A HABITAT SUITABILITY MODEL FOR RICORD'S IGUANA IN THE DOMINICAN REPUBLIC

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1. Introduction

The West Indian iguanas of the genus *Cyclura* are the most endangered group of lizards in the world (Burton & Bloxam, 2002). The Ricord's iguana, *Cyclura ricordii*, is listed as critically endangered by the International Union for Conservation of Nature (IUCN) (Ramer, 2004). This species is endemic to the island of Hispaniola (Figure 1), and can only be found in limited geographic areas (Burton & Bloxam, 2002). The range of this species is estimated to be only 60% of historical levels, with most areas being affected by some level of disturbance (Ottenwalder, 1996). The most recent population estimation is between 2,000 and 4,000 individuals (Burton & Bloxam, 2002). Researchers working in the area and the individuals who live there agree that the population densities of Ricord's iguanas were much higher until the mid 1970's when they began to decline (Ottenwalder, 1999). The number of Ricord's iguanas living in the Dominican Republic before the decline is unknown. The decline in the numbers and distribution of Ricord's iguana is associated with habitat destruction, competition and predation from feral and domestic animals, and unregulated hunting (Ottenwalder, 1996). The available suitable habitat has been severely reduced by the clearing of land so that it can be used for other purposes. In addition to destroying suitable habitat, this process can also lead to habitat fragmentation (Ottenwalder, 1999).

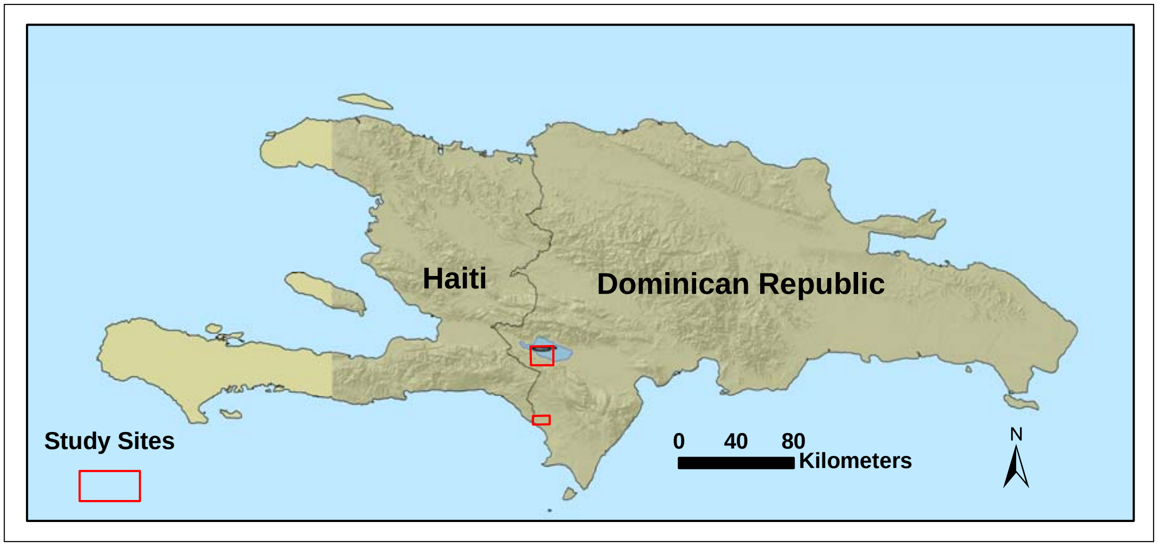


Figure 1 – Hispaniola is comprised of Haiti and the Dominican Republic

All known populations of Ricord's iguana are located in southwestern Dominican Republic along with a recently discovered population near the town of Anse-a-Pitres in southeastern Haiti. Ricord's iguana populations found on Isla Cabritos and the southern shore of Lago Enriquillo, and portions of the Barahona peninsula are currently protected (Figure 2). However, many of the above stated risks still exist (Burton & Bloxam, 2002).

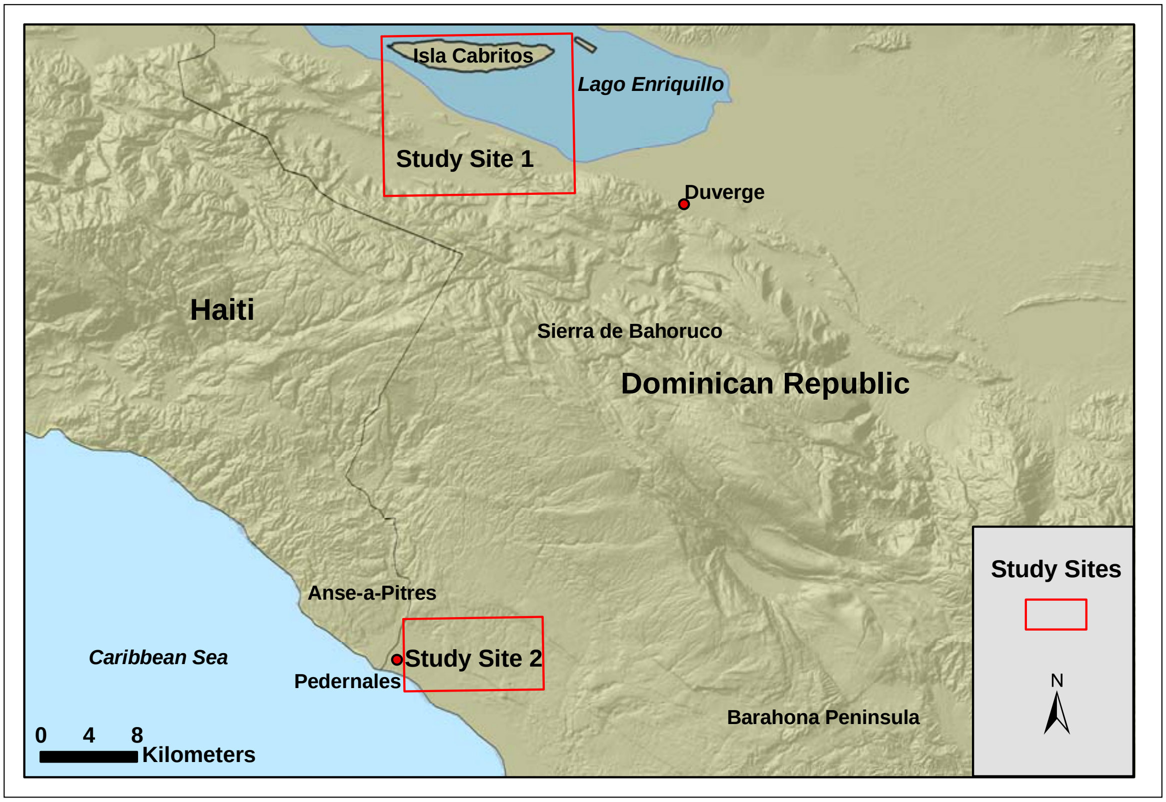


Figure 2 – Study sites 1 and 2 along the Haitian – Dominican Republic border

The Rhinoceros iguana, *Cyclura cornuta* is also found on Hispaniola, often living in close proximity to Ricord's iguana. This species is classified as vulnerable by the IUCN, but has a much wider range than the Ricord's iguana. The most recent population estimation is between 10,000 and 17,000 individuals (Ottenwalder, 1999). The impact of competition between these two species is the subject of research currently being conducted by Rupp, Inchaustegui, & Arias (2007) and the Indianapolis Zoological Society (2007).

Information on potentially suitable habitat can help the conservation efforts for Ricord's iguana. However, intensive ground surveys are not always feasible or cost effective, and cannot easily provide continuous coverage over a large area. This paper presents results from a pilot study that evaluated variables extracted from satellite imagery and digitally mapped data layers to map the probability of suitable Ricord’s iguana habitat. Bayesian methods were used to determine the probability that each pixel in the study areas is suitable habitat for Ricord’s iguanas by evaluating relevant environmental attributes. This model predicts the probability that an area is suitable habitat based on the values of the environmental attributes including landscape biophysical characteristics, terrain data, and bioclimatic variables.

2. Background

2.1 Study areas

Both study sites are located in the southwestern Dominican Republic near the Haitian border. These sites were chosen because they contain the majority of the known Ricord's iguana sightings (Figure 2).

Study site 1 includes Isla Cabritos, the southern shore of Lago Enriquillo, and areas west of Duvergé (Figure 2). This site is approximately 194 square kilometers. It is comprised of 213,104 pixels (Table 1) that each measuring 30 x 30 meters. Since this site includes Lago Enriquillo, a portion of the pixels representing water were excluded resulting in 129,093 pixels to be evaluated. Study area 2 includes the Pedernales area, and encompasses approximately 66 square kilometers. It is comprised of 66,115 pixels (Table 1) that each measuring 30 x 30 meters. This study area contained a portion of the Caribbean Sea (Figure 2). When these pixels were excluded, 65,571 pixels remained to be evaluated.

Table 1 – Number of pixels in each study site

	Total Pixels	**Number of Excluded Pixels**	**Final Size**
Study Site 1	213,104	84,011	129,093
Study Site 2	66,115	544	65,571
Total	**279,219**	**84,555**	**194,664**

The Dominican subpopulations are found in the Enriquillo Basin and the xeric lowlands of the Peninsula de Barahona (Figure 2). These two populations are separated by the Sierra de Bahoruco (Figure 2), which is also referred to as the Massif de la Selle in Haiti (Ottenwalder, 1999*)*. A recently discovered Haitian subpopulation that is located at Anse-a-Pitres (Rupp, Inchaustegui, & Arias, 2007) was not available for inclusion in this analysis, but may be included in future continuations of this research (Figure 2).

