of the region (Smith et al. 2004). RSFs can also be used to map currently and historically used habitat, which sometimes results in locating useful study sites and identifying possible reintroduction locations. Cleve et al. (2011) showed that the environmental variables used to predict habitat likely to contain the threatened Sierra Nevada Red Fox (*Vulpes vulpes necator*) successfully predicted an area that housed a new, previously unknown population. Naves et al. (2003) used resource modeling via logistic regression to outline the possible historic range of the Brown Bear (*Ursus arctos*) in Europe. These data could one day be used to repatriate individuals into previously inhabited areas.

RSFs and use/availability studies can also be used to develop maps of habitats that were worth delineating for official protection or for use in land management decisions. Chetkiewicz and Boyce (2009) used RSFs to identify habitat corridors for Grizzly Bears (*Ursus arctos*) and Mountain Lion (*Puma concolor*). These RSF data can then be used in future land management and planning (Chetkiewicz and Boyce 2009). Likewise, Smith et al. (2014), employing use/availability and habitat selection models, found that Greater Sage-grouse (*Centrocercus urophasianus*) selected against anthropogenically disturbed habitats and suggested that land managers prioritize distinct subunits of sage-grouse habitat when planning new development. When debating land planning and management, this type of information could be the difference between a species persisting in an area or being extirpated.

In this study, we employed use/availability surveys to develop RSFs, which identify critical habitat for an endangered, narrow-range endemic iguana. The Roatán Spiny-tailed Iguana (*Ctenosaura oedirhina*) is found only on the 146 km^2 island of Roatán, ~ 50 km off the northern coast of Honduras (Figure 1.1). Habitat destruction and fragmentation, the introduction of exotic species, and over-harvesting for consumption threaten this species (Pasachnik et al. 2010a). Described in 1987 (de Queiroz), the Honduran government acknowledged this species as in need of protection in 1994 (Wilson and McCranie 2004), the IUCN placed them on the Red List of Threatened Species in 2004, and they were included in Appendix II of CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) in 2010 (Pasachnik and Ariano 2010). Since its description, only larger-scale genetic and taxonomic studies have been conducted on this species (Kohler et al. 2000; Pasachnik et al. 2010b) until recently (Pasachnik 2013; Pasachnik and Hudman in press).

While it is officially illegal to hunt *C. oedirhina*, there is little to no enforcement on the island, and individual iguanas are regularly taken for food. In addition, there are legally protected areas and habitats (e.g., national parks), but the protection of these areas is not enforced. The growing tourism industry on the island heightens cause for concern. In less than 20 years, the urban area on the island increased from 1.8 km^2 in 1985 to 17.1 km^2 in 2001 (Aiello 2007) and over one million tourists visit the island a year (Doiron and Weissenberger 2014). Not only does this result in habitat destruction, but also an influx in people from the mainland arriving in hopes of finding jobs. This in turn increases hunting pressure on the local wildlife, particularly iguanas, as many recent immigrants are not able to find work and it is a custom on the mainland to consume iguanas (Fitch et al. 1982; Pasachnik et al. 2014). With no recognized protection for this iguana or other threatened species, protection through local grassroots efforts, such as localized hunting prohibition, is all that exists. This grassroots movement, which consists of private landowners, resorts, and tourist parks, has limited resources so the effort put forth must be used to the greatest effect.

Habitat utilization is an important ecological aspect that has direct implications for conservation. RSFs estimate the habitat usage and preference for specific resources for a given species. It is important not only to protect where the animals spend most of their time (i.e., their typical home range) but also the habitat(s) that they may use for just a small yet vital portion of the year (e.g., nest sites). It is also important to realize that both sexes have core areas of use within their home ranges and that these may change in size or location due to breeding or other seasonal factors. Thus, the protection of many habitat types may be necessary to support a given species. The objective of this study was to survey the habitat and environmental variables across the island of Roatán in order to determine those characteristics that define the preferred habitat of *Ctenosaura oedirhina*. Since so little land is actually protected for this species it is imperative that the most utilized habitats be incorporated.

Methods and Materials

We collected data over a two-year period, during spring (April–May, 2012 and 2013), fall (August, 2012 and 2013), and winter (November–December 2012) on Roatán, Islas de la Bahia, Honduras (Fig. 1). We focused on two main seasons, the rainy season (September–January) and the dry season (February–August). Breeding and nesting occur in March–June and hatching in early August, after a 70–100 day incubation period (Pasachnik 2013).

Study location.—Roatán is covered primarily in seasonally dry tropical forest. The coastline is either white sand, rocky, or mangrove forest. Smaller islands and cays surround the main island of Roatán, some of which harbor iguanas. Barbareta is the largest (~ 5 km^2) of these and is located off the east end of Roatán. It is privately owned, and we could not obtain permission to survey it during our timeframe. Therefore, it has been excluded from our analyses. Because of the endangered status of this species, specific information about research sites is available only upon a justifiable request.

Data collection.—We used Google Earth to map and calculate the area of available habitats on the island down to 100 m^2 sections. The latest available satellite photos (2013–2014) were used with data from Scripps Institute of Oceanography, National Oceanic and Atmospheric Association, U.S. Navy, National Geospatial-Intelligence Agency, and General Bathymetric Chart of the Oceans (Map data: Google, TerraMetrics). We ground-truthed all areas where the habitat classification was questionable. Since reliable satellite imagery is unavailable for the island for long-term habitat change analysis, we used ground cover data from Aiello (2007) and Programa REDD/CCAD-GIZ (2014) to make relative comparisons. As the Programa REDD/CCAD-GIZ (2014) work was not available during the design of this study, our habitat definitions vary slightly and thus direct comparisons are difficult (see below for additional details).

We conducted use/availability surveys along line transects located at nine study sites. To sample all of the available habitat types we non-randomly distributed transect locations across the island. Each transect was ~ 100 m long (range 90–110 m), and each location had at least three transects, for a total of 50 transects. We included both natural and altered landscapes, ranging from undisturbed to heavily disturbed, in our habitat surveys. We conducted surveys on multiple days between 0800 and 1500 hours during May (2013, 11 days), June (2013, two days), August (2012, 11 days; 2013, four days), November (2012, 11 days) and December (2012, one day). Due to logistics, trips were of varying lengths. Each site was surveyed during each season: spring (May–June), summer (August), and winter (November–December). While not all sites were surveyed an equal number of times, all were surveyed at least twice during each season. During each survey, at least one of us walked each transect and noted every iguana sighted on or along it with its distance along and perpendicular distance from the transect to the nearest meter. We considered these the "used" points, and noted a suite of environmental variables for each point (e.g., habitat type, substrate type, distance to water, and disturbance level; see Figure 1.2 and Appendix I for details). We used a random number generator to select points along the transect, which we surveyed for the same variables.

We considered these the “available” points. We also used the location of “used” points along each transect to determine the density of iguanas at each location.

Data analysis.—To determine if any changes occurred over time in either used or available habitat, we used $\chi 2$ tests of the percentage of each habitat at each location using the chisq.test function in the R software package ($\alpha = 0.05$ throughout) (R Development Core Team, Vienna, Austria). To make the Google Earth data comparable to the data from Aiello (2007), we used only the areas of anthropogenic, forest (“cleaned” and “uncleaned” forest combined, see Appendix I for definitions), and sandy shore habitats in our analysis. Unfortunately, the Programa REDD/CCAD-GIZ (2014) data was not available during the setup of this study and thus direct comparisons were not possible due to variations in habitat type descriptions (see below for more detail). We compared data between and among study sites using contingency tables (chisq.test function in the R software package). We compared data between the study sites and the island as a whole in the same way. We replicated simulated P values 100,000 times because of the prevalence of zeros and small numbers in the data set. To establish the usage of each habitat type, we performed a logistic regression on the “used” and “available” points (logreg function in SAS® software) to determine resource selection functions (SAS Institute Inc., Cary, North Carolina, USA). We then used Akaike Information Criterion (AIC) to determine the preferred model, i.e., the model that best balanced goodness of fit and complexity (Anderson et al. 1998). After testing the global model, following models were pared down by grouping variables by similar P values (i.e., P values within 0.25 of each other were binned and then variables that fell within those bins were grouped together). We used the program Distance to determine the density of iguanas at each study site (Thomas et al. 2010). The program calculated the density of iguanas along each transect based on "used" points from the use/availability transects (i.e., the distance along the transect and perpendicular distance from the transect of each iguana).

Results

From the areas calculated using Google Earth, mainly seasonally dry tropical forests (~ 77%), coastal mangrove stands (~ 7%), and urbanized areas (~ 14%) cover the island. The remainder is mostly agricultural (< 1%, either pasture land for cattle and horses, or stands of bananas) or stripped land (< 1%, mostly cleared for new development, but some for mining operations) (Table 1.1). Satellite images cannot distinguish "cleaned" versus "uncleaned" forest, so we grouped them together. We compared these data to Aiello's (2007) study, which reported data from 1985 and 2001, and to data from 2014, compiled by the Honduran government (Programa REDD/CCAD-GIZ 2014). We determined that large reductions in forest and sandy habitats occurred, while urban area increased dramatically (Table 1.2) between Aiello's (2007) study and ours. However when we attempted to compare our data to the 2014 data (Programa REDD/CCAD-GIZ 2014), it was apparent that different definitions of each habitat type were used. While the percent of forest cover seemed to be comparable across years/studies, there were discrepancies in urban areas and sandy habitats. Like Aiello (2007) we classified villages as "urban" even if they were not "urbanized" with paved roads, as much of the island is not paved but still contains high population density centers. The 2014 (Programa REDD/CCAD-GIZ) data, however, had a narrower classification of urban, only delineating densely populated, paved areas. Likewise our study defined sandy habitat as sand substrate with little to no vegetation occurring predominately along the shoreline, whereas the 2014 (Programa REDD/CCAD-GIZ) data used only the presence of a sand substrate and lack of dense vegetation to define this type of habitat. This possibly led to areas that our study delineated as "stripped" habitat to be identified as "sandy" habitat on the 2014 map. Some degree of discrepancy may also be due to the Honduran government (Programa REDD/CCAD-GIZ 2014) having access to more detailed aerial/satellite images that are not available to public.

From our surveys we concluded that used and available habitats at the study sites did not vary significantly from those available on the island as a whole (100,000 replicates; $P = 1$ for all combinations); however, the habitat did vary significantly among the study sites (100,000 replicates; $P < 0.0001$). Some sites are predominantly anthropogenic habitat while others are exclusively "uncleaned" forest with little to no direct anthropogenic impact. Iguanas were found in all habitat types, but not at all of the surveyed sites. Only six of our nine study sites contained iguanas. While other native fauna (such as Roatán Island Agouti (*Dasyprocta ruatanica*)) was noted within the grassroots protected study sites, neither iguanas nor other native terrestrial vertebrates were seen during surveys at nationally protected locations.

The global model for the resource selection function used all seasonal data from 2012–2013 and contained all 25 variables (nine habitats, nine substrates, four distances to water, and three disturbance levels; see Appendix I for details on variables; Table 1.3). The global model had the best AIC value. However, when using relatively large datasets, AIC tends to select models with too many variables (e.g., the global models) (Hastie et al. 2001). In our case we believe that the global model, while deemed “best” by AIC, is not ecologically significant so the next best model was used for all further analysis. The second-most supported model, based on the AIC value, included the habitat variables anthropogenic, stripped, “uncleaned” forest, and shore, as well as vegetation and substrate variables most optimal for thermoregulation (rock, concrete, and gravel). Coefficient estimates showed that shore, “uncleaned” forest, stripped, and undisturbed habitats were “avoided”, while anthropogenic, vegetation, and rock, gravel, and concrete substrates were “preferred” (Table 1.4).

Locations containing the highest densities of iguanas had significant differences in used versus available habitat between the seasons (mainly between spring and fall, less so in winter) (Table 1.5). Iguanas exist in the highest densities within grassroots protected areas (Table 1.6). These protected areas make up only ~ 0.6 km^2 of the island (less than 0.01% of the total area of the island). We found iguanas almost non-existent in areas unprotected by the grassroots movement, (densities of 0–5 iguanas per km^2).

Discussion

With limited resources, conservationists need to understand the specific distribution of a species, be it based on suitable habitat or human disturbance, so that limited resources can have the greatest impact (Caughly and Gunn 1996). Animals often select habitats and habitat characteristics based on food abundance, thermoregulation, predation, and competition. In these cases, conservation of the species can start with protecting specific habitats discerned by RSF or other similar means (Boyce and McDonald 1999). Our RSF model suggests that *C*. *oedirhina* selects habitats at least in part based on thermoregulation, selecting more often for rock, concrete, and gravel (i.e., substrates that heat up quickly in the sun and hold that heat for much of the day). *Ctenosaura oedirhina* also selects for altered habitats; however, many hectares of altered habitat on the island contain almost no iguanas, suggesting that another factor is likely accounting for the observed distribution.

