Spatio-temporal changes of the herpetofaunal communities in Mount Resaca and Luis Peña Cay National Wildlife Refuges at Culebra Island, Puerto Rico

By

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RESUMEN

La isla de Culebra, como parte del Banco Geográfico de Puerto Rico, ha sido un lugar el cual se han rezagado los estudios científicos. Estudios como el de Grant (1931) han servido de base para el presente trabajo. Los recursos de Culebra han sido perturbados desde principios del siglo 20 hasta los 1970's. Desde ese entonces (1970's), la reserva natural ha sido administrada por el Servicio Federal de Pesca y Vida Silvestre de los Estados Unidos. El propósito de este trabajo es actualizar el listado de especies de anfibios y reptiles, cómo también examinar como los cambios espaciales y temporales afectan la diversidad y la abundancia de la herpetofauna en esta isla. En este estudio, un total de 20 especies de 10 familias diferentes fueron detectadas, de las cuales *Eleutherodactylus coqui* y *Eleutherodactylus cochranae* fueron nuevos registros para Monte Resaca. Mientras, que *Anolis pulchellus* fue un registro nuevo para el Cayo de Luis Peña.

En general, Monte Resaca tiene una mayor riqueza con 10 especies, entre reptiles y anfibios, que el Cayo de Luis Peña estas diferencias en los índices de Shannon-Wiener, Simpson y Margalef fueron estadísticamente significativas. Factores abióticos, tales como la temperatura y la humedad, tuvieron una participación en la abundancia de esta comunidad como también los factores bióticos, tales como la vegetación y la presencia de otras especies.

ABSTRACT

Culebra Island, as part of the Puerto Rican Bank, is a place that a lack of scientific studies. Studies such as Grant's (1931) have provided the basis for this work. The island terrestrial resources have been disturbed since the early 20th century until the 1970s. Since then (1970's), the natural reserve has been managed by the U.S. Fish and Wildlife Service. The purpose of this research is to update the species list as well as to examine how spatial and temporal changes affect the diversity and abundance of the herpetofauna on this island. In this study, 20 different species from 10 families were identified. Two new records for Mount Resaca were *Eleutherodactylus coqui* and *Eleutherodactylus cochranae*. Meanwhile *Anolis pulchellus* was a new report for the Luis Peña Cay.

In general, Mount Resaca has greater richness than the Luis Peña Cay, with a total of 10 amphibian and reptile species, and these differences in Shannon Wiener, Simpson's Index and Margalef's index were statistically significant. Abiotic factors such as temperature and humidity had a share in the abundance of this community, as well as biotic factors such as vegetation and the presence of other species.

This work is dedicated to my loving parents:
Carmen D. Franceschi-Colón
Ángel L. Ríos-De Jesús

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Content

Content

INTRODUCTION

Reptiles and amphibians are important components of many ecosystems because their total number and biomass affect ecosystem function through complex trophic interactions (Dodd, 2010). However, these taxa are not immune from the ravages that are happening on Earth. Herpetofaunas are susceptible to sudden environmental changes (Sala et al., 2000; Cushman, 2006), and these changes can either diminish their populations or, in extreme cases, extinguish them. Some of the factors that affect animal populations are land use, such as agriculture, recreational uses, construction of urban areas and areas for training purposes; all leading to habitat fragmentation (Gibbons, 2000; Thrush, 2008). In such cases, many amphibians and reptiles are unable to escape from the area that has been fragmented or modified, mainly because of their low mobility (Vredebburg and Wake, 2007).

A recent assessment of the World's amphibians found that 32.0% of the 6,000 (2012) extant species are globally threatened and at least 43.0% are experiencing declines in some part of their range. On the other hand, 30.8% of the 9,547 species of reptiles are vulnerable to critically endangered (IUCN, 2012). The areas most affected are located in Central and South America, Western Australia, North America and the Caribbean (Stuart *et al*., 2004; Lannoos, 2005). Furthermore, it is well documented that island ecosystems are more vulnerable to change than continental ecosystems and human-caused extinction rates are much higher (Henderson, 1992; Vitousek, 1990). Ecological studies can give us information about factors limiting distributions or species abundance. This information is critical for habitat management (Rutherford and Gregory, 2003) and enables for proper delimitation of regions that need to be protected (Burt, 1943; Litzgus and Mousseau, 2004), and more important, the persistence of many species depends upon the effectiveness of strategies for conserving biodiversity in human dominated landscapes (Vandermeer and Perfecto, 2007).

One way to perform ecological studies is to give them a spatial focus. Spatial studies can deliver crucial information of how landscape configuration influences the community and population dynamics of organisms (Collinge, 2001; Millar, 2011). Within spatial ecology, we can evaluate movement patterns, home ranges, habitat selection and habitat types such as those used for reproduction. Habitats are critical as they provide different niches for different species to coexist (Buckley, 2005; Millar, 2011).

On the other hand, temporal studies are important for understanding the fluctuations in populations, studying correlations between climatic variables, such as precipitation, temperature, humidity, herpetofaunal diversity and abundance. By measuring these variables, we can acknowledge that temporal changes can influence directly the ecology of amphibians and reptiles by affecting their physiology. It is known that amphibians depend on moisture (precipitation) to be physiologically active, so we can assume that during dry seasons the abundance of frogs will decrease, while the wet season will favor an increase in abundance. In addition, temperature can influence habitat humidity and can cause heat stress in animals. Changes in temperature and humidity may vary the conditions of the habitat in which animal populations are adapted. Dry seasons can decrease the amount of food available, which can reduce the abundance and even decrease the biodiversity in time (Toft, 1980).