2.2 Habitat suitability modeling

The use of satellite imagery can further habitat suitability research when the preferences of the species of interest can be associated with distinct spectral and spatial image characteristics (James & McCulloch, 2002; Boyd, Sanchez-Hernandez, & Foody, 2006). Predicting suitable habitat requires that the species of interest is prevalent in the study area or that their preferred environmental attributes are specialized to a point that they have a significant relationship with one or more habitat classes (Debinski, Kindscher, & Jakubausk, 1999). Many of the environmental attributes preferred by Ricord's iguanas are known, and can be measured by utilizing the values of the digital number at each pixel that comprise the multispectral satellite imagery used in this study. In fact, Ricord's iguanas are one of the most specialized of *Cyclura* species (Rupp, Inchaustegui, & Arias, 2007).

2.3 Ricord's iguana habitat characteristics

Ricord's iguanas are strongly associated with thorn scrub woodlands and thorn scrub dry forested areas (Ottenwalder, 1999). They spend most of their time within close proximity to retreats (Arias, Inchaustequi, & Rupp, 2004). Nesting activities tend to begin in March (Rupp, Inchaustegui, & Arias, 2007) with egg laying mostly taking place between May and June (Ottenwalder, 1999). Hatching tends to take place between June and September (Rupp, Inchaustegui, & Arias, 2007). Rainy periods occur in May to June and September to October with December to March being very dry (Ottenwalder, 1999). These periods tend to correspond with the nesting and hatching activities of Ricord's iguanas. In some areas, Ricord's iguanas have heavily utilized dry creek beds and ravines as areas for den construction (Rupp, Inchaustegui, & Arias, 2004).

Key environmental attributes that define suitable Ricord's iguana habitat are soil depth and texture, landform, bedrock parent material, and climate (Ottenwalder, 1999). They prefer sandy (Rupp, Inchaustegui, & Arias, 2004) and relatively fine, porous soil that provides good drainage. The soil needs to be deep enough to support burrows that can expand over time (Ottenwalder, 1999). These areas tend to have a low risk of flooding, which contributes to the stability of the retreats (Ottenwalder, 1999). The plants in these areas can be dominated by succulents, and/or forest (Ottenwalder, 1999). The vegetation is typically distributed and widely spaced without extensive canopy formation. The topography of the land tends to be relatively flat with gently sloping hills. These areas can be periodically divided by steep cliffs and marine terraces. Ricord's iguanas tend to prefer northern or southern slopes when hills are present (Ottenwalder, 1999). This may be due to variations in soil properties and vegetation changes resulting from topographic aspect-induced microclimatic differences (Yimar, Leden, & Abdelkadir, 2006), and the differences in the retention of moisture as a result of differences in slope and aspect which also affects the amount of solar radiation incident upon the surface (Leij, Romano, Palladino, & Schaap, 2004). Ricord's iguanas tend to prefer arid regions with highly seasonal climate (Ottenwalder, 1999).

Researchers with Grupo Jaragua, a Dominican non-profit organization that has been working for biodiversity conservation for the past 15 years, have identified three sub types of habitats frequented by Ricord's iguanas: fondos, Mucara, and Cascajo. Fondos are flat plains and depressions with fine soils and open canopies. These areas are the main locations of retreats and nesting sites (Arias, Inchaustequi, & Rupp, 2004) possibly because of their deep, well drained soils (Rupp, Inchaustegui, & Arias, 2007). Mucara are mainly dominated by limestone and open canopy vegetation. The vegetation in these areas tends to be more diverse than what is found in fondos. Cascajo are composed of a higher percentage of gravel and small boulders than fondos with a mix of vegetation that is found in fondos and mucara. These areas are also used by Ricord's iguanas as nesting and retreat sites (Arias, Inchaustequi, & Rupp, 2004).

Despite data on habitat preferences of Ricord's iguana, no published studies that model habitat suitability for this species using remotely sensed imagery and digitally mapped data layers were found in a review of the literature. Satellite imagery has been used on a limited basis for visual interpretation of potential research sites by Grupo Jaragua in their work studying Ricord's iguanas (Rupp, Inchaustegui, & Arias, 2004), but this group has not developed a habitat suitability model (Rupp, Inchaustegui, & Arias, 2007).

3. Methods & Data

3.1 Sightings data collection

The locations of Ricord's iguana, and the dens and nests attributable to them, were collected by two groups. Grupo Jaragua collected sightings data on the southern shore of Lago Enriquillo, the Pedernales, and Anse-a-Pitres. These sightings were collected during April through November 2003, and January through December 2006. The sightings from the Lago Enriquillo and Pedernales areas were acquired for inclusion in this study. The sightings data associated with the Haitian subpopulation at Anse-a-Pitres were not included in this study because the data had not been incorporated into Grupo Jaragua's existing database. Dens and nest sites can sometimes be differentiated between Ricord's and Rhinoceros iguanas by inspecting the tail drag marks found in the area (Arias, Inchaustequi, & Rupp, 2004). The den and nest sightings collected by Grupo Jaragua were differentiated from Rhinoceros iguana dens and nests using this method. A total of 94 sightings were acquired, with 52 located in study site 1 and 42 in study site 2. Grupo Jaragua researchers collected the geographic coordinates of the sightings using a Garmin GPS 12 Map handheld unit (Garmin, 2000).

Ricord's iguana sighting data also were collected by Indianapolis Zoo researchers on Isla Cabritos. These data were collected during three trips in 2003 and one in 2008 resulting in 155 sightings comprised of direct Ricord's iguana sightings and their dens. The Indianapolis Zoo researchers differentiated Ricord's iguana dens from those of the Rhinoceros iguana based on differences in the dimensions of the entrance and their location. Ricord's iguana dens tend to have openings with a greater spread of excavated soil and are commonly associated with areas of thorny vegetation. Dens of the

Rhinoceros iguana typically have openings with larger soil particles with less spread of soil and tend to be in more open areas (Ramer, 2004). All of the sightings collected by Indianapolis Zoo researchers were located in study site 1. Geographic coordinates of sightings were determined using two Garmin eTrex venture HC units and one Garmin GPS 12 Map unit while walking north south transects. The eTrex model provided 10 meter accuracy without enabling Wide Area Augmentation System (WAAS) (Garmin, 2007) while the GPS 12 Map unit provided 15 meter positional accuracy (Garmin, 2000). When a sighting was made, the researcher moved along the transect to a point perpendicular to the sighting where the location was recorded. Then the perpendicular distance from the transect to the sighting location was measured to determine how far the sighting was from the transect. This data will also be used as part of a population survey for Ricord's iguanas (Indianapolis Zoological Society, 2007).

Data collected by Grupo Jaragua were joined with an existing GIS database of the sightings collected by Indianapolis Zoo Project Iguana researchers. The pooled sightings were then randomly divided into two groups. The first group served as training data that were used to capture an expression of the environmental attributes found at sighting locations in development of the habitat suitability model. The second group was used in the post model accuracy assessment. The training set consisted of 124 sightings with 98 being located in study site 1, and 26 located in study site 2. The assessment set consisted of 125 sightings. Of these, 99 were located in study site 1 while 26 were located in study site 2. Study site 1 contains 197 total sightings and study site 2 contains 52 total sightings. These totals were divided so that approximately half the available sightings in each study site were used for training and half for post model accuracy assessment.

3.3 Terrain data

Terrain data can be used to derive important variables for habitat suitability models (Osborne, Alonso, & Bryant, 2001; Tucker, Rushton, Sanderson, Martin, & Blaiklock, 1997; Danks, & Klein, 2002; Boyd, Sanchez-Hernandez, & Foody, 2006; and Wallace & Marsh, 2005). Terrain variables used in the current study included slope and elevation. In addition, the evaluation of an existing aspect dataset was performed to determine its appropriateness for inclusion in this or future studies. These variables were derived from SRTM Level-2 (30 meter spatial resolution) digital elevation models (DEMS) as processed by researchers at the International Centre for Tropical Agriculture (CIAT) (Jarvis, Reuter, Nelson, & Guevara, 2006). Aspect refers to the direction of maximum rate of change in elevation between each cell and its eight neighbors, and it is measured from 0 – 360 degrees. Aspect can also be thought of as the direction of the steepest tilt (Heywood, Cornelius, & Carver, 2002). Slope measures the steepness or gradient of a pixel with the values falling between 0 and 90 degrees when the slope is expressed as a percentage (Jarvis, Reuter, Nelson, & Guevara, 2006).

3.4 Climate data

Climate variables evaluated for use in the habitat suitability model include monthly precipitation, monthly minimum temperature, monthly maximum temperature, annual mean temperature, and annual precipitation. These data were downloaded from WORLDCLIM (http://www.worldclim.org/), which provides global climate layers developed by researchers at the Museum of Vertebrate Zoology at the University of

California Berkley, the International Center for Tropical Agriculture (CIAT), and Rainforest CRC (Cooperative Research Centre for Tropical Rainforest Ecology and Management). The database contains climate data in grid format that cover all global land areas excluding Antarctica. These layers consist of 30 arc-second (~ 1 kilometer) grids that were generated through interpolation of average monthly climate data from weather stations collected between 1950 and 2000 (Hijmans, et al., 2005).

3.5 Satellite imagery

Landsat Enhanced Thematic Mapper Plus (ETM+) multispectral imagery covering the study areas was acquired from the Global Land Cover Facility (GLCF) at the University of Maryland (GLCF, 2008). Landsat imagery was selected for this pilot study because these data are freely available and provide spectral sensitivity that permits derivation of potentially important biophysical characteristics like principal components analysis, image texture, and the Kauth-Thomas tasseled cap transformation.

3.6 Information extraction from Landsat imagery

Three analytical methods were used to derive biophysical variables from the satellite imagery for evaluation in the habitat suitability model: principal component analysis (PCA), the Kauth-Thomas Tasseled Cap transformation, and a measure of image texture.