The RSF model chosen to describe the distribution of *C*. *oedirhina* contained a mix of both undisturbed (undisturbed habitat, "uncleaned" forest) and heavily disturbed habitats (stripped habitat, anthropogenic habitat, concrete and gravel substrate), and indicated an avoidance of "uncleaned" forest, stripped, and undisturbed habitat (Table 1.4). "Uncleaned" forest, stripped land, and undisturbed habitat have one very important thing in common: they are usually areas that are accessible to hunters. "Uncleaned", undisturbed areas, such as Port Royal National Park, offer little protection for wildlife against poachers as the area is not fenced nor guarded. These locations look pristine, but appear to lack most of the native fauna that should accompany such habitats, based on our observations. Stripped land is available near many of the urban areas on the island, and is an effect of the developing tourist industry. Construction crews working in these locations have been observed by authors SAP and ABC to hunt iguanas. In one instance, a home construction crew eliminated all of the iguanas within a previously densely populated area in a matter of months. The shore habitat is also "avoided" based on the model parameters (Table 1.4), but from our camera trap data, we know that iguanas use the shore early in the morning for very short amounts of time (3–5 minutes) to warm up, and then do not return there for the rest of the day. The shore typically does not offer refuge from the sun or hunters, and the sand also remains hot all day.

It is interesting that the selected model, discussed above, demonstrates that iguanas prefer anthropogenic habitat, considering the usual perils there, such as increased hunting pressure or domestic dogs and cats. However, on Roatán iguanas are also afforded protection from hunting in many of the anthropogenic areas. Based on our model, we should find iguanas over a much wider area considering that the variables in the model account for over 15% of the island's area. However, less than 30 years after the description of this species (de Queiroz 1987) we find iguanas on less than 1% of the island.

Hunting pressure has been shown to alter the distribution of a species (e.g., Madsen 1998; Grignolio et al. 2011; Imong 2013). Humans have likely hunted *C. oedirhina* for subsistence since they colonized the island approximately four thousand years ago (Fitch et al. 1982). The increase in human population and the onset of tourism on the island, however, has put an accelerated strain on the iguana population. Both local residents and curious tourists consume the iguanas, and recently the threat of poaching for the illegal pet trade has become more serious (Pasachnik and Ariano 2010). With over one million people visiting the island each year (Doiron and Weissenberger 2014), the iguana population simply will not be able to withstand the pressure from these growing threats. Although forests (seasonally dry tropical forest and mangroves) cover most of the island, the increase in urban area is substantial and observable even over the two years of this study. Much of the island is still pristine forest, but hunting pressure has caused these areas to be nearly devoid of vertebrate life. High densities of iguanas occur only in sites where grassroots efforts prohibit hunting, even though the sites themselves are generally small, from 0.008 km^2 (0.8 hectares) to 0.25 km^2 (25 hectares), and quite disturbed. The iguanas are almost non-existent outside of these areas, even in comparable or better habitat.

It should be noted, however, that iguana density reflects habitat usage, but not necessarily individual health. Pasachnik (2013) showed that body condition index (BCI) is highest in the sites with the greatest anthropogenic influence, but an unhealthy diet of scavenged fatty human food could account for this (compare Smith and Iverson in press). Additional research is needed in order to better understand this facet, as well as whether or not stress is induced by daily interactions with humans (e.g., Knapp et al. 2013). This will then elucidate the health of these dense populations, and in turn the overall stability of this species.

Hunting pressure is an important factor determining habitat usage for many species (Imong et al. 2013; Stoner et al. 2013). While some aspects of the habitat (e.g., shore, rock, gravel) of *C. oedirhina* are selected for more than others, the decisive factor in determining whether or not iguanas occupy a site is the degree of protection it affords. This has important implications for conservation efforts. The management and grassroots protection of specific sites is currently very unstable. If the ownership or management of any one of the sites changes, one of these businesses closes, or a private resident moves, it could easily result in the local extirpation of this species. Instead of attempting to protect specific habitats, our results suggest that enforcing protection of the iguanas themselves should be most effective. To achieve this, however, a strong outreach and education campaign involving all stakeholders will be necessary. Many people living on the island are unaware or choose to ignore the endangered status of this species, and the fact that it is distinct from the sympatric Green Iguana (*Iguana iguana*) and other species of ctenosaurs that inhabit the mainland and neighboring islands.

We note that the consumption of iguana meat is of some cultural importance to the people of Roatán, and does provide an important protein source for some people. We thus suggest management approaches that ensure the persistence of this and other endemic species on the island alongside the preservation of cultural traditions and dietary demands. The development of a national conservation plan for this species with the cooperation and input of all stakeholders, including island residents and business owners, local authorities, non-governmental organizations (NGOs), governmental agencies, and scientists is the first step in increasing awareness and ensuring long-term commitments from all parties. Such a plan must consist of actions that guarantee the enforcement of the existing laws occurs, while modifying these laws to consider the needs of the local community. Enacting and enforcing a hunting season in a restricted area is one option. Another option is to work toward refocusing hunting efforts on similar but non-threatened species. Green Iguanas are native to the island but not Endangered. They are already being consumed to some degree, so farming them or purchasing them from mainland farms may be feasible. These actions should not be taken lightly and a strong education component must be incorporated. Accompanying these efforts, managers might also consider a captive breeding program for *C. oedirhina*, with the necessary habitat protection enforced by the government, including local law enforcement agencies. Our results clearly show the generalist nature of this species, thus a reintroduction program is very feasible as long as habitat protection can be assured and hunting can be regulated or prevented.

Table 1.1

Total available habitat for *Ctenosaura oedirhina* on the island of Roatán, Honduras.

Habitat	Area (km^2)	Percent of Total
Forest	99.08	77.65
Urban	18.29	14.33
Mangrove	8.90	6.98
Sandy Shore	0.48	0.38
Agriculture	0.46	0.36
Rocky Shore	0.21	0.16
Stripped	0.17	0.14

Table 1.2

Change in percentage of habitat area over time on Roatán, Honduras. The 2013 data are from Google Earth, the 1985 and 2001 data are from Aiello (2007), the 2014 data are from the Honduran government (Programa REDD/CCAD-GIZ 2014). It should be noted that the government map used differing definitions for some habitat types and thus direct comparison is not always appropriate (see methods for additional clarification).

Habitat	1985	2001	2013	2014
Urban	0.95%	13.87%	14.50%	6.84%
Forest	95.77%	85.47%	85.12%	85.17%
Sand	3.28%	0.66%	0.38%	7.99%

Table 1.3 Resource selection models describing the preferred habitat used by *Ctenosaura oedirhina* across Roatán, Honduras, and are in order of AIC score.

See Appendix 1 for variable details.

Model	Df	χ^2	AIC	ΔAIC
Global - all variables	25	533.7	3518.2	0
Shore, Unclean, Strip, Anthro, Rock, Veg, Undist, Conc, Gravel	9	524.1	3698.2	180.0
Shore, Unclean, Strip, Anthro, Rock, Veg, Undist	7	485.9	3743.9	45.7
Shore, Unclean, Strip, Anthro, Rock, Veg, Conc, Gravel, Clean, Cliff, Dirt	11	600.1	3768.8	24.9
Shore, Unclean, Strip, Anthro, Rock, Veg	6	540.7	3844.5	75.7
Rocky cliff, Rock, Sand, Shore, <50m water	5	395.0	4112.1	267.7
Anthropogenic, heavy dist	2	187.7	4284.8	172.6
Cleaned, low dist	2	7.41	4477.4	192.6
Null – intercept only	0	-	4480.7	3.3

Table 1.4 Resource Selection Function coefficient estimates.

Positive coefficients indicate a “preference” for those habitat variables on Roatán, Honduras by *Ctenosaura oedirhina*, while negative coefficients indicate “avoidance”.

Variable	Estimate
Shore	-0.227
Uncleaned Forest	-0.638
Stripped	-2.297
Anthropogenic	0.552
Rock Substrate	1.963
Vegetation Substrate	2.131
Undisturbed	-2.224
Concrete Substrate	0.808
Gravel Substrate	0.805

Table 1.5 Differences in used and available habitat by location and season, for *Ctenosaura oedirhina* across Roatán, Honduras. A significant *P* value indicates a preference for a specific habitat during that season, i.e., the iguanas were selecting for a habitat more so than the availability of that habitat would indicate. Only six of the nine locations contained iguanas, so only those results are listed.

Location/ Season	X-squared	*P* value	Predominant Used Habitat Type	Predominant Available Habitat Type
1/Spring	256.9	0.003	Anthropogenic	Anthropogenic
1/Fall	308.8	0.005	Anthropogenic/"Cleaned" forest	"Cleaned" forest
1/Winter	250.0	0.001	Anthropogenic/"Cleaned" forest	"Cleaned" forest
2/Spring	154.1	0.042	Anthropogenic	"Uncleaned" forest/Anthropogenic
2/Fall	265.9	0.002	"Cleaned" forest	"Cleaned" forest/"Uncleaned" forest
2/Winter	84.4	0.060	Anthropogenic	"Cleaned" forest/"Uncleaned" forest
3/Spring	229.7	0.005	Anthropogenic	Anthropogenic
3/Fall	296.3	0.001	"Cleaned" forest	"Cleaned" forest
3/Winter	129.6	0.075	Mangroves	"Cleaned" forest/Anthropogenic
4/Spring	105.3	0.007	Anthropogenic	Anthropogenic
4/Fall	137.1	0.001	Anthropogenic	"Cleaned" forest/Anthropogenic
5/Spring	225.0	0.036	Rock cliff	Mangroves/"Uncleaned" forest
5/Fall	312.1	0.026	Rock cliff	Mangroves/"Uncleaned" forest
5/Winter	379.4	0.112	Rock cliff	Mangroves/"Cleaned" forest
6/Spring	25.0	0.050	"Cleaned" forest	"Cleaned" forest
6/Fall	18.6	0.251	"Cleaned" forest	"Cleaned" forest

Table 1.6 *Ctenosaura oedirhina* densities at each study location across Roatán, Honduras. Densities were calculated using the program Distance (Thomas et al. 2010) and extrapolated to km^2. The densities shown are not the actual population size at any location, as none of the study locations were more than 0.2 km^2.

Location	Grassroots Protection Status	Sightings	Calculated Density (iguanas/km^2)	Site Area (km^2)
1	Protected	275	7504	0.115
2	Protected	72	2513	0.293
3	Protected	150	2688	0.100
4	Protected	19	2439	0.004
5	Protected	179	5288	0.096
6	Not Protected	2	1	0.670
7	Not Protected	1	1	0.130
8	Not Protected	0	0	0.100
9	Not Protected	0	0	5.320

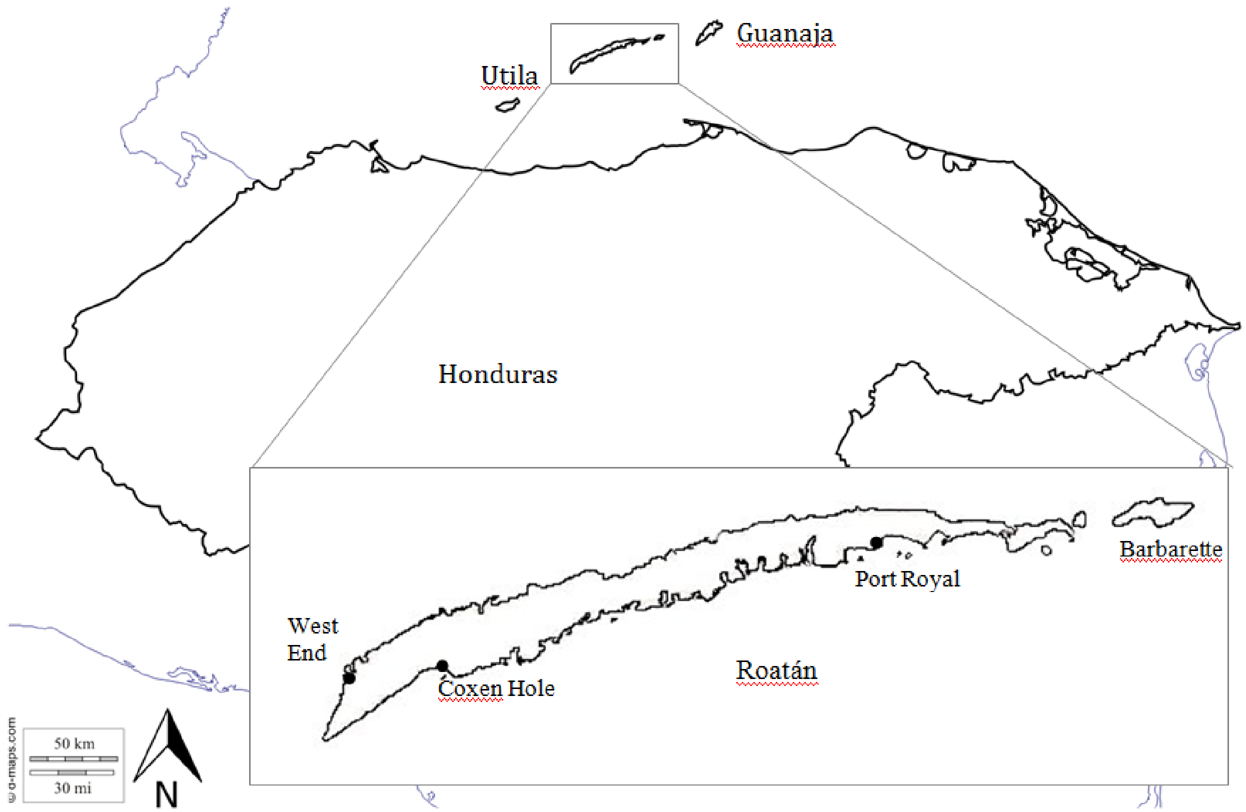

Figure 1.1 Map of Honduras and the Bay Islands, highlighting the study island, Roatán.

D-maps.com. 2014. Map of Honduras (boundaries). Available from http://d-maps.com/m/america/honduras/honduras04.gif [Accessed 25 August 2014]).

Figure 1.2 Representative examples of habitat types on Roatán.

(A) Shore; (B) “Cleaned” forest; (C) “Uncleaned” forest; (D) Mangroves; (E) Stripped land (strip); (F) Agricultural land; (G) Anthropogenic land (anthro); and (H) Rock cliff (cliff). See Appendix for more details. Photographs by Ashley Campbell.

2. DEMOGRAPHY OF THE ROATÁN SPINY-TAILED IGUANA (*CTENOSAURA OEDIRHINA*)

Introduction

Endemism is known to be more common on islands than on continents because of the geographic isolation, small area, and general lack of predators and/or competition. These characteristics can drive a colonizing population to differentiate in a relatively short time (Barton and Mallet 1996, Crawford and Stuessy 1997, Kier et al. 2009). Further, insular endemics are often at a higher risk of extinction given their limited range sizes, intrinsically small populations, and genetic homogeneity. Thus even seemingly innocuous or small stochastic perturbations could cause extirpation or extinction. Island species are known to be more susceptible than their mainland relatives to changes in habitat (via loss and fragmentation), natural catastrophes, disease outbreaks, invasive species, predation from introduced species, harvesting for consumption, stochastic environmental and demographic events, and anthropogenic forces (Groombridge 1992). Monitoring demographic parameters of these populations is an effective way to detect environmental impacts before the risk of extinction is high (Gilpin and Soulé 1986).

Such demographic studies of long-lived iguanas have shown important population trends over time. A 25-year mark-recapture study by Iverson et al. (2006) indicates that increased tourism negatively impacts iguana survival rates on two cays in the Exuma

Islands, as the population has increased over the study period, but not at the rate expected based on population growth rates of other, similar taxon (Iverson et al. 2006). Sporadic monitoring of the populations of *Iguana delicatissima* on islets off the coast of Martinique, French Virgin Islands, showed that release from hunting pressure and improved habitat allowed the populations to increase greater than three-fold in less than a decade. Similar studies of other populations of this species have shown that they have been extirpated because of competition and hybridization with *I. iguana*, predation from other introduced species, and hunting pressure (Knapp et al. 2014). Population studies like these can help identify specific threats and their impacts, and provide a basis by which such populations can be monitored over the long-term.

The Roatán Spiny-tailed Iguana (*Ctenosaura oedhirina*) (de Queiroz 1987) is a lizard endemic to the 146 km^2 island Roatán located ~50 km off the northern coast of Honduras. This species was acknowledged as threatened by the Honduran government in 1994 (Wilson and McCranie 2004), placed on the IUCN Red List in 2004 (Pasachnik et al. 2010), and on Appendix II of CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) by the Honduran government in 2010 (Pasachnik and Ariano 2010). They are threatened by habitat destruction and fragmentation due to human encroachment, over-harvesting, and potentially, hybridization with an invasive iguana brought from the mainland, *Ctenosaura similis* (SAP pers. comm.). Genetic analysis shows that the populations were once connected across the island, but are now isolated from one another (Pasachnik and Hudman in press) and geographic survey work shows they now occur on less than 1% of the island's area in high densities (Campbell et al. in press). Anthropogenic factors, such as hunting and habitat destruction, likely caused the pattern of isolation now observed. These iguanas are omnivorous (Pasachnik 2013) and habitat generalists, and their current distribution is limited mostly by mortality from hunting (Campbell et al. in press). There are currently ~5 isolated populations with high population densities and with very sparsely populated areas in between (Campbell et al. in press).

An estimate of population size is sometimes necessary to gain legislative protection for a species and is useful for monitoring the population over the long term. However, there has been no quantitative estimate of population size for this species to date. The IUCN determines listing status based on many factors – population decline, geographic range, population size, and probability of persistence in the wild (IUCN 2012). The population assessment that estimated 5,000 individuals was the basis for the Endangered listing of *C. oedirhina* by the IUCN (Pasachnik et al., 2010) was based on the best information available at the time, but is in need of updating given the data collected over the past five years.

In order to successfully monitor the species, baseline data are necessary. Without knowing the initial population, upward or downward trends cannot be detected. It would impossible to determine if future conservation efforts will positively impact the species and what the effect of certain threats may be. These data will be useful for population modeling, and policy and management changes, including updating the IUCN Red List assessment for this species. The objectives of this study were to: 1) obtain baseline population data to create a species recovery plan for monitoring the species, 2) estimate density, abundance, and mortality of each population, and 3) estimate total population size of *C. oedirhina* within the known range.

Methods

Study Location.—Roatán is a small island that is, at its maximum, 40 km long and 8 km wide (Figure 1.1). It has a mountainous spine reaching ~300 m in elevation and is predominantly covered in tropical dry forest. Most of the island's forest is undisturbed, but the urban area is expanding and now covers >14% of the island, which has increased from <1% in 1985 (Aiello 2007, Campbell et al. in press). *Ctenosaura oedirhina* are found in a few protected areas across the island. A "grassroots" movement of private landowners and park managers protects these areas from hunting and poaching. Outside of these locations the iguanas, and other native wildlife, are hunted for food (pers. obs., Pasachnik 2013et al. 2010a). Study sites are located within five grassroots protected areas that include resorts, tourist attractions, and ecoparks. These areas range from 0.8-30 hectares each and total ~0.6 km^2, less than 0.01% of the island's area. Initially, the majority of the island was assessed and the high-density areas were chosen as study sites. Iguana densities are too low (0-5 iguanas per km^2) outside of these areas for systematic sampling, though sporadic sampling of unprotected areas was done by car or boat, or surveyed on foot, and information was also gathered from informal interviews of residents. Since iguana population density appears dependent on protection from hunting, not habitat type, there can be one estimate for all hunted areas (Campbell et al. in press). This estimate was be added to both the MARK and Distance estimates to approximate the entire island population. The locations of our study sites are not identified by name due to the endangered status of the species, but can be obtained from the authors upon legitimate request.

Data Collection.—In order to estimate the population of this species, two types of surveys were conducted – mark-recapture/resight and distance sampling. Compared to traditional mark-recapture surveys, mark-resight surveys are intrinsically less stressful to study animals. When combined, mark-recapture and mark-resight surveys together can avoid variability in recapture probability. Some iguanas were also fitted with radio transmitters in order to track their movements, determine home range, and assist in estimating resightability.

From 2012-2015 sampling was conducted for both survey types on the same days. In these years, mark-recapture/resight sampling occurred along the distance sampling transects as well as other areas within the study sites. In previous years (2010-2011), distance sampling was not done, however mark-recapture was conducted over the entire area of the study sites.

For mark-recapture/resight work, isolated populations of *C. oedirhina* were sampled at least twice annually between 2010 and 2015 (Table 2.1). Iguanas were captured by hand or noose pole. They were then measured for snout-vent length (SVL) and tail length (TL) to the nearest millimeter with a measuring tape. Weight was measured to the nearest gram with a Pesola scale. Sex was determined by cloacal probing as well as an evaluation of external characteristics. Individuals were released at or near the point of capture. Hatchlings (individuals that were ≤30g) were toe clipped and their ID number marked on their side in non-toxic marker. Larger individuals (>30g) were marked with bead tags placed through the nuchal crest consisting of a unique combination of glass 3 mm and 6 mm beads (Rodda et al. 1988) and had a passive integrated transmitter (PIT) tag injected subcutaneously anterior to the left hind leg. Their

ID number was also painted on their side using non-toxic paint so that they would not be immediately recaptured. They were released after less than 15 minutes at or near the capture site. During each subsequent sampling period, new individuals were captured and previously tagged individuals were opportunistically recaptured and/or resighted (when recapture was not possible).

Distance sampling is a population surveying technique that does not require animals to be individually marked or handled frequently, thus keeping stress levels low. This technique uses a line to mark the center of an observable area, any iguana (tagged or not) seen while the researcher is walking the line is recorded and its perpendicular distance from the line measured. Distance sampling relies on the assumptions that individuals are perfectly detected along transect lines, that distances are measured correctly, and that the individuals do not move during the survey (Thomas et al. 2010). These assumptions may be impossible to meet for a more cryptic species, but yearling and older *C. oedirhina* are large enough to be readily detectable on the transect line. The other assumptions were met by using a laser rangefinder to measure the distances to the nearest meter and by designing a transect layout that can be surveyed relatively quickly, before the lizards move. Additionally many of the individuals are visually marked such that their identity can be recorded along the transect and repeated observation noted. Thirty-four transects, ~100 m (range = 90-160 m) long, were surveyed. The number of transects at each location varied, but was based on the area of the location and the habitats within, such that the maximum area was covered without transects overlapping (Table 2.2).

Twenty-one of the captured adult iguanas (SVL range = 107-281 mm, SVL average = 206.8 mm, weight range = 205-890 g, average weight = 410.1 g) were fitted with radio transmitters in 2011 (N=12), 2013 (N=4), and 2014 (N=5). Transmitters were small (1.8 g, 17mm x 8.5mm x 5.5mm) and acrylic coated with an external whip antenna (BD-2 transmitters, Holohil Systems Ltd., Ontario, Canada). They had a battery life of 10-20 weeks on average. Transmitters were glued anterior to the hind leg on the left flank using 5200 Marine Adhesive (3M, St. Paul, Minnesota). This placement was chosen so as not to interfere with the iguana's ability to fit into crevices and burrows. Individuals were tracked via hand held Yagi antenna at least once a week until the transmitter fell off (N=12) or the batteries failed (N=9).

Data Analysis.—Mark-recapture/resight data was analyzed using Program MARK (White and Burnham 1999, Cooch and White 2006). In Program MARK, mark-resight models can account for imperfect detection, as well as use data from unmarked individuals to estimate population variables (McClintock and White 2009, McClintock et al. 2009). Only data from adults was used in the analysis because hatchling toe clip markings are difficult to resight consistently in the field and external marks wear off quickly as this age class sheds often. In total, data from 778 individuals were analyzed as five separate populations because genetic analysis indicated these populations are mostly isolated from each other (see Pasachnik and Hudman in press), tracking data indicated that individuals do not travel far, and because resampling periods were not consistent across populations (Table 2.3). A robust design mark-resight model was used because it estimates apparent survival (φ) and abundance (N), among other parameters. Robust design models assume a closed population within sampling periods and open populations between them allowing for estimation of abundance from the "closed" population and survival from the "open" population (McClintock and White 2009, McClintock et al. 2009). In our study, sampling periods took place within a small enough time frame that this was considered acceptable. Even though iguanas were given unique, individual tags, a Poisson log-normal estimator was used because the exact number of marked individuals available within the study sites for resighting during each period was unknown and sampling was always with replacement. The individual marks reduce the possibility of resighting the same individual multiple times during a single survey. The logit link was used to account for small sample size in some of the populations. Akaike's Information Criteria for small sample sizes (AICc) was used to determine the best model after fitting the global model and multiple other models, including models with constant or reduced parameters (Anderson et al. 1998). Specifically, a model with time dependent variables mean resighting rate (α; a rate derived from the number of times marked and unmarked individuals are resighted during a closed interval), individual heterogeneity level (σ; any differences between individuals in behavior or other aspects that would cause variability in their survival or resightability), number of unmarked individuals (U), and apparent survival (φ) = probability of transitioning from an observable state to an unobservable state (γ"; when an animal moves from inside the study site to outside of the study area) = probability of remaining at an unobservable state to an observable (γ'; when an animal moves from outside the study area to within the study area) was created for all populations. The φ = γ" = γ' parameter was used to limit the number of parameters that needed to be estimated and therefore allow for the estimation of α. The top ranked models for each population were averaged for more robust parameter estimates. Since we assume no emigration/immigration, the model estimated apparent survival (φ) equals actual survival. Total population in the survey area was estimated by summing the estimated N for all populations.

The program Distance was used to analyze the distance sampling data (Thomas et al. 2010). This program estimates population density based on the probability of detecting an individual as a function of its distance from the center line of the transect. A modified, two-observer transect method with conventional distance sampling was used because detection of iguanas along the transect line was assumed to be perfect (Buckland et al. 2001, Thomas et al. 2010). Since this was a direct survey of individual iguanas, no multiplier for indirect observations was needed in the calculations. Due to small sample sizes during the spring and winter seasons, only data from the fall (2012, 2013, 2014, 2015) were used to determine density at the study sites. Total population was then estimated by multiplying the estimated density by the area of each location.

Home range was estimated from the radio telemetry points using Google Earth. For individuals with $N \geq 3$ points, a minimum convex polygon area was calculated (Rose 1982). Visual inspection of the data points indicated whether individuals consistently used the same refuge(s) and if they went outside of the protected area boundaries.