3.6.1 Principal components analysis (PCA)

Interband correlation is frequently encountered when using multispectral imagery as a result of separate wavelength bands conveying similar information (Lillesand, Kiefer, & Chipman, 2004). PCA can be used to eliminate data redundancy between bands resulting in a smaller dataset composed of uncorrelated variables (Jensen, 2005). The new dataset is comprised of bands with decreasing amounts of scene variance (Jensen, 2005). For instance, the first principal component explains the largest percentage of the variance found in the original dataset with each subsequent band explaining decreasing amounts of scene variance (Lillesand, Kiefer, & Chipman, 2004). Essentially, the purpose of this procedure to express what is found in *n*-bands of the original image in less than *n*-bands of the PCA image, thus reducing the images dimensionality (Jensen, 2005). The new number of bands that express the majority of the scene variance is often referred to as the images intrinsic dimensionality (Lillesand, Kiefer, & Chipman, 2004). The PCA transformation can lead to increased efficiency when the newly created bands are used in place of the original data because the number of components used is typically reduced to the data’s intrinsic dimensionality (Lillesand, Kiefer, & Chipman, 2004).

3.6.2 Kauth-Thomas tasseled cap transformation

The Kauth-Thomas tasseled cap is a widely-used, orthogonal linear transformation often applied to Landsat imagery that establishes three new axes of the spectral data (Jensen, 2005). This is done by rotating the data so that the new bands of imagery are more directly related to biophysical scene characteristics (Lillesand, Kiefer, & Chipman, 2004). The tasseled cap variables evaluated as part of this study and included brightness, greenness, and wetness. Brightness is a weighted sum of the data found in all the original bands, and typically is defined in the direction of variation in soil reflectance (Jensen, 2005). Greenness is associated with the amount of green vegetation found in the image (Lillesand, Kiefer, & Chipman, 2004). Wetness is associated with moisture content of soil and vegetation canopies (Lillesand, Kiefer, & Chipman, 2004).

3.6.3 Image texture data

Processing of remotely sensed imagery often focuses on reflectance values for individual pixels locations. However, other factors, like image texture, can yield valuable information about a scene (Jensen, 2005). Image texture can be thought of as a measure of the structure of a group of pixels which incorporates spatial context (Wallace & Marsh, 2005). Texture is visually interpreted as changes in brightness and color. This information can potentially be used to distinguish differences in habitat (Tuttle et al., 2006). When considering the texture of a scene, an *n* x *n* pixel window is employed to quantify variations in brightness values within the pixel window (Jensen, 2005). Some areas may show little variation, indicating the area within the window is similar in composition or spectrally homogeneous. Greater variation may indicate a window that encompasses pixels representing different habitats and higher texture values. Texture data are most often incorporated in an analysis as a separate band where the value of the pixel represents the texture found in the pixel group (Jensen, 2005). Image texture has previously been used in habitat suitability modeling by Wallace & Marsh (2005), Pasher, King, & Lyndsey, 2007), and Tuttle et al. (2006).

3.6.4 Land cover data

Land cover data used in this study were created by researchers associated with the Global Land Cover Facility (GLCF). The data set was created using the red and infrared portions of the spectrum, thermal data, and Normalized Difference Vegetation Index (NDVI) data. This combination of bands was chosen because it can help to discriminate between vegetation cover types (Hansen, et al., 2000). The data were constructed from AVHRR Pathfinder imagery which has a spatial resolution of 1 kilometer. The training sites used in the classification process were acquired by the Landsat Multispectral Scanner System (MSS), Landsat Thematic Mapper (TM), and the Linear Imaging Self-Scanning Sensor (LISS) (Hansen, et al., 2000). These resulting global land cover map is comprised of comprised of 13 classes.

3.7 Data sources

The data used in this research project came from several sources. The geocoded locations of Ricord's iguanas' nests and dens collected by researchers from Grupo Jaragua and the Indianapolis Zoo were used to determine the values of environmental predictors. Landsat satellite imagery was used to estimate landscape biophysical characteristics. Additionally, terrain data from the Shuttle Radar Topography Mission (SRTM) provided information on topographic slope, aspect, and elevation. Data from the WORLDCLIM database of bioclimatic variables including monthly precipitation, monthly minimum temperature, monthly maximum temperature, annual mean temperature, and annual precipitation were also evaluated. The values from these data sources were measured or interpolated at the sighting locations to determine the range of values that represent the characteristics of habitat preferred by Ricord’s iguanas. All GIS and remote sensing operations were conducted using components of ArcGIS 9.2 and ERDAS IMAGINE 9.2.

3.7 Hierarchical Bayesian modeling

A model to estimate the probability that a pixel is suitable habitat for Ricord’s iguana was developed by evaluating the previously mentioned environmental attributes using Bayesian statistical methods. The model predicts the probability that an area is suitable habitat based on the values of the environmental attributes at each pixel. Bayesian methods are useful when the goal is to make inferences based on probabilistic statements pertaining to an area (McCarthy, 2007). This approach is valuable because it can incorporate prior information of species presence that is conditional on the value of the environmental attributes (McCarthy, 2007), by combining prior knowledge, likelihood values, and data in a model to yield posterior probability (Spiegelhalter, Thomas, Best, & Lunn, 2003). The posterior probability is the updated prior probability calculated with Bayesian methods. This combination of the prior evidence or observations and new data has the effect of adjusting probabilities given new evidence in a logically consistent, objective, and repeatable way (McCarthy, 2007).

Bayesian analysis was implemented using WinBUGS, a freely available analytical software package. The acronym WinBUGS refers to the Windows version of Bayesian inference using Gibbs sampling (Spiegelhalter, et al., 2003). WinBUGS was developed by the Medical Research Center (MRC) Biostatistics Unit, Cambridge, UK and the Department of Epidemiology and Public Health of the Imperial College School of

Medicine at St Mary's Hospital in London (Lawson, Browne, & Vidal Rodeiro, 2003). Gibbs sampling has become a very popular sampling method when hierarchical Bayesian methods are employed (McCarthy, 2007). This application utilizes Markov Chain Monte Carlo (MCMC) methods for sampling the posterior distribution. A Markov chain is a series of random numbers where each number is determined by the value of the previous number (McCarthy, 2007). Monte Carlo simulation is a relatively common method that refers to the process of iterative simulation of values within a Markov chain (Lawson, Browne, & Vidal Rodeiro, 2003), and is commonly used to estimate the probability that uncertain events may occur (McCarthy, 2007).

The habitat suitability model developed in the current study required a number of iterations for the posterior distribution to become stable or to reach convergence. Convergence occurred through the implementation of an iterative estimation algorithm that began with arbitrary values and eventually ended with convergence to a target value (Lawson, Browne, & Vidal Rodeiro, 2003). During each iteration of the habitat suitability model the posterior probability was updated until an equilibrium distribution of the Markov chain occurred resulting in the posterior probability value becoming stable (Lawson, Browne, & Vidal Rodeiro, 2003). Since the first iterations of this habitat suitability model did not converge to an equilibrium distribution, these first sets of iterations were disregarded (McCarthy, 2007). Convergence should be checked to determine if the values have stabilized (Lawson, Browne, & Vidal Rodeiro, 2003). Since WinBUGS offers trace plots to help determine when convergence has been reached, these trace plots were evaluated to ensure that the process had occurred. Bayes theorem has been employed by using various methods in habitat suitability modeling as seen in

Osborne, Alonso, & Bryant, 2001; Tucker, Rushton, Sanderson, Martin, & Blaiklock, 1997).

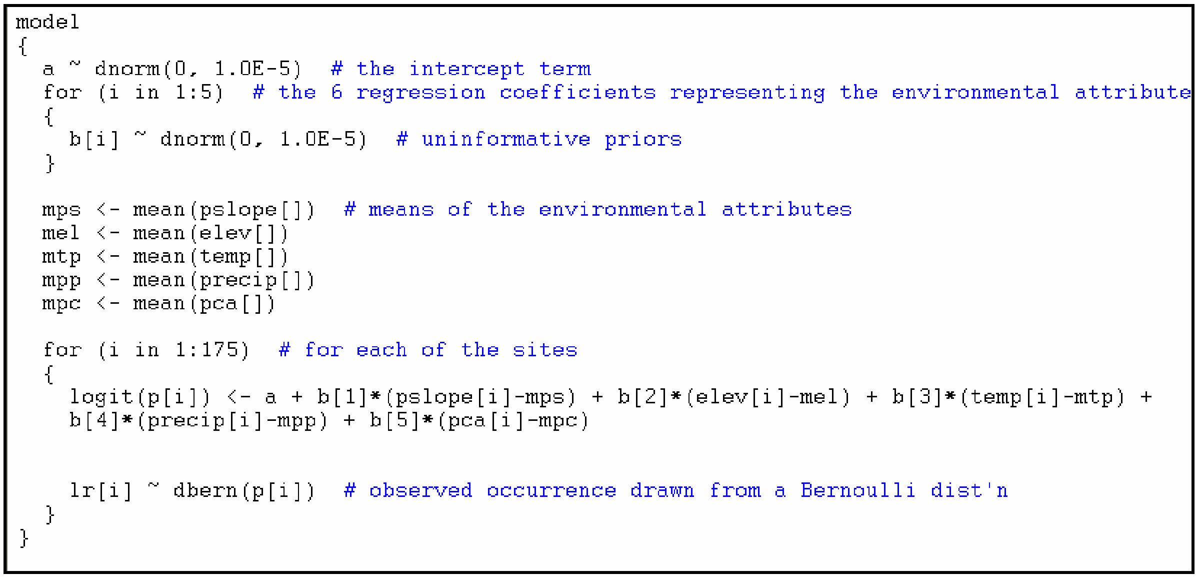
3.8 Habitat classification and visualization

The probability predictions derived from the model were joined to existing GIS layers based on a common field. These data were evaluated to determine what percentage of the known sightings of Ricord’s iguanas, nests, and den sights from the assessment dataset fell within the boundaries of suitable habitat predicted by the model.