Results

Of the 778 individuals captured in the study, 134 individuals were recaptured and 217 were resighted. Based on all captured individuals, the sex ratio of males to females was 1:1.08 for all individuals captured (Table 2.5). The number of recaptures/resightings declined the longer they had been marked, i.e. an iguana marked one year ago was more likely to be seen than one marked three years ago (Table 2.4). Of the recaptured individuals, 35.8% had lost their bead tag and 4.5% had lost their PIT tag (or had the tag fail). Tag failure rate over time was determined by grouping recaptures/resightings by number of years since tagging and dividing by the total number of individuals in the cohort. Bead and PIT tag loss was not different between males and females. The mark-resight analysis was not able to reliably estimate population parameters because survival between primary sampling occasions (φ), individual heterogeneity level (σ), and transition probabilities (γ", γ') could not be reliably calculated, and resight rate was generally low (λ, 0.1-0.25, Table 2.7).

The distance sampling analysis estimated the density in 2015 to be between 3,667 and 13,523 iguanas per km^2 at the study locations (Table 2.3). Encounter rates fell between 63.4 and 97.4 depending on the year and location (Table 2.3). When multiplied by the area of each location, the current (2015) total surveyed population was estimated at 4,130 and the total island population (the total surveyed population plus the amount estimated in the unprotected areas) was estimated at 4,130-4,860 individuals (Table 2.6). Based on these estimates, the population appears to have decreased 36% over the past three years (2012-2014), but recently rebounded 22% from 2014. Thus, the current population estimate has not recovered to the size estimated during the 2012 season.

Iguanas with radio transmitters were located between 3 and 28 times each (average = 12.2) over an average of 8 weeks (range = 2-24 weeks). In general, iguanas did not move far from where they were captured and released and their home ranges included a main refuge that the iguana used regularly and preferentially compared to other nearby refuges. Male home ranges were 3.7 times larger on average than female home ranges (male average = 10,117 m^2, female average = 2,833 m^2) and did not relate to SVL. Tracking efforts showed that at least four of the tagged iguanas near the boundary of the protected areas sometimes roamed outside of the site and into areas where hunting is known to occur. One female iguana with a range primarily outside of a protected area had moved 0.42 km over the course of the 15 weeks it was tracked. Twenty-four hour tracking of three individuals in 2014 showed that iguanas were only active during daylight hours, generally from 0700 to 1500 and stayed in their refuge during the night.

Discussion

Narrow-range endemic species have intrinsically small populations, making them more susceptible to extirpation or extinction by stochastic events and anthropogenic factors such as habitat loss and hunting pressure (Groombridge 1992, Imong 2013, Campbell et al. in press). When such taxa are fragmented into smaller, denser, genetically homogenous populations the risks only increase. The range of *Ctenosaura oedirhina* has been fragmented into several small areas because of hunting pressure, thus occurring in high densities on less than 1% of Roatán, Honduras. This hunting pressure severely limits emigration/immigration between populations (Campbell et al. in press). Genetic analysis shows low heterozygosity in these populations, indicating isolation for a substantial amount of time (Pasachnik and Hudman in press). These two factors combined with the observed high population densities at the protected sites and the low resight and recapture rate for tagged individuals shows a picture of a species at significant risk of extinction.

Wildlife studies often use multiple survey methods in order to develop robust population estimates (Hayes et al. 2004, Harlow and Biciloa 2001). Studies of three subspecies of *Cyclura rileyi* involved multiple locations and survey methods, including mark-recapture and behavior ecology studies, over eight years and provided an array of data that one type of survey alone would not have been able to produce. The results were useful in identifying threats and endangered status of the subspecies, and making recommendations for future management of the populations (Hayes et al. 2004). A study of Fijian crested iguanas (*Brachylophus vitiensis*) used line transect and vegetation surveys to assess the population and monitor the effects of management methods, enabling researchers to identify differences between two populations and make recommendations for future management of the species (Harlow and Biciloa 2001). We attempted to use two different population estimation techniques to determine the total number of *C. oedirhina* on the island of Roatán – distance sampling and mark-resight/recapture. These techniques estimate different population parameters, but both can give dependable estimations of population size. While many animals were captured and tagged, few were resampled (resighted/recaptured). This does not significantly affect the distance sampling outcome, but the mark-recapture analysis relies heavily on a large resampling size.

Low resight rates can result from high tag failure rates, cryptic organisms, or high mortality. In this case, we can estimate tag failure rate based on recapture data and we know that these iguanas, in general, are easily observable both along the line transects and elsewhere in the environment. However, the tag failure rate alone cannot account for such a low resight rate, especially when many iguanas can be observed within the study areas. The percent of iguanas tagged and then resighted within the same year is approximately 60%, this is when bead and PIT tag failure rates are negligible (~6% within one year of initial tagging). By using resight data as well as recapture data, recapture bias is eliminated. Observations occurred during times when iguanas would be the most active and spanned different times of the year so as to increase the chances of seeing marked individuals. The home range calculated in this study is similar to the estimate for this species based on their size in Perry and Garland, Jr.'s (2002) study of the relationship of lizard home range size to SVL. Some individuals were resighted on a regular basis and the radio tracking data shows that these iguanas tend to stay in a relatively small area. Therefore, I conclude high mortality to be the likely cause of the lack of resightings.

While hunting within the study sites is prohibited, hunting is known to occur on occasion within some of these areas (pers. comm. local research site staff). In addition, hunting immediately outside of the site boundaries is known to occur on a regular basis; daily in some cases (pers. obs. ABC). Based on observations of radio-tagged individuals, we know that individuals captured within protected areas occasionally go outside of the area's boundaries. Once outside of the protected area, iguana densities decline dramatically. We believe the lack of resight data is directly related to the mobility of the iguanas, the small size of the protected areas (0.8-30 hectares), and the hunting pressure they encounter outside of the protected areas.

The sex ratio from all captured individuals indicates a skew toward more females, but is similar to other iguana species with healthy breeding populations (Fitch and Henderson 1977, Munoz et al. 2003). It has also decreased from an earlier estimate (Pasachnik 2013), possibly indicating a decrease in the number of females in the population. The seasonality of the surveys affected the calculated sex ratio because many of the survey dates occurred in the spring concurrent with breeding and nesting of this species (Pasachnik 2012). During this time, it was noted that females were not seen as often, probably due to decreased activity because of egg production and nesting.

Female biased hunting is common in other species because the eggs (*in utero*) are considered a delicacy. For example, *C. bakeri* on the island of Útila has a sex ratio of 1:0.6 males to females as a result of female-biased hunting (Pasachnik et al. 2012a). *C. melanosterna* populations on the mainland of Honduras have a sex ratio of 1:0.5 males to females and are also impacted by female biased hunting (Pasachnik et al. 2012b). It is likely that this bias does not occur on a large scale in *C. oedirhina* for a couple reasons. While there is some amount of sexual dimorphism in SVL and TL between males and females (males having a longer SVL and TL on average, Pasachnik 2013), there is a large overlap in the sizes. With no other obvious differences (such as coloration or a dewlap that can be observed in the previously mentioned congeners), it is very difficult to distinguish males from females without having them in hand to probe for gender or observe femoral pore development. In addition, since finding an iguana outside of the protected areas is somewhat uncommon, most hunters will attempt to capture it regardless of the perceived sex of the iguana (Campbell and Pasachnik, pers. obs.). It is fortunate that female-biased hunting does not occur consistently with *C. oedirhina* as an additional decrease in genetic diversity and in reproductive output for this species could be disastrous for the population at this point.

Density estimates have generally declined since the beginning of the study (Table 2.3). This is unlikely to be a result of sampling effort, as all locations except Location 1 have been declining over time while sampling effort has varied between years and between sites. Location 1's density has decreased and then recovered during the course of the study. At this location, while protected from outside incursions, a hired construction crew eliminated all of the iguanas within the vicinity of the construction project during 2013 (Campbell and Pasachnik pers obs.). The population in this location and the ones in Locations 2 and 3, while all declining from 2012 estimate, did rebound slightly in 2015. This may be due to normal fluctuations or be because of more consistent protection recently in those areas. Encounter rate remained consistent across years for all other locations, except for Location 4 in 2014 and 2015. During this time there was a change in management and thus accessibility was limited to days in which the park was opened to the public when there can be 3,000-9,000 guests on site. At Location 4, the habitats used by the iguanas are also heavily used by pedestrian and ATV traffic when the park is open to tourists, decreasing the likelihood that iguanas will be available for resight/recapture.

Hunting pressure not only impacts population numbers, but also directly influences the distribution of this species (Campbell et al. in press, Pasachnik and Hundman in press). The species shows low genetic diversity within isolated subpopulations and the subpopulations which have differentiated from each other. This indicates that the populations were once connected, but have since lost their connectivity (Pasachnik and Hudman in press). They inhabit already degraded habitat in higher densities than nearby undisturbed habitat (Campbell et al. in press). Supporting this is the lack of recaptures/resightings and decreasing density at the sites over the course of the study even though there are plenty of opportunities to observe individuals and the areas are not changing in size. The high densities could also affect the population's health, increasing the risk of disease. However, more data will be needed to assess this issue and such studies are currently underway.

The current population trend is not sustainable, particularly with an ever growing human population. Without significant changes to the management and protection of this species, the threat of extirpation and extinction must be considered. Recommendations for stabilization and growth of this population revolve around enforcing laws protecting this species and managing the current protected area to prevent hunting incursions. Reducing the hunting pressure on this species, and creating corridors between populations, could potentially increase reproductive output and increase genetic diversity at those sites.

Table 2.1 *Ctenosaura oedirhina* survey days by study location on Roatán, Honduras. Surveys at Location 4 did not begin until 2011. Mark-recapture/resight suveys began in 2010 and distance sampling began in 2012.

Location	2010	2011	2012	2013	2014	2015
1	6	9	10	3	6	8
2	9	35	14	13	11	10
3	4	3	4	5	7	9
4	.	14	11	3	4	6
5	5	24	10	10	7	9
Total	24	85	49	34	35	42

Table 2.2 *C. oedirhina* Distance Sampling Transects at Each Study Location on Roatán, Honduras.

Locations varied in size and habitat, so the number of transects varied by location. Transects were designed to cover the most area without overlapping with one another.

Site	# of Transects	Area Covered (m^2)
1	7	25,530
2	8	23,415
3	3	2,270
4	6	14,576
5	10	18,898
Total	34	84,689

Table 2.3 Density Estimates per km^2 of *C. oedirhina* on Roatán, Honduras.

The density and encounter rate (ER) estimated for each population. Location 3 was not surveyed in 2012. While Location 3 was surveyed in Fall 2013, there were not enough sightings to reliably estimate density. Also, in Fall 2015, there were not enough sightings at Locaion 3 to reliably estimate ER.

Loc	Fall 2012				Fall 2013				Fall 2014				Fall 2015			
	Estimate	ER	95% CI		Estimate	ER	95% CI		Estimate	ER	95% CI		Estimate	ER	95% CI	
1	4027.1	96.7	778.14	20842	2305.8	97.4	303.14	17539	6458.9	96.5	1641.4	25416	9025.9	87.6	1960.3	41559
2	11262	87.3	6852.4	18509	9237	95.6	5660.8	15073	8596.1	96.2	3310.4	22321	13523	96	6709.4	27255
3					*	*	*		3159.2	85.2	744.94	13398	10104	63.4	4365.7	23384
4	11456	94.9	2806.4	46765	11832	93.9	3023.8	46297	4021	74.5	103.92	155580	3667	*	1657.4	8113.2
5	9392.4	93.4	4914.1	17952	7452.8	86	4038.8	13753	5658.1	91.6	2330.7	13736	5588.9	73.8	2633.5	11860

Table 2.4 Recaptures/Resightings of *C*. *oedirhina* on Roatán, Honduras Over Time. The number of recaptures or resightings declines with increased time since initial tagging. Table shows the number of recaptures/resightings occurring after a number of years. Total available iguanas are individuals that have been tagged for ≤1 year, >1 year, >2 years, and >3 years. The maximum life span of *C*. *oedirhina* is estimated to be 15 years (Rittman 2007). Percent rows indicate the percentage of iguanas tagged for that time span that have been recaptured or resighted.

	≤1 yr	>1 yr	>2 yrs	>3 yrs	>4 years	>5 years
Total Available	99	106	645	511	473	138
Recaptures	61	23	30	8	10	2
Resightings	72	52	38	16	23	16

Table 2.5 Sex ratios of *C*. *oedirhina* on Roatán, Honduras for 2010-2015.

Year	m:f
2010	1:1.75
2011	1:1.49
2012	1:0.72
2013	1:0.35
2014	1:1.11
2015	1:1.08

Table 2.6 Population Estimates for *C. oedirhina* on the island of Roatán, Honduras.

Density was derived from distance sampling analysis. Population was extrapolated from density estimate and area of each study site.

Population totals are rounded to the nearest whole number. Total island population is the total site population calculated from distance sampling plus 0 - 5 iguanas km^2.

Location	Area	Fall 2012		Fall 2013		Fall 2014		Fall 2015	
	(km^2)	Density	Population	Density	Population	Density	Population	Density	Population
1	0.1	4027.1	402.71	2305.8	230.58	6458.9	645.89	9025.9	902.59
2	0.11	11262	1238.82	9237.9	1016.169	8596.1	945.571	13523	1487.53
3	0.008	.	.	.	.	3159.2	25.2736	10104	80.832
4	0.3	11456	3436.8	11832	3549.6	4021	1206.3	3667	1100.1
5	0.1	9392.4	939.24	7452.8	745.28	5658.1	565.81	5588.8	558.88
Total (Sites)	0.618		6018		5542		3389		4130
Total (Island)	146		6018-6748		5542-6272		3389-4119		4130-4860

Table 2.7 Resighting rates of *C. oedirhina* at study locations on the island of Roatán, Honduras.

Location 5 lambda hat could not be estimated due to small resampling size.

Location	Lambda	SE	Upper CI	Lower CI
1	0.1091771	0.273129	0.673606	0.1769531
2	0.1311668	0.0145846	0.1055521	0.162997
3	0.2139033	0.074278	0.1104089	0.4144106
4	0.1235156	0.0523303	0.0557008	0.2738938
5	.	.	.	.

3. POPULATION VIABILITY ANALYSIS OF THE ROATÁN SPINY-TAILED IGUANA (*CTENOSAURA OEDIRHINA*)

Introduction

Traditionally, intensive, long-term (10-20 year) mark-recapture studies or indirect population estimation techniques (transect surveys, demographic ratios, captures per unit time, etc) were necessary to create a reliable estimate of population stability (Seigel and Sheil 1999). Now population viability analysis (PVA) can be used as a conservation tool that takes life table analysis farther and can incorporate all of the available data on a species into a model that estimates population persistence and potential causes for decline (Boyce 1992, Lacy et al. 2009). This method does not rely on long-term or indirect studies, but incorporates advanced modeling techniques to calculate estimates from a variety of input data (Lacy et al. 2009).

PVAs can be a useful tool in identifying threats to a species and can help estimate the effects of these threats so that effective conservation strategies can be implemented. A population of tuataras (*Sphenodon punctatus*) found on North Brother Island off the coast of New Zealand has a male-biased sex ratio and reduced female fitness. A population viability analysis of this vulnerable population showed that there is a low threat of extinction, but that some assistance may be necessary to mitigate the effects of climate change in the more isolated populations. Even though there is a significant sex bias, this doesn't appear to affect the population over the long-term as expected (Grayson et al. 2014). Without a PVA, conservation efforts may have focused on the wrong threat, and the more likely issue may have been missed.

Regional and landscape level management strategies can be evaluated using species-specific PVAs. Multiple landscape management plans affect Natterjack Toads (*Bufo calamita*), whose range crosses multiple countries in Europe. A PVA showed that the increase in transportation infrasructure (roads) is detrimental to the carrying capacity in that region and that roadkill mortality affects population dynamics. Previous multispecies analysis did not indicate this particular management issue (Franz et al. 2013).

PVAs can help determine thresholds, or the amount of pressure from a certain source that a species can endure before populations start to decline. The White-lipped Peccary (*Tayassu pecari*) is facing crippling hunting pressure in Costa Rica and extirpation from a majority of its historic range across the neotropic. Recently the population within a protected National Park has experienced immense hunting pressure from miners working in the park illegally. A PVA was used to determine the threshold of hunting that the species could withstand. It was shown that if at least a 50% reduction in the number of miners does not occur, the species is likely to be completely extirpated from the park within 5-10 years (Rivera 2014).

PVA models, like any other model, are only as good as the data put into them. Short-term studies will not show long-term trends when working with long-lived species or in highly variable habitats. PVA programs, such as VORTEX, mitigate this by including sensitivity analyses into the framework. This additional analysis is used to identify which variables influence the model the most, not only indicating which data need to be the most robust and in which direction future studies should go, but also which threats are the most influential.

When looking at a species facing complex threats, it is necessary to determine which threats are most serious and how quickly those threats will impact the population. It is especially critical when, as in most conservation cases, resources are limited and the target population is already in a vulnerable state.small. *Ctenosaura oedirhina* is a narrow-range endemic lizard found only on the island of Roatán, ~50 km off of the northern coast of Honduras. These iguanas are listed as Endangered by the International Union for the Conservation of Nature (IUCN; Pasachnik et al. 2010), as threatened by the Honduran government, and listed on Appendix II of the Convention on International Trade of Endangered Species (CITES; Pasachnik and Ariano 2010). This species was historically likely found across the entire 146 km^2 island and smaller, adjacent islets, but is now limited to a few small, isolated populations that together cover only 0.6 km^2, less than 0.1% of its historic range. The force driving this distribution is the intense hunting pressure from the island's human residents. Through habitat loss and fragmentation by the building of roads, poachers can access once protected areas throughout the island threatening the island's native terrestrial wildlife (Campbell et al. in press).

The endemic nature of this species along with its isolated populations, their decline over just a short period of time (3 years) as shown by distance sampling (Table 2.6), and the continued hunting pressure caused by an ever increasing human population is a combination that could easily send this species to extinction. In order to estimate the probability of extinction and to determine factors that could potentially exacerbate this condition a population viability model (PVA) was used along with demographic and genetic data gathered during previous and concurrent studies.

The objectives of this study were to 1.) model the population of *C. oedirhina* on Roatán and determine the likelihood of its persistence over the short- and long-term (10 years and 50 years), 2.) determine the most imminent threats to the population based on sensitivity analysis of the current population, 3.) use the data to provide conservation and management recommendations for this species.

Methods

The population viability analysis was performed in VORTEX Version 10.0 (Lacy and Pollack 2014). VORTEX models population data based on sequential events using Monte Carlo simulations and estimations of environmental stochasticity. This software allows input of species natural history, genetics, and demography and calculates a suite of variables including time to extinction, probability of extinction, and population growth rates (Lacy 1993, 2000).

Data from multiple studies were used to make the analysis as robust and comprehensive as possible. If data on the target species (*C. oedirhina*) were not available, data from a related or similar species was used. Two base scenarios were initially created: a single population model and a metapopulation model. The models use data derived from all previous studies mentioned above (Table 3.2, 3.3) and are considered a snapshot of the current population as a functional metapopulation and as a single population at a high and low population estimate. A metapopulation model was used to model the nearly isolated populations and five subpopulations were created based on study sites and the results of genetic analyses. In this model, dispersal input was based on genetic analyses that show little to no dispersal between most populations (Pasachnik and Hudman in press). The results of the two different models were compared.

All scenarios were tested for sensitivity to adult mortality rate, hatchling mortality rate, and carrying capacity. The sensitivity testing was intended to indicate the effects of increased/decreased hunting pressure on adults, increased predation of hatchlings by feral cats and dogs, and climate change. Changes in population age structure were also assessed by using the actual structure (from previous studies) and a Vortex calculated "stable age distribution" estimated from total population.

All scenarios were run for 100 iterations of a 50 year period. A time frame of 50 years was chosen for the model because Beissinger and Westphal (1998) advised that shorter time frames should be modeled in order to reduce problems associated with low quality data. Though we feel much of the supporting data is robust the reproductive data is not from a wild population, and the ever increasing threat of over harvesting is likely to impact the population quickly, thus we felt this shorter time frame was more appropriate than what has been used in other wildlife studies (100 years is more common; Seigel and Shiel 1999, Famelli et al. 2012, Lacy et al. 2015). The extinction criterion was defined as the loss of all members of one sex. The order of events was not altered from the original Vortex settings (See Lacy et al. 2015).

All scenarios were tested with and without inbreeding depression using the suggested 6.29 lethal equivalents as reported by O'Grady et al. (2006). As the number of lethal equivalents necessary to cause inbreeding depression has not been assessed in most wild populations, a meta-analysis of 30 species was used to estimate average lethal equivalents to be used in other simulations, such as PVAs (O'Grady et al. 2006). No unique state variables were used in any model. In the metapopulation model, dispersal was set to occur for all ages and both sexes. However, dispersal probabilities above zero were only set between populations where genetic analysis indicated some movement between populations occurs. Percent survival of dispersers was varied between 10-90%.

Demographic data were collected from isolated populations of *C. oedirhina* on the island of Roatán and surrounding islets from October 2010 – November 2011 and during eight trips between August 2012 and August 2015. Iguanas were captured by hand or noose pole and data on weight, length (snout-vent length and tail length), sex, and reproductive status were recorded. Individuals were uniquely identified with bead and PIT tags and released at the point of capture within 15 minutes. Additional demographic and reproductive data was obtained from Pasachnik (2013) and personal communication with private breeders of this species. Genetic data from Pasachnik and Hudman (in press) was used to model genetic structure. Reproductive data was also obtained from studies of *C. bakeri*, a closely related, endemic species found on Utila, the island east of Roatán (Gutsche 2006). Allee effect was not used in the models due to the small size of the island.

Population size, structure, and juvenile/adult mortality was estimated from mark-resight-recapture data from 778 individuals (See Chapter 2) using Program Mark via a robust design mark-recapture model (White and Burnham 1999, Cooch and White 2006). Mortality rate could also not be estimated by Program Mark reliably because of low resighting rate (a resighting rate of >0.25 is necessary to calculate mortality). The mortality estimate used in this PVA was estimated by Program Mark, but is likely an overestimation as it has a large 95% confidence interval (0.60-0.97) and does not account for tag failure. This variable was sensitivity tested since it is based on a potentially inflated estimate. Mortality estimates from Program Mark are confounded with harvest rate, and as such a separate "harvest rate" variable was not added to the PVA model. It is illegal to hunt this species and official data concerning harvest rates is not available. Informal surveys of residents show that poaching is widespread, customary, and socially accepted.

It appears that harvesting affects both sexes similarly, as the average sex ratio was 1 m: 1.08 f during the study period. However, the ratio of females declined from 2010 to 2015, potentially indicating a preference for females, although this bias in the data could have also been caused by the seasonality of the sampling. In other species, females are selectively hunted for because of their eggs (Pasachnik et al. 2012a,b) and this may be occurring at a low rate in this species, but is unlikely a widespread occurrence. Hatchling mortality is not known as captive data is unreliable in this aspect and there is no wild data for this species. Estimates of hatchling mortality were calculated from a formula developed by Pike et al. (2008) that determines the survival rate of hatchlings needed to maintain a stable adult population size. The sensitivity testing for this variable included a range of values from other iguana species for which hatchling mortality has been estimated (*C. pectinata* (Aquirre-Hidalgo 2008), *Cyclura cyclura cyclura* (Knapp et al. 2010), *Cyclura cornuta stejnegeri* (Perez-Buitrago and Sabat 2007)). These species were selected because they face similar threats of population isolation and decline.

The total population was estimated using distance sampling data collected between 2012-2015. Distance sampling uses a line transect to mark the center of the observable area, individuals iguanas are then located along the centerline and their distance along and perpendicular from the centerline is noted. Density estimator software Distance (Thomas et al. 2006) was used to calculate the density of iguanas at each study site (See Chapter 2). The total population was then calculated based on the area of each site and its density, an additional 1-5 iguanas/km^2 was then added to the total estimated population at the study sites to estimate the population across the entire island. The density of iguanas on the rest of the island, outside of the study sites, was calculated based on sporadic sampling of unprotected areas that was conducted by car or boat, or surveyed on foot, and information was also gathered from informal interviews of residents. Carrying capacity (K) was estimated from the highest density study location and extrapolated out to the area of the island (Table 3.1) as previous surveys indicated that iguanas are habitat generalists and show no preference for habitat type.

Natural catastrophes were modeled in two ways – changes in hurricane regime and loss of habitat due to rising sea level. Hurricanes, while common in the Gulf of Mexico, rarely make landfall as far south as Honduras, generally occur only once every ten years (Ensor and Ensor 2009), and are usually weak (Batke et al. 2014). Global climate change is predicted to alter the timing and intensity of hurricanes in the Gulf of Mexico by decreasing their frequency but increasing their intensity (Biasutti et al. 2012). No formal studies have been done on the effects of hurricanes on this species, but other insular endemic iguana species, such as *Ctenosaura melanosterna* and *Cyclura rileyi*, are considered very susceptible to local extirpation due to hurricanes (Pasachnik et al. 2012, Hayes et al. 2004). Observations made on Roatán after a strong storm in 2013 indicated that there was a decrease or total loss of iguanas in the area where the shoreline experienced storm effects (high winds, storm surge, rough tides). The high-density populations of *C. oedirhina* are all found along the shoreline of Roatán. Some of these locations have rocky cliffs that face the ocean where many individuals bask and take refuge in rock crevices (Campbell et al. in press), so a strong hurricane with a large storm surge could catastrophically impact this species. This was modeled in Vortex by a 50% mortality event every 15-20 years, given the known hurricane cycle (Batke et at. 2014).

Climate change was also modeled by reducing carrying capacity based on shoreline lost to rising sea levels. As *C. oedirhina* is omnivorous and a habitat generalist (Pasachnik 2013, Campbell et al. in press), changes in habitat structure due to climate change are less likely to affect their populations than the total loss of habitat area and potential nesting locations along the sandy shoreline around the island caused by sea level rise. This was modeled by a decrease in carrying capacity (K) due to loss of habitat.