4. Results

4.1 WinBUGS model

The model used in this study was a logistic regression model written in WinBUGS format (Figure 3). The code for logistic regression modeling was modified from McCarthy (2007) as an example of modeling distribution based upon environmental attributes measured at each unit in a study area. This model is designed to center the data by subtracting the mean value from the individual value of each environmental variable. This was done to reduce the amount of correlation between consecutive samples and to improve the efficiency for the MCMC sampling process (McCarthy, 2007). This model did not include an explicit spatial component because the two study areas were not contiguous. Future research would benefit from the incorporation of methods to account for spatial autocorrelation. Spatial autocorrelation refers to the concept that spatial units that are closer together share more in common than those that are farther apart, and it is a potential problem with data that they have a spatial element. For example, the values of the environmental attributes in neighboring pixels utilized in this study are likely to be similar. Incorporating measures to account for spatial autocorrelation could result in more stable estimates for parameters utilized in the model (Lawson, Browne, & Vidal Rodeiro, 2003).



```
model
{
  a ~ dnorm(0, 1.0E-5)  # the intercept term
  for (i in 1:5)  # the 6 regression coefficients representing the environmental attribute
  {
    b[i] ~ dnorm(0, 1.0E-5)  # uninformative priors
  }

  mps <- mean(pslope[])  # means of the environmental attributes
  mel <- mean(elev[])
  mtp <- mean(temp[])
  mpp <- mean(precip[])
  mpc <- mean(pca[])

  for (i in 1:175)  # for each of the sites
  {
    logit(p[i]) <- a + b[1]*(pslope[i]-mps) + b[2]*(elev[i]-mel) + b[3]*(temp[i]-mtp) +
    b[4]*(precip[i]-mpp) + b[5]*(pca[i]-mpc)


    lr[i] ~ dbern(p[i])  # observed occurrence drawn from a Bernoulli dist'n
  }
}
```

Figure 3 – Habitat suitability model for Ricord's iguana in WinBUGS format adapted from McCarthy 2007

4.2 Variables excluded in final model

4.2.1 Aspect

Aspect was not evaluated as part of the modeling process because the dataset was not complete. Portions of study site 1, specifically on Isla Cabritos, did not have values associated with them. Unfortunately, this made the prediction of Ricord's iguana habitat suitability using the aspect dataset impossible. This may have been due to the variability of the water level in Lago Enriquillo. Lago Enriquillo is the largest lake in the Caribbean (Buck, et al., 2005), and Isla Cabritos is an island that measures approximately 12 x 2 kilometers. The highly seasonal variation in precipitation is partially affected by tropical depressions and hurricanes which make the level of the lake vary based on seasons and between years (Buck, et al., 2005). Additionally, the lake experiences extreme changes in water level on a 15 – 30 year cycle. These extreme changes are due to severe droughts and high evapotranspiration (Ottenwalder, 1999). One example of the variability in water level occurred during 1979 – 1980 when the level of the lake changed by 3 meters (Ottenwalder, 1999). Additional evaluation of aspect as a parameter in a habitat suitability model for Ricord's iguanas would be extremely beneficial in the continuation of this research. When the research is continued, an aspect layer will be created from the DEM used in the study. This will ensure that no gaps in the dataset are present, and will help to answer questions about how aspect fits into Ricord's iguana habitat suitability. Currently, it is not clear if the preferences for northern or southern slopes by Ricord's iguanas are linked to the population on Isla Cabritos which is dominated by an east west ridge that leads to a predominance of northern and southern slopes or if the preference for northern and southern slopes extends to the other subpopulations.

4.2.2 Image texture

The image texture dataset was not utilized in the final model. The addition of the texture component to earlier models created as part of this study did not show any significant influence on the overall accuracy of the probabilities when applied to the post model accuracy assessment dataset. It was thought the inclusion of image texture techniques would be a way to capture a quantification of vegetation canopy and/or landform characteristics preferred by Ricord's iguana. However, the method used and the spatial resolution of the imagery resulted in a very spectrally homogenous depiction of the area. The continuation of this research with finer spatial resolution data could include the evaluation of a number of image texture techniques to determine if one of these methods adds to the overall accuracy of the probability predications.

4.2.3 Land cover

The land cover dataset was not utilized in the final model because it did not add to the overall predictive capabilities. This data set was evaluated as a part of an earlier model as a separate component and not as an alternative to either the tasseled cap or the PCA datasets. The poor performance of this model variable may be due to the relatively coarse spatial resolution of the land cover data, and the lack of a regional classification focus that would more closely correspond to the types of land cover found in the study region. The land cover dataset classified several pixels with Ricord’s iguana sightings as water. These pixels were found on Isla Cabritos and the southern shore of Lago Enriquillo and are most likely due to the same fluctuation of the water level that potentially affected the aspect dataset. A classification based on finer spatial resolution imagery with more thematic detail on the land cover types common in the study region (and not the entire globe) may be a valuable explanatory component.

4.2.4 Tasseled cap

The tasseled cap dataset was not utilized in the final model because the PCA dataset performed better. The addition of the tasseled cap dataset resulted in an overall lower probability prediction for the assessment set with approximately 57% of the post accuracy assessment pixels being classified with high suitability compared to the approximately 63% when the PCA dataset was utilized. If finer resolution imagery is obtained, the tasseled cap derived from these images would be evaluated for inclusion in that model.

4.3 Variables included in final model

4.3.1 Slope

Slope was measured as a percentage, and was divided into five classes based on criteria defined by Hansen et al. (2000). The slope classes include: Level, Gently Sloping, Undulating, Rolling Hills, Steep Hills, and Mountain (Table 2). These classes can be matched with descriptions in the literature that describe the slope preferences of Ricord's iguana where it is stated that Ricord's iguanas prefer flat to gently sloping hills (Ottenwalder, 1999). Slope values found in sites 1 and 2 ranged from 0 – 90 percent with a mean of 9.20 and standard deviation of 5.46 (Table 3).

Table 2 – Classification of the percent slope variable

.Class	Range
Level – Gently Sloping	0 – 3.0%
Gently Sloping – Undulating	3.1 – 8.0%
Undulating – Rolling Hills	8.1 – 18.0%
Rolling Hills – Steep Hills	18.1 – 30.0%
Steep Hills – Mountain	30.1 – 90.0%

Table 3 – Descriptive statistics for environmental variables

	Site 1					Site 2					Site 1 & 2 Combined				
Attribute	**Min**	**Max**	**Range**	**Mean**	**SD**	**Min**	**Max**	**Range**	**Mean**	**SD**	**Min**	**Max**	**Range**	**Mean**	**SD**
Slope	0	90	90	11.96	6.66	0	90	90	6.44	4.27	0	90	90	9.20	5.46
Elevation	-43	439	482	32.83	56.83	6	393	387	101.21	51.88	-43	439	482	67.02	54.35
PCA	24	28	3.70	170.08	29.80	24.1	27.20	3.10	143.06	33.07	24.1	28	3.9	156.57	31.46
Annual Mean Temp.	602	1246	644	273.33	4.44	501	1167	666	264.46	4.17	501	1246	745	26.99	4.30
Annual Precip.	100	372	272	732.60	68.08	90	439	349	650.98	88.33	90	439	349	691.79	78.20

4.3.2 Elevation

Elevation was not explicitly mentioned in the habitat preferences of Ricord's iguana discussed in the literature. However, these sources do mention that some populations of Ricord's iguanas inhabit "lowlands" and "lower foothills" (Ottenwalder, 1999). In one example, Rhinoceros iguanas have been found at higher elevations near lower elevation Ricord's iguana habitat with a shared marginal area between (Ottenwalder, 1999). In this instance, the higher elevation area has similar temperature, but higher rainfall (Ottenwalder, 1999). Elevation values found in both study areas range from -43 to 439 meters above sea level with a mean of 67.02 and standard deviation of 54.35 (Table 3).

4.3.3 Annual Mean Temperature

Ottenwalder (1999) reported the annual mean temperature of two representative Ricord's iguana habitats ranged from 23.6 – 28.1 degrees Celsius. The lowest temperature found in the study site data utilized in the habitat suitability model was 24.1

and the highest temperature was 28.0 degrees Celsius. This shows that the annual mean temperature values found in the study areas are similar to established values found in the literature for Ricord’s iguana habitat. The range in values found in both study areas range from 24.1 – 28 degrees Celsius with a mean of 26.99 and standard deviation of 4.30 (Table 3).

4.3.4 Annual precipitation

The WORLDCLIM precipitation dataset used in this study contains values measured in millimeters. For the initial dataset evaluation, these values were classified into 6 classes based on those suggested by Wimberly, Baer, & Yabsley (2008) with the first two being representative of Ricord’s iguana habitat preferences found in the literature (Table 4). Ottenwalder (1999) reported annual precipitation is 470.6 millimeters in study site 1, and 633.3 millimeters in study site 2. Annual precipitation data derived from the WORLDCLIM data set for both study areas ranged from 501– 1216 millimeters with a mean of 691.79 and standard deviation of 78.20 (Table 3). For the final evaluation and inclusion in the model, the precipitation variable was further aggregated into two classes defined as xeric or not xeric. Xeric environments are those with very little moisture (United States Department of Agriculture, 2008). For the purpose of this study, xeric values fall within precipitation classes 1 and 2 because these values represent the driest found in the study areas. Additionally, these values are similar to examples of Ricord’s iguana habitat preferences found in the literature as reported by Ottenwelder (1999). “Non xeric” includes classes 4 – 6, representing higher values than those shown for Ricord's iguana habitat preferences. Xeric was represented by a 1 and not xeric as a 0 in the habitat suitability model.