Results

The *C. oedirhina* population on Roatán was modeled as one single population across the entire island and as a metapopulation (Table 3.4; Campbell et al. in press, Pasachnik and Hudman in press). After comparing the two types of models, the metapopulation model was used for all subsequent analyses because there was little difference between the metapopulation model (time to extinction (TE) = 7.1 years) and the one population model (TE = 5.8 years), and because the ecology of the species indicates that it functions most like a metapopulation. Changes in carrying capacity (based on loss of island area due to rising sea levels), age distribution (from the actual age distribution based on mark-recapture data to a "stable age distribution" calculated by Vortex), inbreeding depression/genetic structure (including genetic structure in the model versus modeling the population with no genetic structure), and limiting dispersal between nearby subpopulations (based on known genetics) had little effect on time to extinction (varied from 6.8-7.1 years). Changing the age of first reproduction in females from 4 years of age to 2 (input must be an integer) and 6, did not significantly change the outcome, and only pushed TE to 7.8 years and 6.7 years respectively. Changes in hatchling survival rates alone changed the TE from 5.5 years to 7.5 years, and even at 90% hatchling survival, all iterations went extinct within 50 years (average 7.5 years).

Changes in adult mortality had significant effects, a change of 90% mortality to 50% mortality increased TE from 5.7 years to 19.9, and a decrease to 10% mortality made TE >50 years. The metapopulation begins to go extinct within 50 years when adult mortality was 25-30%. At 20% adult mortality, the metapopulation begins to taper off at 50 years, and at 30% adult mortality it crashes at 47.9 years on average. When male mortality was kept at the current estimate of 80% and female mortality decreased to 30%, the average TE increased to 13.4 years. When the situation was reversed, with only males with decreased mortality, the TE remained low at 7.5 years.

Discussion

A PVA may be the only way to "experiment" on a vulnerable or small population without inflicting additional pressure on it. Even when using the best available data, the output of a PVA is still a probability estimate and so should not be treated as an absolute. This output should be used to make management decisions and choose a direction for further research or monitoring (Grayson et al. 2014, Riviera 2014).

Sensitivity testing was used to identify the most important variables controlling changes in population size. In some species, this has been a useful way to direct management. In *Hydromedusa maxmiliani*, PVA sensitivity analysis indicated that reduction in deforestation could decrease extinction probability and that demographic stochasticity may play an important role in population viability. While some populations of this species are found in protected areas, the model shows that even those populations are at risk with even a 10% change in mortality (Famelli et al. 2012). In *C. oedirhina*, sensitivity tests identified that adult mortality is the main factor influencing population viability. Specifically female mortality most influences the model, making it even more fortuitous that female biased hunting likely does not occur on a large scale with this species. Hunting of adults of both sexes (more so females than males) most influences the population dynamic more than other known threats, including hatchling predation, loss of habitat due to human encroachment or climate change, and genetic isolation of the populations. If female biased hunting does begin to occur regularly and on a large scale, it could eliminate this species faster than any of the other threats currently facing it. Aside from the obvious changes in population structure, female-biased hunting can cause changes in size classes and genetics, which can also negatively impact the species and exacerbate threats already impacting them (Pasachnik et al 2012, Faria et al. 2010).

Hunting of this species occurs regularly across the island including along the borders and within some of the grassroots protected areas where the majority of the demographic data were collected. Even remote pieces of the island only accessible by boat are now devoid of iguanas, presumably due to hunting. In the PVA, reduction in mortality increased the time until extinction. In other PVAs, the exact causes of mortality could be isolated, such as deforestation and illegal poaching, and recommendations for management and reduction of those threats can be made (Rivera 2014, Famelli et al. 2012) where as in this case it is impossible to separate mortality from hunting from natural mortality.

The inclusion of genetic information via a population based model option or with input of allele frequencies did not affect the model to a large degree (change in TE between models = 0.7 years). The lack of effects from genetic structure is probably due to the time frame of the model. The populations are already have low genetic diversity (Pasachnik and Hudman in press), and since the model populations crashed in a relatively short time, the long term effects of this and the compounding effects of the additional loss of genetic diversity likely cannot be seen. Over the long term, the effects of reduced genetic diversity in the populations could impact the population by decreasing fitness, fecundity, and causing increased susceptibility to disease (Reed and Frankham 2003).

Even though this species has relatively small clutch sizes (5-7 (Pasachnik 2013), 7-12 eggs (Rittman 2007)), the additional pressure on hatchlings from domestic species does not appear to affect the population as much as other factors, based on this model. In other iguana species, including *Cyclura nubila caymanensis*, feral cats can cause complete cohort mortality of hatchlings (Hudson et al. 1994). Domestic species may be causing isolated or localized extirpation of this species, but the model does not show this to be the main threat driving their decline.

Based on habitat and diet analyses, this species is a generalist and can make use of many different habitats and food sources (Campbell et al. in press, Pasachnik 2013). Genetic data suggests it occupied the entire island (Pasachnik and Hudman in press). Because of this, the possibility of loss or change in habitat due to climate change will likely not significantly affect the population. The island has a huge potential carrying capacity for this species based on the high densities seen at some of the study locations (up to 13,523 iguanas per km^2), so the loss of ~9.5 km^2 of shoreline and the ensuing shift in habitats is unlikely to impact the population as much or as quickly as other threats. However, the shoreline may be where nesting occurs, and if so this could impact reproduction, sea level rise will happen gradually and the habitats will likely shift inland as the inundation occurs.

Population viability models take many variables into account during estimations and because of this, are only as good as the data used. In this case, many population variables have been quantified including genetics and population size and structure. However, reproduction is an area that is lacking in data due to the small numbers of this species kept in captivity and the cryptic nature of their nests in the wild. The best data available for this species was used in the model, as well as data from related species when necessary. Sensitivity testing of these parameters, specifically the female reproductive numbers, indicated that variation within the expected range of parameters did not affect the model. This range was used as the estimated environmental variation for those parameters in the model.

If the population stays within the current parameters, with high adult mortality and isolated populations with little dispersal between them, the population is likely to go extinct within 50 years and potentially within the next decade. This is very concerning, considering the already apparent downward trend in density estimations (Table 2.3). The IUCN lists "the probability of extinction in the wild is at least 50% within 10 years or three generations, whichever is longer" as Criterion E for listing of a species as Critically Endangered (IUCN 2001). Based on this IUCN Red List guideline, this species may be qualified for uplisting.

Significant changes to the management and protection of this species need to take place in order to avert extinction in the wild. Identifying the most pressing threat is critical for changing management practices and using the limited resources available most effectively. Adult mortality would have to be significantly reduced, by more than 50%, in the next few years to stabilize the population over the short-term. In order to do this, enforcement of the current no hunting laws needs to begin immediately, especially around the high density populations. If local authorities begin enforcing the laws that already exist, including the repercussions associated with harming, killing, and selling iguanas and other wildlife, then the local residents will begin to make changes.

While enforcement is what needs to occur immediately, education of the local communities cannot be far behind. In order to protect this species over the long term, education needs to occur in the schools and in the community in general. A large part of the problem behind protecting this species is that it looks similar to the common mainland species, *Ctenosaura similis*. By teaching that *C. oedirhina* is a different species, and that it is only found on Roatán, a sense of ownership can be created in the local communities (Grant and Lemm 1996, Grant and Hudson 2015, Knapp 2005, Burton 2010). This will then instill a sense of pride and lead to the protection of the iguanas, discourage poaching, and encourage reporting of illegal activities.

Steps need to be taken immediately to slow the decline of this species. Many issues threaten their existence, and their limited geographical range, low genetic diversity, and the increasing human population on the island only exacerbate this tenuous condition. By using a PVA to identify and determine the intensity of known and potential threats, the proper steps can be taken to reduce the current threats or mitigate additional pressure on the population.

Table 3.1 Current (2015) estimated population and carrying capacity (K) of *C. oedirhina* by study location.

Carrying capacity was estimated using highest known density of iguanas (13,523 iguanas/km^2 from Location 2 in 2015) and the area of each study location.

Location	Area (km^2)	Estimated Population	Estimated K
1	0.1	902.59	1,353
2	0.11	1487.53	1,488
3	0.008	80.832	109
4	0.3	1100.1	4,057
5	0.1	558.88	1,353
Total (Sites)	0.618	4130	8,358
Total (Island)	146	4130-4860	1,974,358

Table 3.2 Vortex input variables.

Sensitivity tests (ST) were conducted for some variables.

Variable	Input (ST range)	Source
Breeding system	Polygynous	
Age of first breeding – females	4 (2-6)	Gutsche and Streich 2009
Age of first breeding – males	4 (2-6)	Gutsche and Streich 2009
Maximum breeding age	15	Gutsche 2006, Gutsche and Streich 2009
Sex ratio at birth	1:1	Default software setting (Lacy et al. 2015)
Maximum clutch size	15 (0-15)	Gutsche 2006 (*C. bakerii*), Pasachnik 2013 (*C. oedirhina*)
Percentage of females breeding yearly	50%	Default software setting (Lacy et al. 2015)
Percentage of males breeding yearly	100%	Default software setting (Lacy et al. 2015)
Percent survival of females		
-Hatchlings	58.1% (0-100%)	Calculated from Pike et al. 2008
-Juveniles	11% (10-90%)	Mark analysis
-Adults	11% (10-90%)	Mark analysis
Percent survival of males		
-Hatchlings	58.1% (0-100%)	Calculated from Pike et al. 2008
-Juveniles	11% (10-90%)	Mark analysis
-Adults	11% (10-90%)	Mark analysis

Table 3.3 Age distribution of *C. oedirhina* by study location.

Locations	All	1	2	3	4	5
Adult size (150mm+)	0.7	0.71	0.76	0.92	0.79	0.68
Juveniles (80-150mm)	0.22	0.23	0.17	0.08	0.18	0.38
Hatchlings (<80mm)	0.08	0.06	0.07	0	0.03	0.14

Table 3.4 Results of *C. oedirhina* PVA analysis scenarios and sensitivity testing.

Scenario	Mean Growth rate *r* (SD)	Mean Probability of Extinction (%)	Average Time to First Extinction in Years (SD)	Mean Final Population (SD)
Current Metapopulation (No Dispersal)	-1.2762 (0.6100)	100	7.1	0
Current Metapopulation (With limited dispersal)	-1.2799 (0.5774)	100	7.1	0
Current Metapopulation (With full dispersal)	-1.4679 (0.5797)	100	6.4	0
Current Metapopulation (With limited dispersal, high adult survival 50%)	-0.3365 (0.2216)	100	20.8	0
Current Metapopulation (With limited dispersal, high adult survival 10% mort)	0.0764 (0.0700)	0	-	8268.19 (166.24)
Current Metapopulation (With limited dispersal, high adult survival 30% mort)	-0.1198 (0.1242)	17%	47.9	16.11 (16.00)
Current Metapopulation (With limited dispersal, high adult survival 25% mort)	-0.0693 (0.0826)	0	-	147.14 (83.31)
Current Metapopulation (With limited dispersal, high adult survival 20% mort)	0.0136 (0.0724)	0	-	2125.96 (888.71)
Current Metapopulation (With limited dispersal, high adult survival 15% mort)	0.0328	0	-	7512.07 (874.11)
Current Metapopulation - Low male survival only	-0.2644 (0.1801)	100	13.4	0
Current Metapopulation - Low female survival only	-0.4223 (0.1264)	100	7.5	0
Current Single Population - low	-1.3814 (0.7591)	100	5.7	0
Current Single Population - high	-1.3664 (0.7117)	100	5.8	0
Current Metapopulation - Hatchling survival 90%	-1.1963 (0.6379)	100	7.5	0
Current Metapopulation - Hatchling survival 10%	-1.6478 (0.6532)	100	5.8	0

4. CONSERVATION OF AN ENDEMIC IGUANA IN HONDURAS

Introduction

Honduras lies within the Caribbean biodiversity hotspot identified by Myers et al. (2000). Biodiversity hotspots are characterized as containing a high diversity of species and undergoing severe habitat degradation. Within these relatively small hotspots, many endemic species have evolved, making conservation of these places a very effective way of conserving the maximum amount of global biodiversity (Myers et al. 2000). Honduras is part of a biodiversity hotspot for many reasons. Its Caribbean coast has a chain of Bay Islands with many endemic species and its interior contains forests with many more, totaling 58 endemic, 213 CITES Appendix listed, and 254 IUCN Red List species across the country.

Honduras is known for its forests, but it also contains a variety of other ecosystems including savanna, mangroves, and marine. Some of these habitats, such as the dry forest in the Valle de Aguán, are very rare, and some, like the Bay Islands, are isolated. This allowed for the evolution of many endemic species. However, these areas are disappearing rapidly due to deforestation, degradation, and fragmentation of the habitat, caused by illegal logging and uncontrolled forest fires, and are threatened by poaching of wildlife. Poor communication between local residents, local government, and other stakeholders, mainly caused by unequal distribution of land rights and unstable policies, also cause mismanagement of the forest's natural resources (Thorne 2004, SERNA 2005). Much of the mainland relies on firewood for fuel and most of the county relies on agriculture as a source of income (SERNA 2005). This not only directly affects the forest, but because of the clearing of hill sides and ground near the shore line, sediment now washes into the ocean during rainstorms, affecting the barrier reefs. Roads leading to rural farms and villages now fragment once continuous habitat, not only disconnecting important habitat corridors, but also giving hunters access to previously untouched areas.

Honduras has put in place many laws and policies to protect the biodiversity of the region. The 112,492 km^2 country has 91 national parks in its National System of Protected Areas (SINAPH), which are protected by Decree Law 63 (SERNA 2001). Habitats in these SINAPH areas range from cloud and rainforests to savanna and marine ecosystems. These areas, along with other non-protected areas contain 7,524 native plant species and 1,933 native animal species, 211 of which are reptiles (SERNA 2001). However, no comprehensive inventory of flora or fauna has been conducted, so these are potentially under estimates.

The Bay Islands are a chain of continental islands totaling ~250 km^2 combined and are isolated off the northern coast of Honduras. The IUCN Redlist database indicates that the Bay Islands contain 12 endangered species, eight of which are reptiles. Half of the six endangered Spiny-tailed Iguanas *(Ctenosaura)* in the country are found in the Bay Islands, including *C. oedirhina, C. bakeri*, and *C. melanosterna*. The Bay Islands contain nearly 5% of the total number of Endangered species in Honduras.

On Roatán, the largest of the Bay Islands, the forests and wildlife face the same threats. There are still large areas of forest left on the island because many island residents use other sources of fuel (pers. obs.); approximately 85% of the island's area is still forested (Campbell et al. in press). Hunting pressure on the island's wildlife is severe and is the primary threat and main driving force in the distribution of Roatán Spiny-tailed Iguana (*Ctenosaura oedirhina*), one of five reptiles endemic to Roatán (Wilson and McCranie 2003, Campbell et al. in press). This iguana, along with the Green Iguana (*Iguana iguana*), is consumed by island residents and tourists (Pasachnik et al. 2014). While there are laws in place that forbid the take of native wildlife for any purpose without permits (Articles 115-118, National Congress 2007), they are often not enforced.

Locations that are protected by a grassroots movement of private land owners and managers have high population densities of iguanas, which are separated by areas of very low iguana population density (Campbell et al. in press). Declining densities of *C. oedirhina* at protected sites over the past five years indicate increasing hunting pressure. Based on genetic data, there is little to no immigration/emigration between these populations (Pasachnik and Hudman in press) further increasing their vulnerability to inbreeding depression and stochastic events.

The objectives herein are to 1.) summarize the past and current legislation governing forestry and wildlife protection in Honduras; 2.) present a comprehensive update on the current status of *C. oedirhina* on Roatán; and 3.) offer recommendations for the management and conservation of this species.

Previous Laws and Policies

Starting in the mid-1980s, Honduras began passing environmental laws and policies mainly focusing on forestry, curbing the exploitation of the forests, and stopping illegal logging (Table 1). These policies created the National System of Protected Areas of Honduras (SINAPH) and laid the foundation for the conservation and protection of important biomes, watersheds, and marine ecosystems.

In 2004, Executive Agreement 002-2004 decided on the protection of the native habitats and their vulnerable species. It prohibits hunting, capture for sale or collection, or sale of products made from listed flora or fauna unless a permit is obtained first (Presidential House 2004). While previous legislation spoke of protecting wildlife, the protection was more an indirect effect of protecting the forests and national parks; however, Article No. 29 of this Agreement does not specify that listed wildlife be within the confines of a protected area to be legally protected.

Current Laws and Policies

A comprehensive Decree (No. 98-2007), put into effect in 2007, established guidelines for the management of forest resources, protected areas and wildlife, and put in place the infrastructure to fulfill all of the objectives put forth by creating the National Institute of Forest Conservation and Development of Protected Areas and Wildlife (ICF) (National Congress 2007). Within the decree there are 211 Articles; however, only a few deal directly with protection of wildlife and their habitat. Article 29 created the National

Forest, Protected Areas, and Wildlife Research System (SINFOR) to conduct research on the habitats and native flora and fauna found in Honduras. This decree also gives rights to indigenous peoples who have traditionally used the land, if they use environmentally friendly practices, such as certain types of agriculture (Thorne 2004). Indigenous peoples generally refers to those of Mayan descent on the mainland and those of Afro-Indian groups, such as the Garifuna, in the Bay Islands. These groups have traditionally lived in the forest, using and selling forest products, and also taking wildlife for sustenance (Gonzalez 1988, Thorne 2004). Articles 115-118 deal directly with the marketing and take of plants and wildlife. All import/export of threatened or endangered species falls under CITES regulation (which Honduras ratified in 1985) and hunting or capture of these species is prohibited.

Chapter IV of this legislation (Articles 156 and 157) introduced a specialized unit of rangers to enforce ICF regulation, including monitoring and surveillance of resources, controlling poaching, sale, and trafficking of native plants and wildlife (all natives, not just threatened and endangered species), and educating the public via programs and projects. These rangers and other associated law enforcement are a critical piece of infrastructure that had been missing from previous policies. They help enforce Articles 187-190, which deal with repercussions for capturing wildlife for commercial purposes or profit, damaging wildlife, and for officials who grant authorization to hunt, fish, or remove wildlife without the proper authority or without going through the proper procedures (Table 2) (National Congress 2007).

The National Forest Program (PRONAFOR) was developed as a guide for the 2010-2030 National Plan and the 2010-2038 Country Vision and includes a sub-program for Protected Areas and Biodiversity. The sub-program focuses on reinforcing SINAPH and managing biodiversity for sustainable use by developing management plans, creating ecological corridors, and continually evaluating the management of the lands. It also supports studies and inventories of wildlife within protected areas, including the creation of research stations and collaboration with research and educational institutions (Republic of Honduras 2010).

The newest forest policy developed by the ICF (2013) includes goals for forest sustainability, reduction of vulnerability of ecosystems, and community inclusion. Increasing governmental transparency and consolidating management, halting unsustainable forestry practices, incentivizing conservation, and promoting community participation are some of the practices the plan proposes. Some of these goals include a national inventory of biodiversity, preservation of biodiversity through management and sustainable practices, promotion of projects that focus on conservation and recovery of at risk species, development of a plan to prevent and control illegal wildlife trade, and creation of “regional communities“ to monitor poaching (ICF 2013). With the backing of the ICF’s previous laws that provide for infrastructure, funding, and governmental support, these goals are obtainable within the National Plan and Country Vision.

Many of the policies put forth in the past two decades have focused on the forests and marine ecosystems, with protection of the fauna being a side effect of their habitat being protected. More recent legislation specifically targeted native wildlife, both within and outside of protected areas and parks. This specific protection of native and listed wildlife, along with the infrastructure to enforce it and substantial repercussions for violation of it, could help many unique species persist in the wild against growing anthropogenic threats. However, social custom (Thorne 2004), economic hardships (Johnston and Lefebvre 2013), and lack of secondary level education in many rural areas (IADB 2013) where most residents make their living from subsistence farming and forestry related occupations (Throne 2004, SERNA 2005), could negatively impact many species, even when adequate legal barriers have been created.

Current Status of C. oedirhina

One of the species being impacted by this situation is *Ctenosaura oedirhina*, a lizard endemic to Roatán. *Ctenosaura oedirhina* is a medium sized iguana found only on Roatán and Barbaret, in the Bay Islands. While these iguanas were historically likely found across the entire island, their range is now limited to five geographically and genetically isolated populations covering ~0.6 km^2 (Pasachnik and Hudman in press, Campbell et al. in press).

They are threatened by loss of habitat and are also at risk from stochastic events such as catastrophic weather and disease and anthropogenically driven threats including the introduction of an invasive ctenosaur (*C. similis*) that can potentially hybridize with *C. oedirhina*, predation by domestic species, and poaching for sale in the pet trade (Pasachnik 2013, Campbell et al. in press). However, their biggest threat is over harvesting for consumption (Campbell et al. in press). *Ctenosaura oedirhina* has likely been consumed on Roatán for generations (Pasachnik 2013). Now as the human population increases, as shown by the increase in urban area from 1% to 15% of the land cover since 1985 (Aiello 2007, Campbell et al. in press), the consumption pressure on this species is likely increasing and thus causing a decrease in the overall population.

This species is omnivorous and a habitat generalist, being found even in anthropogenic and urban areas (Pasachnik 2013, Campbell et al. in press). However, they are only found in high densities in a few localities. These localities vary in habitat type, but all are protected from hunting by a grassroots movement (Campbell et al. in press). The islet of Barbaret to the east of the main island may have a stable population, but visitation is very limited because the island is privately owned thus the status of the species there is uncertain. The locations that are protected by grassroots efforts are often only able to provide minimal protection to wildlife, as they are generally small (range = 0.8-30 hectares), have unguarded and sometimes unfenced borders, and inconsistent enforcement of the no hunting rules within, depending on the management at the time. Within these protected areas, 778 iguanas have been captured and marked for population monitoring purposes. While individuals of this species can live up to 15 years (Köhler and Rittmann 1998), there are many iguanas within these areas, and the iguanas are easily observable, very few marked individuals are recaptured or resighted. Tag failure does occur, but not at a rate that would explain the loss of individuals that is observed, thus it is likely indicative of mortality. Radio tracking of a subset of these individuals indicates that while their home ranges are small (most are <0.5 hectare) they are mobile and do move in and out of the protected areas (pers. obs.).

A decline in iguana density at the protected sites over the past four years and perceived high adult mortality indicates a growing problem. This decline in density has resulted in a 31% population decline in the study sites (Table 2.6). The small individual sizes of these high density sites, the imperfect protection of their borders, and the mobility of this species results in some iguanas being poached nearby, if not from within the protected areas.

A population viability analysis shows the population declining within the next decade and the main factor in the population dynamics to be adult female mortality. While this species does not have a sex ratio suggestive of intense female-biased hunting, sampling has indicated a decrease in the number of females since 2011. Hunting of juvenile and adult sized individuals is prevalent outside of areas where private landowners and managers protect them, which a PVA indicates, is likely to cause extinction of this species in less than a decade.

Recommendations for Management

While loss of habitat, predation by domestic species, poaching for sale in the pet trade, and the potential for hybridization are all very real threats, the main force driving the distribution and population size is likely hunting for consumption. Mitigating or alleviating the pressure from overharvest is vital to protecting this species. This could be accomplished in a few different ways: 1) educating the inhabitants of Roatán on the uniqueness and vulnerability of this species and of the role of biodiversity in the health of the ecosystem they live in, 2) enforcing the already existing wildlife laws, 3) breeding the iguanas in captivity *in situ* for reintroduction and translocation, and 4) breeding them *ex situ* at facilities outside of Roatán as part of a reintroduction program and as an assurance population.

Education has previously been a useful tool in promoting conservation in the Bay Islands (Köhler 1997) and has been suggested as a conservation measure for *C. oedirhina* (Pasachnik 2013). In some cases, the local residents are just unaware of the conservation status and threats of a species, and so do not even know there is a problem. This is partially the case with *C. oedirhina*. Since it is similar in appearance to the common mainland species, *C. similis*, many people do not know they are unique and therefore do not understand why one needs to be protected over the other. While all iguana species are illegal to hunt, a trip to the mainland quickly illustrates why some people think there is a huge supply of iguanas, as *C. similis* is abundant in many places there (Pasachnik 2015). Educating the residents of Roatán on the uniqueness of their species, and the many economic benefits in the form of tourism that the iguanas can provide, is a way to increase local support.

Education programs for other Endangered iguana species have been successful in helping protect the species, their habitats, and encouraging pride in the local human residents that share the land with them. With the rediscovery of the Jamaican Rock Iguana (*Cyclura collie*) and the ensuing partnership with the Hope Zoo in Jamaica were initiated at the beginning of its conservation plan. Jamaican school children and adults alike know about "their" iguana, even if the government does not always support the public's opinion (Grant and Lemm 1996, Grant and Hudson 2015). Educational efforts in the Bahamas for the Andros Iguana (*Cyclura cyclura cyclura*) have included school presentations and the inclusion of local school children and other residents in the field studies (Knapp 2005). In the Cayman Islands, the Blue Iguana Recovery Program, along with the National Trust for the Cayman Islands, and other conservation groups and local schools have put a huge effort into the protection of the Blue Iguana (*Cyclura lewisi*) ("Campaign on to save blue iguanas" 2007, Burton 2010). While direct public outreach like what has been done with these other species is important, disseminating information via publishing reports (both to the Honduran government and peer reviewed journals), making the status of the species known to the island residents, and updating the IUCN Red List assessment (Pasachnik et al. 2010a) will also raise awareness and provide support for enforcing existing conservation laws.

As stated above, the hunting of all wildlife is illegal in Honduras. On Roatán, hunting of iguanas of both native species, as well as other wildlife, is pervasive. Iguana is served in restaurants and bought and sold on the streets for as little as 100-150 lempiras (US$4.50-$6.80) per plate/each and is often served to tourists as a local delicacy (pers. obs., Kutnik 2014). In the past, there has been little to no enforcement of the wildlife laws and poachers have been let off with only their catch being confiscated, if there are any repercussions at all (pers. obs.). If enforced, the legal ramifications of being caught with captured wildlife can range from 1 to 18 years in jail based on the circumstances (Table 2). Recently, more iguanas of both species have been seen in trees and basking along roads, including the Principal Via (pers. obs.). This is a positive sign, as few iguanas were ever observed along these high traffic routes. In addition, local residents mentioned police officers actively enforcing the no hunting law and arresting offenders, however no official reports of this could be found. Since the repercussions of capturing, killing, and selling iguanas of either species are deterrent enough to most people, the possibility that it is being enforced seems to have caused at least some to change their behavior. This anecdotal evidence is a positive sign of at least intermittent enforcement, but consistent, full enforcement would be necessary to slow or stop the population decline already observed. Even if enforcement does begin to occur regularly, it will take years before the iguana population rebounds As females may take up to four years to reach maturity (Rittmann 2007).