Table 4 – Classification of the annual precipitation measured in millimeters

Range (mm)	Class	Xeric / Non-Xeric
0 – 366	1	Xeric
366.1 – 770	2	
770.1 – 1,290	3	Non-Xeric
1,290.1 – 1,993	4	
1,993.1 – 2,976	5	
2,976.1 – 11,401	6	

4.3.5 PCA

The PCA dataset provided a higher level of accuracy in predicting the probability for the post model accuracy assessment dataset while ultimately utilizing fewer parameters as compared to the tasseled cap dataset. The tasseled cap dataset was evaluated utilizing the greenness, wetness, and brightness bands, but it did not reach the level of accuracy for the probability predications when they were applied to the post model accuracy dataset as the model employing the PCA. Additionally, a model utilizing the PCA band 1 was evaluated and it performed as well as the model using PCA bands 1 – 3 as individual components of the model when the probability predictions associated with the post model accuracy assessment dataset were measured at the tenths level. The PCA value at each pixel was used without further classification because a relevant classification scheme was not found in a review of the literature. PCA values found in both study areas ranged from 90 to 439 with a mean of 156.57 and standard deviation of 31.46 (Table 3).

4.3.6 Sightings datasets

The sightings data used to specify the model were used to divide the study sites into values of 1 or 0 based on whether there was a Ricord's iguana sighting at a location. The values for the environmental attributes found in sightings pixels (both separately and combined) showed some variation from the values found in all pixels (sightings and no sightings) found in the study sites (Table 5).

The mean slope in sightings pixels was 4.90% (sites 1 and 2 sighting pixels combined), while the mean slope value of all the pixels found in both study sites was 9.20%. Elevation also showed a difference with the sightings pixels having a mean value of 73 meters while the values representing all the pixels found in both study sites had a mean of 63.02 meters. Another difference between the environmental attributes of pixels with sightings vs. the set of all pixels in both study sites was the mean values of the PCA. The mean PCA value found in the sightings dataset was 152 compared to a value of 156.57 for all pixels in both study sites (Table 5).

A comparison of the elevation attribute shows that sightings pixels had a slightly higher mean value for elevation when compared to all pixels in both study areas. However, a comparison of mean values between sightings pixels located in study site 1 and study site 2, show values of 49 and 163.77 (Table 5). This may be due to the group of pixels in study area 1 with values below sea level. The range of values for study site 1 is -43 to 439 meters (Table 3).

In other attributes, a comparison of the descriptive statistics of the sightings pixels and all pixels found in both study areas show less variation. The mean values for annual mean temperature and annual precipitation showed little difference between sightings pixels and all pixels found in both study areas (Table 5). The value of these variables in future habitat suitability models would potentially be much greater when a larger, more varied study area is explored.

Overall, comparison of descriptive statistics between sightings locations and the study region as a whole indicates Ricord's iguana tend to be located on sites with lower slope, somewhat higher elevation, and lower PCA values. Even though the values of annual mean temperature and annual precipitation show little variation between sightings pixels and all pixels found in both study sites, the values indicate that Ricord's iguanas prefer areas with higher temperatures and lower annual precipitation. These findings are consistent with habitat preferences discussed in the literature as summarized in section 2.3.

Table 5 - Descriptive statistics for environmental attributes associated with sightings pixels vs. all pixels

	Sightings Pixels						All Study Area Pixels	
	Site 1		Site 2		Site 1 & 2 Combined			
Attribute	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Slope	3.73	6.25	9.34	7.92	4.9	7	9.20	5.46
Elevation	49	114	163.77	123.47	73	125	67.02	54.35
PCA	156.10	30.98	138.56	37.27	152	33.10	156.57	31.46
Annual Mean Temp.	27.02	10.43	25.91	9.94	26.80	11.26	26.99	4.30
Annual Precipitation	685.14	134.89	754.87	216.73	699.7	157.63	691.79	78.20

Differences between the environmental attributes of study site 1 and study site 2 sightings pixels are summarized in Table 5. The mean elevation in study site 1 was 49 meters above sea level with standard deviation of 114, while study site 2 had a mean value of 163.77 and a standard deviation of 123.47. The average annual precipitation in study site 1 was 685.14 millimeters with a standard deviation of 134.89, while study site 2 had a mean of 754.87 with a standard deviation of 216.73. The values of the PCA dataset found in study site 1 were slightly higher (Table 5).

The greatest variation between the two study sites can be found by comparing the mean values of the elevation attribute. Study site one contains the lowest elevations on the island which explains why the mean values of the two study sites exhibit so much variation. This difference in elevation could be partially responsible for the variation found in the other attributes. The higher elevation mean value associated with Study site 2 could contribute to the higher mean and higher standard deviation values for slope, lower mean values for annual mean temperature, and higher mean values for annual precipitation. The variation in all of these values could contribute to the lower mean values for the PCA variable.

As previously stated, the sightings data were divided into training and post model assessment sets. When environmental attributes were compared between these two datasets, one main difference emerged. The elevation of the post model assessment dataset was higher in all measures. The mean value of the post model assessment dataset was over two times higher than that for the training dataset with values of 106.32 and 55.62 (Table 6). This difference in values between the assessment and training datasets may have been a barrier to higher levels of accuracy in the probability measures predicted by this model.

Despite the difference in this value, the other environmental attributes showed little variation. The mean value for slope in the training dataset was 8.15 (Table 6) which falls within the undulating (8.1%) – rolling hills category (18%) (Table 3). The value may be higher than expected given that the literature describes the habitat preferences of Ricord's iguanas as typically flat to gently sloping (Ottenwelder, 1999). However, the mean value is only .05% above the gently sloping (3.1%) – undulating (8.0%) category which correspond more closely with those indicated by the literature. The post model assessment dataset has a mean slope value of 6.54 (Table 6) which falls within the gently sloping (3.1%) – undulating (8.0%) category (Table 3). The mode for the training and the post model assessment datasets are both within the level to gently sloping category with values of 4.16 and 2.08 respectively. The PCA values of the post model assessment dataset were lower than that of the training dataset, with values of 147.33 and 161.07. The annual precipitation values for both sets fell within the xeric classification detailed in section 4.3.4 and outlined in Table 4. The annual mean temperature variable showed little variation with less than one degree difference between the training and post model assessment datasets (Table 6).

Overall, the descriptive statistics associated with the training and post model accuracy assessment datasets correspond with Ricord's iguana habitat characteristics outlined in the literature and section 2.3. In addition, the values between the training and post model assessment datasets show little variation except for the difference in values associated with elevation.

Table 6 – Training and post model assessment data comparisons

Sightings Pixels				
	Training Dataset		Post Model Assessment Dataset	
Attribute	Mean	SD	Mean	SD
Slope	8.15	4.86	6.54	7.09
Elevation	55.62	55.18	106.32	118.74
PCA	161.07	30.89	147.33	34.13
Annual Mean Temp.	27.03	4.35	26.46	10.19
Annual Precipitation	705.39	74.83	720	198.31

4.3.7 Model results

This study resulted in the production of habitat suitability maps that contain estimates for each pixel on the probability that it is suitable habitat for Ricord’s iguana. The habitat suitability maps for study sites 1 and 2 are shown in Figures 5 & 6, respectively. Study site 1 showed large aggregations of pixels with very high probability predications of 0.9 – 1.0 with smaller areas of pixels with mixed distributions. The vast majority of pixels that comprise Isla Cabritos, the island in study area 1, had probability predictions of $\geq$.7 (Figure 4). It is possible that the addition of higher spatial resolution datasets would provide a different classification with potentially lower probability predications over portions of the island. This is possible because researchers have indicated that portions of the rocky plateau on the island typically yield low numbers of Ricord’s iguana sightings (Ramer, 2004). This phenomenon is not seen in the probability predications of this model.

Study site 2 showed a large area of very high probability predications of $\geq$.9, but it also had a large area where pixels with high levels of probability were mixed with pixels classified with lower probability predications. This area of mixed pixels was much larger and more widespread than the areas of pixels with mixed distributions found in study area 1. These areas are found in portions of the study area with increasing elevation values as well as differences in annual mean temperature and annual precipitation (Figure 5). This combination of differences was not seen in study site 1 and may have contributed to this pattern of probability predications.

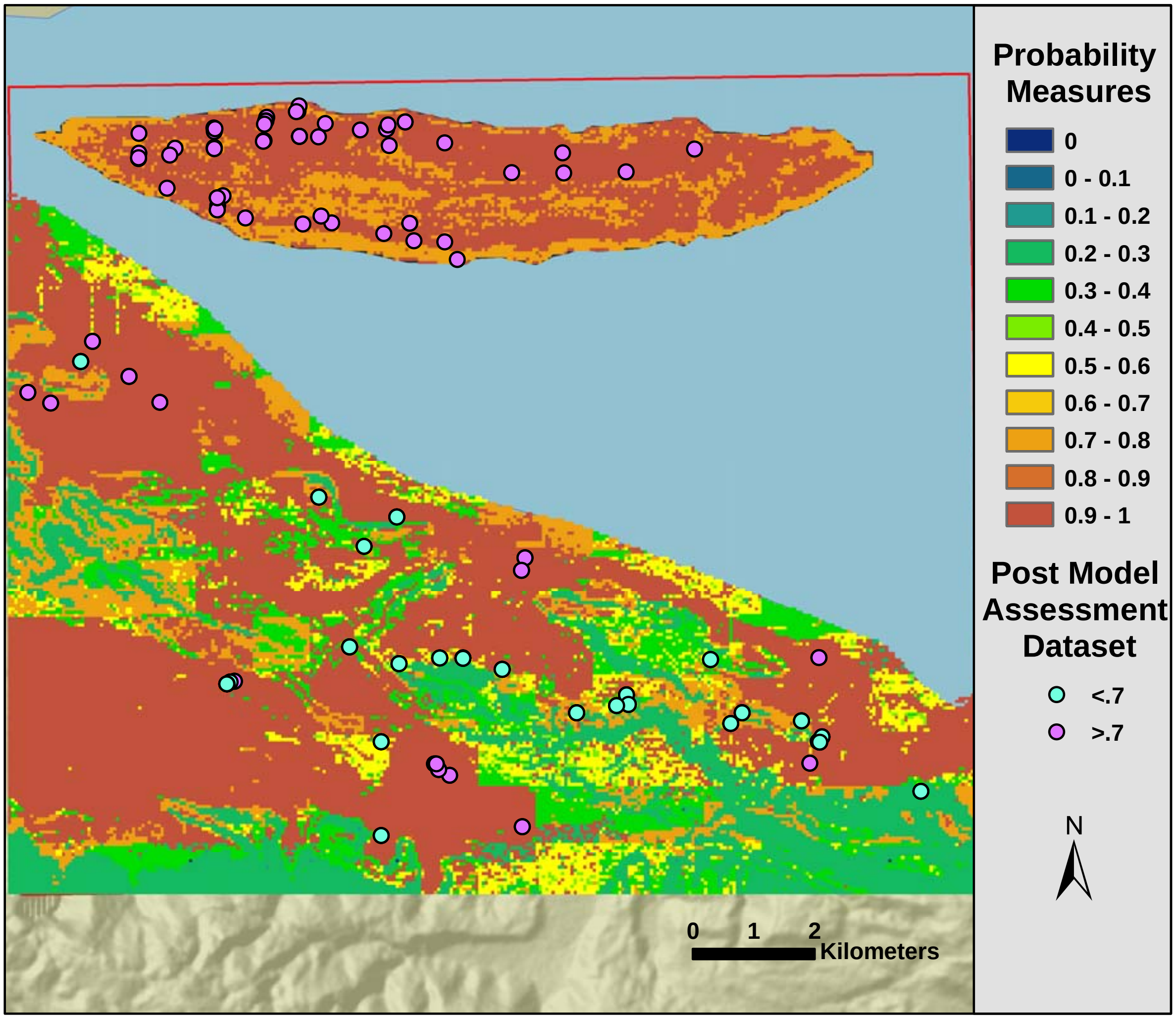


Figure 4 – Probability of suitable habitat with locations of sightings post model accuracy assessment dataset – study site 1

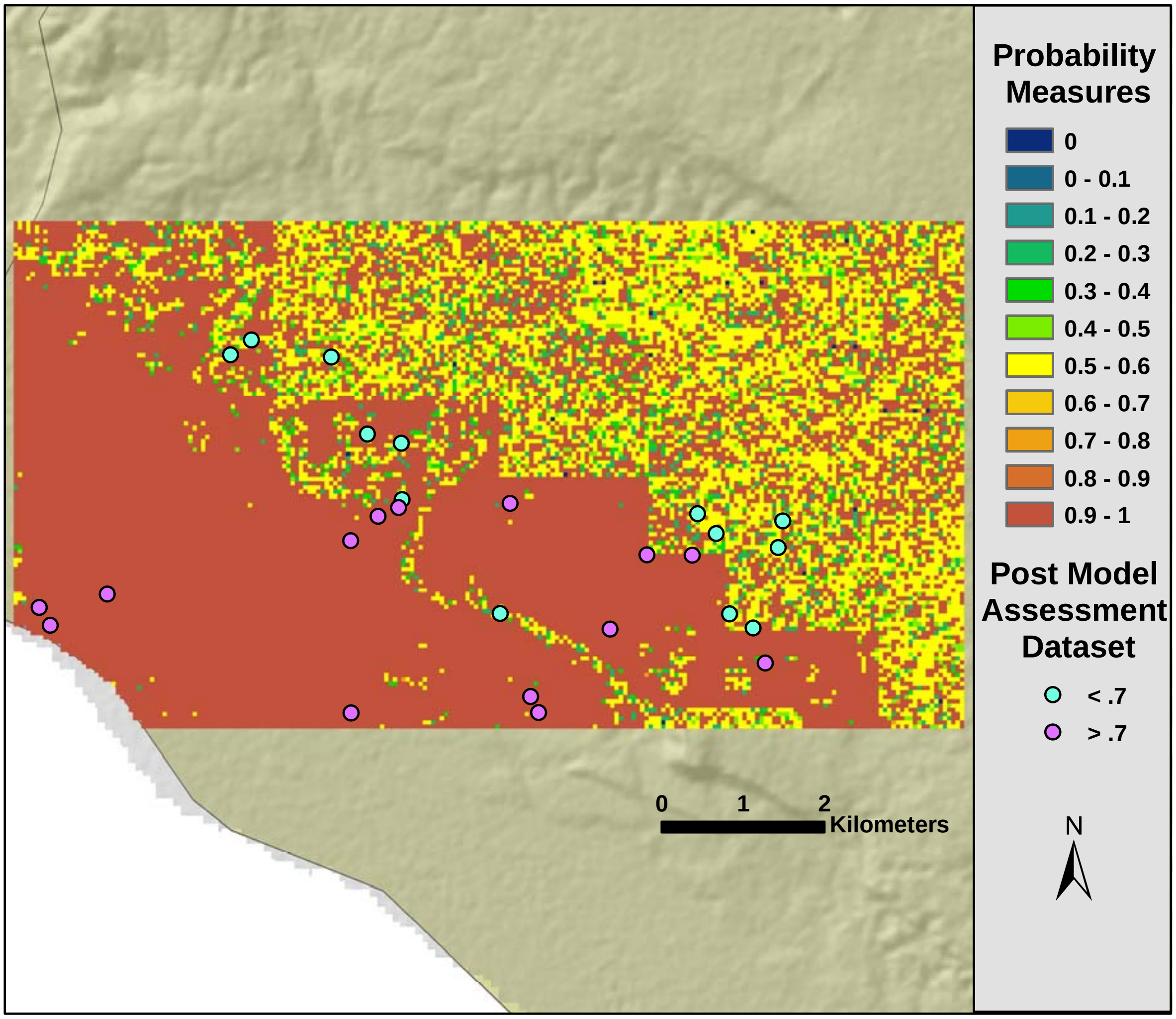


Figure 5 – Probability of suitable habitat with locations of post model accuracy assessment dataset – study site 2

Assessment pixels were used to derive an indication of the overall accuracy of the habitat suitability maps. The determination of a probability threshold to evaluate the habitat suitability maps was informed by the work of Pasher, King, and Lindsay (2006) that used a probability threshold of ≥ 0.7% as a measure of high probability in their study of hooded warbler habitat. The distributions of the probability predictions when the ≥0.7% high probability measure was applied are shown in Figures 6 & 7.

The distribution of the post model accuracy assessment dataset pixels in study site 1 showed all the pixels located on Isla Cabritos were above the 0.7 threshold. This may be partially due to the spatial resolution of the datasets which yielded a less detailed distribution of probability predications than predications from a future model that could utilize higher spatial resolution datasets. In general, the probability predictions for the southern shore of Lago Enriquillo showed large connected areas classified as being $\geq$ 0.7. These areas were surrounded by areas with probability predications $\leq$ 0.7. When the probability predications are viewed at this threshold, this study site showed only small areas of mixed probability distributions.

The distribution of the post model assessment set pixels in study site 2 showed a large area classified as being $\geq$ 0.7, and a large area of pixels with mixed probability distributions. Many of the post model assessment pixels classified as being $\leq$ 0.7 found in both study sites were in areas with a high concentration of pixels classified as being $\geq$ 0.7. The fact that the locations of these post model accuracy assessment pixels were located in areas classified as being $\leq$ 0.7 may be partially due to the accuracy of the locations of the sightings data or an iguana sighted while on the move between areas classified with higher probabilities.

Researchers from the Indianapolis Zoo plan to fit several Ricord's iguanas with radio transmitters as part of their continuing work on Isla Cabritos. This research plans to use radio telemetry techniques to locate and track these individuals, and to record their locations and behaviors during tracking periods (Indianapolis Zoological Society, 2007). If this type of data were part of future habitat suitability research, these studies could explore how much time the tagged iguanas spend in areas classified as being $\leq$ 0.7 and if their behaviors in these areas differ from behaviors exhibited when the iguanas are in areas classified as being ≥ 0.7. This information could lead to a more detailed picture of Ricord's iguana habitat suitability by determining how long the iguanas spend in less than optimal habitat and if areas with lower probability predictions are associated with specific behaviors.

The maps in this study were also evaluated against a more conservative threshold of ≥ 0.9% probability. Table 7 shows the distribution of probability values for the 155 sighting locations included in the assessment data set. More than 60% of the assessment pixels were classified by the model as having ≥ 90% probability of being suitable habitat. The model correctly predicted 79 of the 125 assessment pixels (63.20%) as occurring in suitable habitat pixels using the 0.7 threshold. When the 0.9 threshold level was applied, 77 of the 125 assessment pixels (61.6%) were classified as suitable.

Table 7 – Post model assessment dataset probability distribution for both study sites

Probability	**Number of Assessment Pixels**	**Cumulative Count**	**Percent Assessment Pixels**	**Cumulative Percentage**
0.99	8	8	6.40%	6.40%
0.98	17	25	13.60%	20.00%
0.97	24	49	19.20%	39.20%
0.96	14	63	11.20%	50.4%
0.95	13	76	10.40%	60.80%
0.94	1	77	0.80%	61.60%
0.78	2	79	1.60%	63.20%
0.58	27	106	21.60%	84.80%
0.42	6	112	4.80%	89.6%
0.38	4	116	3.20%	92.8%
0.33	3	119	2.40%	95.2%
0.26	2	121	1.60%	96.8%
0.23	4	125	3.20%	100%
Total	**125**		**100%**	