While other iguana species, like the Jamaican Rock Iguana and Grand Cayman Iguana, are bred in captivity for release to increase and maintain wild populations as part of conservation strategies (Hudson and Alberts 2004, Wilson et al. 2004, Knapp and Hudson 2004), they are not primarily threatened by hunting for consumption (Grant et al. 2010, Burton 2012). Since over hunting is a major threat to *C. oedirhina*, this type of model alone would not be as effective in this area, as newly released individuals would be hunted. Educating the community would have to begin first, before this type of program could be successful.

Iguanarios are a way to produce iguanas for release back into the wild and as tourist attractions. Article 119 of the 2007 decree legalized breeding facilities for wildlife, which is implied to mean zoos and botanical gardens. However, it may potentially be interpreted to allow iguanarios, a system developed in other Caribbean and Central American countries (Pasachnik and Carreras de León 2014, Powell et al. 2002, Reyes 2004). Iguanarios are permitted to legally take initial stock from the wild and then breed the species in captivity. Iguanarios can have many purposes depending on the species being bred and the community the facility is located in. In some, iguanas are bred for consumption, but this has only been somewhat effective in Central and South American countries (Reyes 2004). In others, iguanas are bred specifically for release back to the wild or are strictly tourist attractions, such as in the Dominican Republic (Pasachnik and Carreras de León 2014, Powell et al. 2002, Uzzo 2014).

Iguanarios were first established in the Dominican Republic as conservation tools for the native iguanas, but what ultimately happened was iguanas from all over the island were placed together with no regard for population genetics, and hatchlings and juveniles were released with no tags or markings and no way of tracking their success or failure (Pasachnik and Carreras de León 2014). On the island of Utila, the endemic *Ctenosaura bakeri*, a Critically Endangered iguana and the sister species of *C*. *oedihrina*, is also threatened by hunting for consumption and loss of habitat (Pasachnik et al. 2012) and has been bred at the Iguana Research and Breeding Station since 1997 (Iguana Station Utila 2015). Since the research station does not tag or track released animals, the success of the program is hard to measure. If an *in situ* breeding program was developed for *C*. *oedirhina*, it would have to be managed with translocation in mind and monitoring of the genetic structure of the captive population would be necessary.

Creating a breeding program for *C*. *oedirhina ex situ*, where small groups of iguanas are housed at existing facilities in other countries, may be a way to preserve the genetics and breed individuals for eventual reintroduction on the island. These individuals in captivity would be a back-up population in case a catastrophic event occurred on the island, such as a hurricane or disease outbreak, that eliminated a large number of iguanas.

Breeding *C*. *oedirhina* in captivity may pose more difficulties than breeding other iguana species. Ctenosaurs in general tend to be aggressive towards conspecifics (Stephen et al. 2012). However, *C*. *oedirhina* is known to live in very dense populations on Roatán in areas where they are protected from hunters (Campbell et al. in press). Also, there are not currently many individuals of this species in captivity and what breeding has occurred in captivity has been inconsistent with minimal success (Köhler and Rittmann 1998). Attempts to find nests in the wild have also had limited success (Pasachnik 2013). This being said, it may be difficult to breed this species given that so little is known about their reproductive habits.

Conclusions

In the past decade, Honduras has established legislation to protect its natural resources. These laws, policies, and plans indicate a need and a willingness to protect biodiversity within the country. However, even these well laid plans cannot account for all local customs, economic states, and other situations. On the island of Roatán, *Ctenosaura oedirhina*, an endemic lizard is facing extinction because of a mix of tradition, lack of information, and economic hardship.

A population viability analysis was conducted with current data on the species. If the management of *C. oedirhina* continues as it is, the analysis estimates that this species will be extinct in the wild in less than a decade, with a very limited number of individuals left in captivity. Changes need to be made on many fronts in order to stop and reverse this decline. While any of the recommendations above alone would make a difference in the population trend, a combination of some or all would be more effective.

Education is always a critical aspect of any conservation program. Knowledge of the unique species found on Roatán and biodiversity in general would help the local residents understand the importance of protecting the native species of their island. Once a solid base of knowledge is developed, an *in situ* breeding program for *C. oedirhina* would provide support for the iguana population and an educational facility for locals and tourist.

While education will help change the perception of this species, it will take time to implement curricula and make headway in changing the behavior of the hunters and their communities. To make an immediate impact, education of landowners and managers should begin first. This will help ensure more grassroots protected areas where iguana populations can be managed without hunting pressure are created quickly. These areas are important refuges for the species and can help maintain populations while an island-wide education campaign is implemented.

Even though previous captive breeding situations have had limited success and Ctenosaurs are known to exhibit interspecies aggression, given the apparent success with *C. bakeri* in captivity and the declining population and perilous genetic situation of *C. oedirhina* (Pasachnik and Hudman in press), it is still beneficial to bring some founder individuals into captivity while the chance to gather a variety of genetic backgrounds is possible. A facility on Roatán could focus on breeding and reintroduction into protected areas, be an educational center for locals and tourists, and collaborate with local NGOs to monitor and protect the species and educate the public. Facilities in other countries could house back-up populations. Given the limited range of this species and the host of ever increasing anthropogenic threats they face, captivity is a viable option to preserve some of the already reduced genetic diversity and retain individuals that may eventually breed.

With other iguana species being conserved via captive rearing, the base of knowledge on the husbandry of these animals is ever increasing.

Table 4.1 Honduran environmental laws and policies (MCT 1989, National Congress 1993, 1997, 2002, 2007). Ministerial Agreement (MA), Decree (D), Executive Agreement (EA), Presidential Agreement (PA).

Year	Legislation	Actions	Protection for Forests	Protection for Reefs	Protection for Wildlife	Infrastructure	Enforcement	Community Involvement
1989	MA 213	Bay Islands named an Ecological Conservation Area	X	X				
1993	D 104-93	Department of the Environment was created to handle SINAPH				X		
1997	EA 005-97	Bay Islands Marine Park was added to the SINAPH		X				
2002	PA 005-2002	Created the Executive Commission for Sustainable Tourism of the Department of Bay Islands (CETS)				X		
2004	EA 002-2004	Protection for the native habitats and their vulnerable species in the Bay Islands	X	X	X	X	X	
2007	D 98-2007	Establishes guidelines for the management of forest resources, protected areas and wildlife	X	X	X	X	X	X

Table 4.2 Wildlife related crimes and their repercussions as listed in Honduran Decree No. 98-2007, Articles 187-190.

Crime	Sentence
Anyone capturing wildlife for commercial purposes without appropriate license or permit.	4-7 years
Anyone profiting from the capture of wildlife (either by sale, purchase, exchange, import, or export) without appropriate license or permit.	4-9 years
Anyone damaging wildlife (including death, damage, or mistreatment).	1-3 years
Officials who grant authorization to hunt, fish, or remove wildlife without the proper authority or without going through the proper procedures	6-9 years

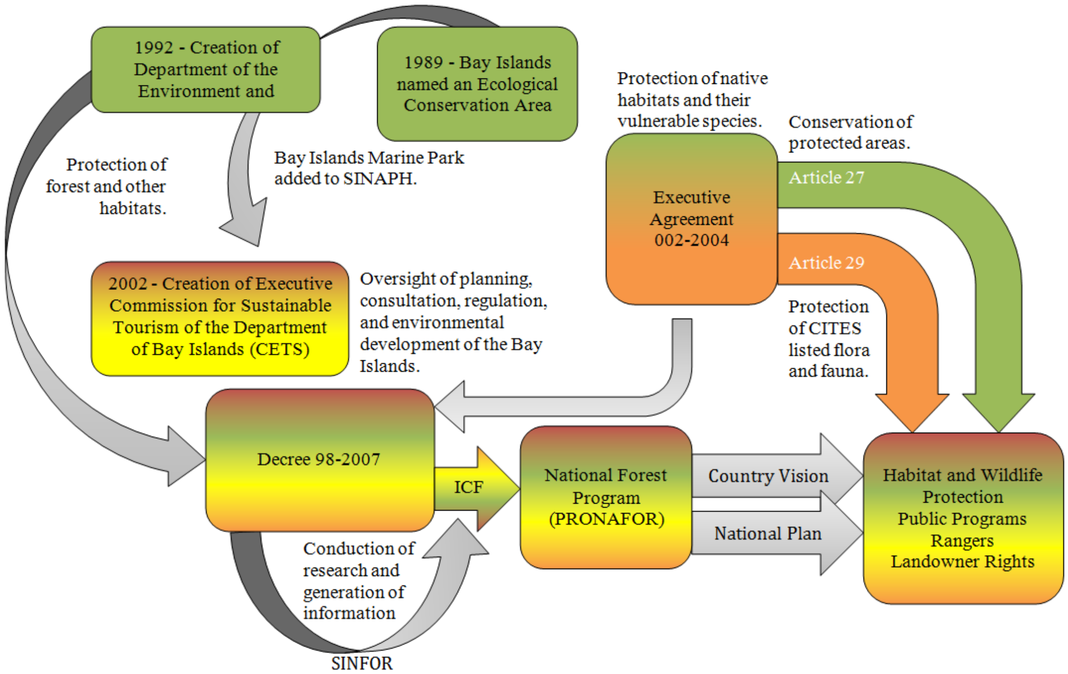

Figure 4.1 Conceptual model of Honduran legislation leading up to current policies. Major environmental policies began changing the way Honduras manages and protects its natural resources in the 1980s. Over time, policies on legal protection, enforcement, tourism, and sustainability have built a base for the current forest policy developed by ICF in 2013. This conceptual model shows important decrees and the increasing comprehensiveness of laws. Not all environmental laws dealt directly with wildlife or law enforcement as some specifically protected natural areas and habitats only. This legislation indirectly protects the faunal diversity of the areas by restricting access and development within and nearby the areas. The ratification of CITES and the oversight by multiple entities (CETS and ICF) increases protection for the most vulnerable species. The newest policies combine all aspects – protection, enforcement, education, sustainability, and economics. Wildlife policy is delineated in orange, forest/habitat in green, enforcement in red, and economy/tourism/sustainability in yellow.

APPENDIX

Appendix. Environmental variables used in the Resource Selection Functions (RSFs) to describe the habitat accessible to *Ctenosaura oedirhina* across Roatán, Honduras.

Habitat type.—The general habitat types found across Roatán include shore, "cleaned" forest, "uncleaned" forest, mangroves, stripped land (strip), agricultural land, anthropogenic land (anthro), water, and rock cliff (cliff) (Figure 2).	
Shore	Consists of sandy beach habitat along a salt body of water. Shore is naturally narrow (< 5 m) on the island, but humans have altered it in some areas to be wider for tourism. Shore has a sand substrate, but often there is washed-up vegetation from the ocean and occasionally live vegetation (*Ipomoea* spp.) growing low on the ground.
Forest	Consists primarily of seasonally dry tropical forest (Pennington and Ratter 2010). Canopies of Gumbo-limbo (*Bursera simaruba*), Dogwood (*Piscidia piscipula*), Hog Plum (*Spondias mombin*), and Bullhorn Acacia (*Vachellia cornigera*) are commonly found, some reaching heights of 10–20 m. The understory includes Palmettos (*Sabal* spp.), Wild Grape (*Vitis* spp.), and perennial grasses when an understory is still present. "Cleaned" forests are areas cleaned of their understory, often around houses and businesses. "Uncleaned" forests have an intact understory that is often very dense.
Mangrove	Consists of mainly Red Mangroves, but sometimes also contains White and Black Mangroves. This habitat often has standing salt or brackish water for most of the year; usually shallow (< 0.5 m).
Stripped land	Consists of land stripped of all vegetation down to a sand, dirt, or gravel substrate. This is usually done in preparation for development or mining operations.
Agricultural land	Consists of land primarily being used to graze livestock (cattle or horses) or grow crops (mainly bananas).
Anthropogenic	Land consisting of landscaped areas, usually around residences or in parks, and urban areas.
Water	Habitat consisting of any open water, fresh or salt.
Rock cliff	Habitat consisting of cliffs 5–15 m high along a marine body of water. Cliffs have sheer faces or are boulder strewn, with some boulders measuring 1–2 m across.
Substrate type.—The substrates within the habitat type consist of rock, dirt, sand, mulch, grass, other vegetation (veg), gravel, water, and concrete (conc).	
Distance from water (salt or fresh).—Distance from water is measured in four levels: 0 (in water), < 50 m, 50–100 m, > 100 m.	
Anthropogenic effects.—Anthropogenic effects were divided into three levels: undisturbed (undist), lightly disturbed (light dist), and heavily disturbed (heavy dist).	
Undisturbed	Areas consisting of undeveloped land with no human residents or livestock. There were no streets, buildings, or other infrastructure except for hand-cut walking trails.
Lightly disturbed	Areas that have some development or infrastructure, but not significant amounts, and there is no landscaping. These areas had natural vegetation and low human or livestock populations.
Heavily disturbed	Areas that have been significantly altered by humans. This consists of urbanized districts: streets, buildings, or large-scale landscaping, and high human or

	livestock populations were found in these areas.
Seasonality.—Data were also divided by season: (1) spring (April–May); (2) summer (August); and winter (November–December).	

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