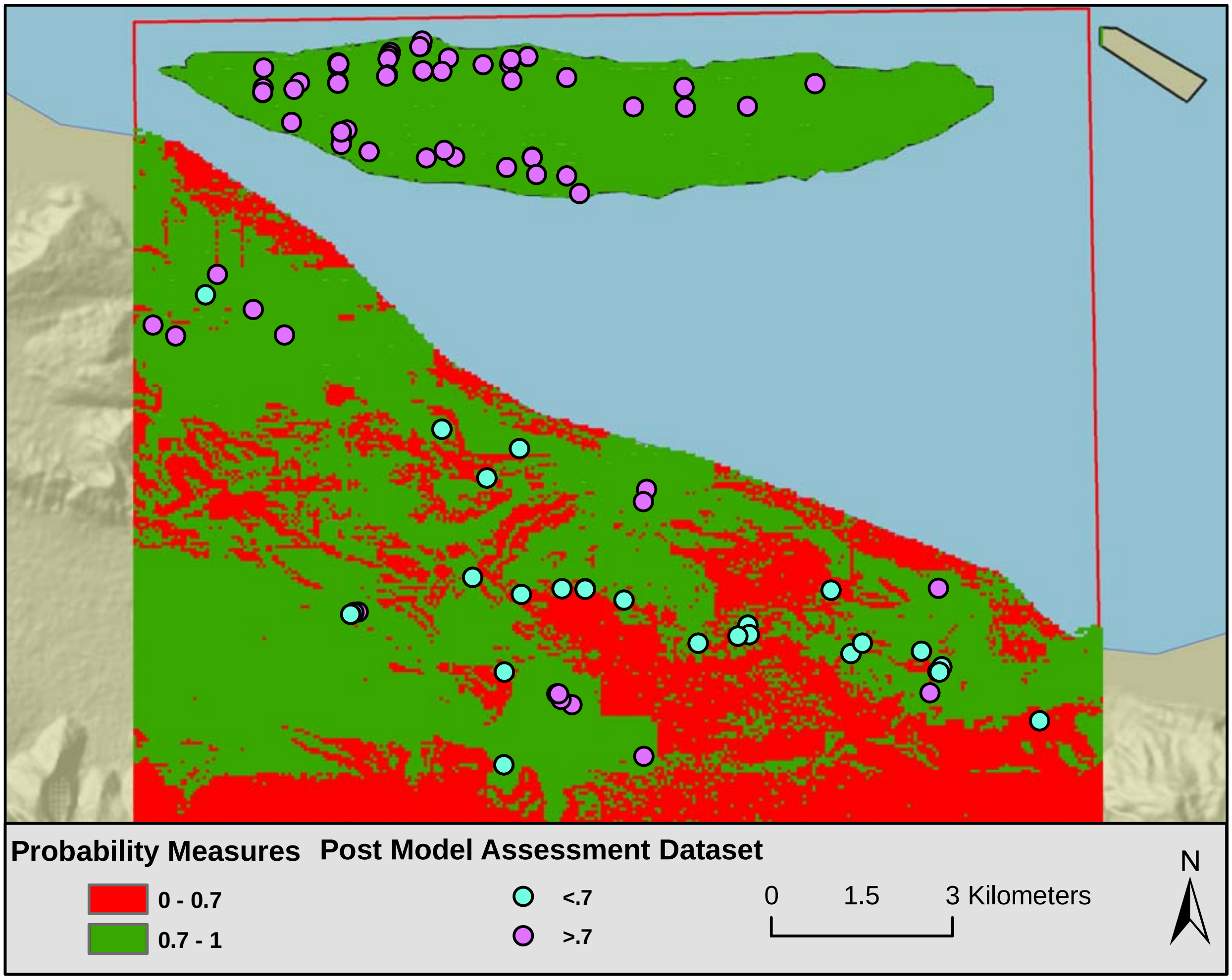


Figure 6 – Probability measures > 70.0% shown with locations of post model accuracy assessment dataset – study site 1

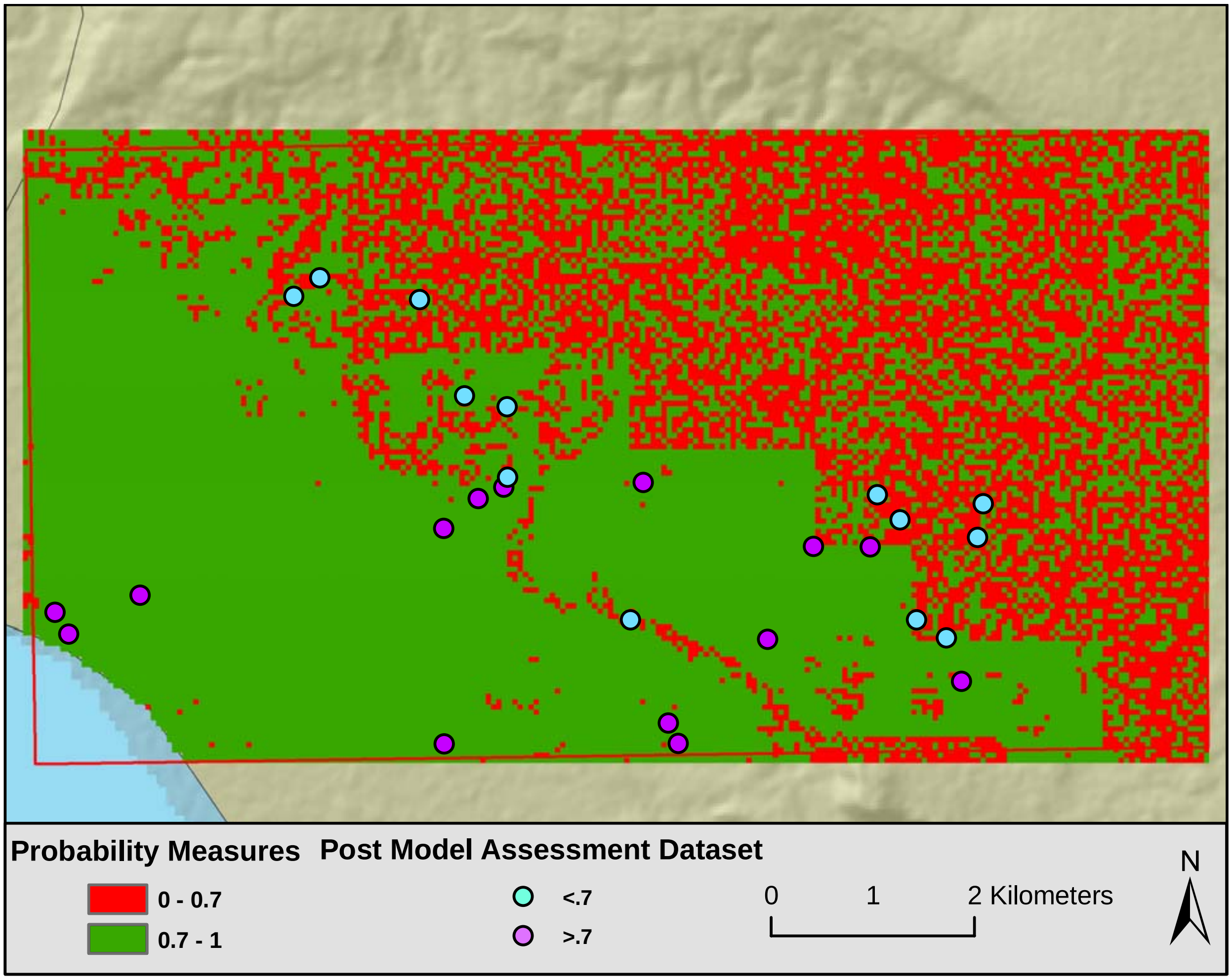


Figure 7 – Probability measures > 70.0% shown with locations of post model accuracy assessment dataset – study site 2

4.3.8 Study site 1 model results

Study site 1 contained 99 pixels that were utilized as part of the post model accuracy assessment dataset. When study site 1 is considered independently from study site 2, this model correctly predicts 65 of the 99 pixels in the post model accuracy assessment dataset or 65.66% with probability values ≥ .7 high probability threshold. Of the 99 pixels, 63 or 63.64% were classified with a range in probability values from .95 – 1.0. The next largest cluster of pixels was found at .58. This probability level consisted of

20 pixels or 20.20% of the pixels found in the study site 1 post model assessment set. Despite this large cluster of pixels being predicted with low probability, 65.66% of the pixels from the post model accuracy assessment dataset were correctly predicted with high probability values. Study site 1 resulted in probability predictions for the post model accuracy assessment dataset that range from .23 - .99 (Table 8).

Since many of the environmental attributes in study sites 1 and 2 had similar values, the variation in elevation values between sites may be one of the key factors that led to study site 1 having a higher percentage of post model accuracy assessment pixels being classified with high probability at both the $\geq$.7 and $\geq$.9 thresholds. The elevation mean value in study site 1 was much closer to the mean value of the training dataset than study site 2. Study site 1 had a mean value of 49 while the training dataset had a mean value of 55.62. The mean value of elevation in study site 2 was 163.77 meters above sea level (Tables 5 & 6).

Table 8 – Study site 1 post model assessment dataset probability distribution 0.0 -1.0

Probability	Number of Assessment Pixels	Cumulative Count	Percent Assessment Pixels	Cumulative Percentage
0.99	8	8	8.09%	8.09%
0.98	17	25	17.17%	25.26%
0.97	19	44	19.19%	44.45%
0.96	12	56	12.12%	56.57%
0.95	7	63	7.07%	63.64%
0.78	2	65	2.02%	65.66%
0.58	20	85	20.20%	85.86%
0.42	4	89	4.04%	89.90%
0.38	3	92	3.03%	92.93%
0.33	2	94	2.02%	94.95%
0.26	1	95	1.01%	95.96%
0.23	4	99	4.04%	100.00%
Total	**99**		**100.00%**	

4.3.9 Study site 2 model results

Study site 2 contained 26 pixels that were utilized as part of the post model assessment set. When study site 2 is considered independently from study site 1, this model correctly predicts 14 of the 26 pixels in the post model accuracy assessment dataset or 53.85% with high probability values $\geq .7$. Of the 26 pixels, 13 or 50% were classified with a range in probability values from .95 – 1.0. The next highest aggregation of pixels was found at .58. This probability level consisted of 7 pixels or 26.92% of the pixels found in the study site 2 post model assessment set. Despite this large cluster of pixels being predicted with low probability, 53.85% of the pixels from the post model accuracy assessment dataset were correctly predicted with high probability measures of $\geq .7$. Study site 2 resulted in probability predictions ranging from .26 - .97 (Table 9). The difference in the elevation values between sites discussed in section 4.3.8 may also have been partly responsible for the lower overall values of the probability distributions in study site 2. Study site 2 had a maximum probability value of .97 (Table 9) while study site 1 had a maximum value of .99 (Table 8). Another factor that could have contributed to the lower values of the probability predictions associated with study site 2 could have been this site's lower number of training pixels when compared to study site 1. Study site 2 had 26 pixels in the training dataset while study site 1 had 98 (section 3.1.a).

Table 9 – Study site 2 post model accuracy assessment dataset distributions 0.0-1.0

Probability	Number of Assessment Pixels	Cumulative Count	Percent Assessment Pixels	Cumulative Percentage
0.97	5	5	19.23%	19.23%
0.96	2	7	7.68%	26.91%
0.95	6	13	23.08%	49.99%
0.94	1	14	3.85%	53.84%
0.58	7	21	26.92%	80.76%
0.42	2	23	7.69%	88.45%
0.38	1	24	3.85%	92.30%
0.33	1	25	3.85%	96.15%
0.26	1	26	3.85%	100.00%
Total	**26**		**100.00%**	

4.3.10 – Model results – .58 cluster comparisons

In study site 2, a large cluster of pixels can be found at .58 with 26.92% of the pixels being measured at this value (Table 9). Study site 1 also exhibits a large cluster with 20.20% of the pixels being classified with a probability prediction of .58 (Table 8). This may indicate that these pixels were incorrectly predicted with low probability values in each study site, that these sightings represent marginal Ricord's iguana habitat, that this aggregation of pixels represents a different class of sighting than the pixels with higher probability values, or that the values of the environmental variables at these pixels may represent the habitat preferences for Ricord's iguanas at a different season than the aggregation of pixels found between .9 and 1.0. Future research should explore whether these clusters are present with the addition of other environmental parameters including aspect, image texture, and land cover datasets.

The clusters that are found in both study areas at the same probability measurement (Tables 8 & 9) could be correlated with the variation in habitat preferences of Ricord’s iguanas based on seasonality or the sighting classification. As previously stated, the sightings datasets that comprise the model training and the post model accuracy assessment datasets were collected at different time periods that fall within each of the breeding, nesting, and hatching seasons. The dataset was also comprised of direct Ricord’s iguana sightings and their dens, nests or tracks. The continuation of this research would benefit from a comparison of the dates when the sightings were collected to see if a majority of the sightings found in these clusters are from the same season. This incorporation of this information in future models would potentially increase the number of sightings that receive probability values above the 0.7 high probability threshold. In addition, these clusters may indicate a response by Ricord’s iguanas to varying environmental conditions during these time periods. Future research should also explore whether these clusters are mainly comprised of one class of sighting which could lead to a more detailed depiction of Ricord’s iguana habitat suitability that can differentiate suitability based on different classes of sightings.

5. Discussion

5.1 Results

Even though this model performed well with the prediction of high suitability to 79 of 125 pixels or 63.20% (Table 7) of the total pixels in the post model assessment dataset, this study has uncovered numerous directions for future research and ways to strengthen the results, making them more valuable with regard to conservation decision for these endangered animals. In general, these improvements include the addition of other datasets including a regionally focused, higher resolution land cover dataset and an exploration into different measures of image texture; and the incorporation of the temporal dimension found in the data. The incorporation of additional datasets could add valuable information to improve the performance of the model. The Landsat ETM+ scene used in the creation of the PCA, tasseled cap, and image texture variables was collected on September 15, 2000. Since this study utilized imagery collected on one date, the incorporation of imagery from additional time periods that correspond with the dates the sightings were collected along with the inclusion of the temporal element in the sightings data would potentially be very valuable in exploring Ricord's iguana habitat suitability and enhance the predictive value of this model. Since the Landsat scene selected was collected during a time period before the sightings data, changes to the landscape may have occurred. These potential changes could have been a barrier to a higher percentage of pixels being classified as being higher than the .7 threshold.

The large percentage of pixels, 61.60% found within the .9 – 1.0 range and the cluster of pixels found at .58 in both study areas (Tables 8 & 9) may be partially due to the lack of inclusion of a dataset or sets that explore the link between seasonality and Ricord's iguana habitat preferences or the difference in the values of environmental attributes associated with different classifications of sightings.

5.2 Future directions

This study was meant to serve as a foundation for future research concerning the conservation of *Cyclura* iguanas in Hispaniola in general, and for Ricord's iguanas specifically. The future continuations of this research could continue in multiple directions. First, this research could utilize higher spatial resolution imagery and more spatially precise data products that could provide a more precise measure of what areas should be classified as suitable habitat for Ricord’s iguanas. Second, this research could benefit from the production and evaluation of additional datasets including land cover and image texture. Third, the temporal element of the sightings data and satellite imagery should be explored. Fourth, the addition of data from studies planned by Indianapolis Zoo researchers should be incorporated. As previously mentioned, some of the planned research studies include a floral survey of Isla Cabritos and the fitting of Ricord’s iguanas with radio transmitters to track and record their locations and behaviors. Fifth, future models would benefit from the addition of an explicit spatial component by incorporating methods to account for spatial autocorrelation.

This study utilized Ricord’s iguana sightings data that were comprised of direct Ricord’s iguana sightings, and tracks, dens, and nests attributable to Ricord’s iguanas. The conservation efforts designed to help Ricord’s iguanas would potentially be strengthened by looking at differences in suitability between direct iguana sightings, and their tracks, dens, and nesting sites to see if there are measurable differences in the criteria associated with these four classes of sightings. As field data on sightings is collected, the body of knowledge that can contribute to this type of study will grow.

As previously mentioned, Grupo Jaragua has identified three sub-types of habitat preferred by Ricord’s iguanas. These sub-types include fondos, murcara, and cascajo. The incorporation of a land cover classification designed to differentiate these three sub-types of habitat could lead to a more detailed and accurate depiction of suitable Ricord's iguana habitat.

The sightings data was collected in multiple time frames including 2003, 2004, 2006, and 2008. Future research could couple each time period with imagery from the same year to see how conditions have changed over time. Another temporally related option would be to look at the major time periods associated with the biology of Ricord's iguanas including nesting season, egg laying, and hatching. Models that utilize data collection from these periods potentially could predict suitability based on seasonality and the biology of Ricord's iguanas. However, they would require obtaining datasets that were collected during each time period of interest. The combination of the temporal element of the data with the sub-type classification discussed above could yield a more complete depiction of Ricord's iguana habitat suitability.

Hispaniola is the only place where two sympatric species of *Cyclura* iguanas can be found. This research can also serve as a foundation into exploring Rhinoceros iguana habitat suitability utilizing similar datasets and methods. This direction of the research can then be applied to a comparison between Rhinoceros iguanas and Ricord's iguanas leading to additional information about both species and their interactions. The comparison of habitat preferences between Ricord's and Rhinoceros iguanas is key to understanding the differences between these two species. This information would be valuable in determining why Ricord's iguanas are critically endangered and Rhinoceros iguanas are not as critically endangered.

5.3 Stakeholders

The use of satellite imagery, digitally mapped data layers, and habitat suitability modeling can provide valuable information concerning the probability that an area is appropriate habitat for Ricord's iguanas and therefore help to further the objectives of key organizations. In 2002, the Ricord's Iguana Species Recovery Plan was created by the Iguana Specialist Group (ISG) of the IUCN Species Survival Commission (SSC). This document lists several difficulties associated with current conservation work including the identification of a "…severe lack of information…" on the status and distribution of Ricord's Iguana (Burton & Bloxam, 2002 pg 8). This lack of information is exemplified in the Barahona Peninsula range where the distribution of Ricord's iguana has yet to be accurately established (Ottenewelder, 1999). Contributing to this lack of information on their status and distribution is the difficulty of survey work in some areas of known and suspected Ricord's iguana presence. In addition, the lack of technical, financial, and human resources are barriers to conservation work. This study and the continuation of this research can contribute to the achievement of these and other objectives undertaken by this organization. The ISG seeks to establish a comprehensive management plan for the long term survival of Ricord's iguanas, and to maintain existing, quality habitats. In addition, they want to ensure that Rhinoceros iguanas, not be released into known or suspected Ricord's iguana habitat (Burton & Bloxam, 2002). The identification of potential habitat areas can help to further these objectives by contributing to the body of knowledge needed to make informed decisions.

The research of the Indianapolis Zoo Project Iguana team could also benefit from the results of this study and the continuation of this research. One major component of their research is to carry out a long term habitat study of Ricord’s iguana. They wish to contribute to the efforts to maximize the conservation of Ricord’s iguanas and in determining their distribution (Indianapolis Zoological Society, 2007). This study and the continuation of this research can provide many benefits to Ricord’s iguana conservation efforts.

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CURRICULUM VITAE

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Education:

Bachelor of Science in Informatics
School of Informatics
Indiana University ─ Purdue University Indianapolis, May 2005

Master of Science in Geographic Information Science
School of Liberal Arts, Geography Department
Indiana University ─ Purdue University Indianapolis, April 2009

Professional Activities:

Preparing Future Faculty Scholar 2008 –2009

- Attended conferences and workshops on teaching and professional development

Geographic information systems (GIS) Research Intern 2007 - 2008
Indianapolis zoo – Project Iguana team, Indianapolis, Indiana

- Completed an internship in GIS as part of graduate studies in Geography
- Organized and mapped field data to facilitate visualization and data analysis
- Coordinated GPS settings and planned transects for the most current field work
- Created a website to facilitate communication and data sharing between team members

Golden Key Honor Society 2003 - Present

- International Honor Society

Phi Theta Kappa 2002 - Present

- International Honor Society of the two year college

Professional Experience:

Indiana University ─ Purdue University Indianapolis 2007 –2008
Aerial imagery interpreter

Functioned as part of a team investigating the possible link between childhood obesity and access to recreational amenities by performing aerial imagery interpretation for a National Institutes of Health (NIH) funded research project