Puerto Rico lies within one of the biodiversity hotspots (Cox and Moore, 2000). Diversity consists of approximately 26,410 species of plants, fungi and animals (Joglar, 2005). These populations within the Puerto Rican Bank have been isolated from each other by physical barriers for approximately 8,000-10,000 years by the rising sea levels after the last glacial maximum (Heatwole et al. 1981). The fauna on the Puerto Rico Bank has been exhaustively studied, but have been mostly centered in the main Island, excluding neighbor islands such as Culebra (Pregill, 1981). The herpetofauna of Culebra has only been listed in 1930 (Grant, 1932a) and has been mostly neglected ever since, due to potential problems and historical reasons. Only 12 species were reported in Grant's work. Among these species is the Culebra Giant Anole (*Anolis roosevelti*) (Figure 1), species that is now believed to be extinct (Ojeda, 1986 and 2010). There is also the Virgin Islands' Boa (*Epicrates monensis granti*) (Appendix A; Figure 2), which is known to be endangered (Tolson, 2005).

Herpetofaunal studies at Culebra Island are scarce due in part to the military activities that were conducted by the U. S. Marine Corps. in the refuge areas. As mention above, studies done in the Culebra were first made by Grant in 1930-1932. He reported two frogs, seven lizards and three snakes. Later, Rivero (1998) cited eight lizards and three snakes.

The U.S. Marine Corps arrived in Culebra in 1903 and began to use the Culebra Archipelago as gunnery and bombing practice site in 1939 (Feliciano, 2001). In 1971, the people of Culebra began protests, known as the Navy-Culebra protests, for the removal of the U.S. Marine Corps from the Island. Four years later, in 1975, the use of Culebra as a gunnery range ceased and all operations were moved to nearby Vieques Island. The land in Culebra previously used by the U.S. Marine Corps was then transferred to the U.S. Fish and Wildlife Service (Feliciano, 2001). These areas were kept restricted to the public and a minimum of environmental and ecological studies have been conducted ever since.

The purpose of this study is to document how diversity and abundance of reptiles and amphibians changes in contrast to spatial and temporal changes such as elevation, location, vegetation, seasonality, temperature, precipitation and humidity. Another objective is to update the actual species list for Culebra Island.

MATERIALS AND METHODS

Study System

Study Sites

The island of Culebra is located at 18º 18' 18" N: 65º 18' 05" W, approximately 17 miles (27km) east from the Puerto Rico mainland, 12 miles (19km) west of St. Thomas and 9 miles (14km) north from the northern Vieques. It comprises the main island and 23 smaller islands or cays. This study took place in two reserves of the U.S. Fish & Wildlife Service Refuge System: Mount Resaca and Luis Peña Cay (Figure 3). These areas were transferred to the Fish and Wildlife Service when the Navy left the island in 1975. Since that date these areas have been relatively undisturbed, giving time to native and endemic species to settle down once again.

Mount Resaca is approximately 1.0 km long by 1.5 km wide and has an elevation of 185.0m above sea level. It is located at 18º 19' 33.2" N: 65º 18' 2.3" W, to the northern part of the main island. It is composed of dry subtropical forest known as a boulder forest. This name is due to the fact that in the area has boulders (big rocks), which give it a particular look and abiotic conditions. Also, its soils are composed of about 70% to 80% volcanic soil. Boulder forests brings within its structure different kinds of microhabitats such as intermittent streams, bromeliads clusters, boulders, thorny bushes, leaf litter and tall trees that provide shade and maintains high soil humidity.

Mount Resaca has primary forest patches and a variety of endemic plant species. Some of the rare and endangered plant species that can be observed at this site are the Wheeler's peperomia (*Pepperomia wheeleri)* and the Sebucán (*Leptocereus grantianus*). On the other hand, animals such as Virgin Island Tree Boa (*Epicrates monensis granti)* and the Lesser Antillean skink *(Spondilurus culebrae)* are present at this forest. In addition, it is in this area where the Culebra giant anole (*Anolis roosevelti)* was collected (USFWS, 1982).

The other study site was Luis Peña Cay, which has a different type of forest. This area is about 2.2 km long by 1.0 km wide, and it is composed of a subtropical dry forest habitat with a mean temperature and humidity of 86.47 °F and 74.25%, respectively. It is located at 18° 18' 05.2" N: 65° 19' 51.1" W to the west side of Culebra Island. This area, compared to Mount Resaca, was disturbed drastically by the Navy. It now has a road that goes from the coast to the top of the Cay, and it was also highly deforested and bombarded. Luis Peña Cay has a young forest comprised mainly of thorny bushes (*Acacia*). Seedlings are not common in the area; however, when present, they appear to be in bad shape. The Cay appears to have high concentrations of invasive species such as goats (*Capra hirca*) and, sporadically, deer (*Odocoileus virginianus*; pers.comm.).

Survey

Transects

Four transects of 125 meters were established at each study site. Transects were selected randomly at low and high elevations. Two of these transects were located at the lowest elevations of the areas and gradually increased in elevation: the other two began at the highest elevation of the permitted sampling area and gradually decreased in elevation. In Mount Resaca, the highest transect was located at 163.0m above the sea level and the lowest transect was located at 11.0m above the sea level. At Luis Pena Cay, the highest transect was located at 63.0 m above sea level and the lowest at 3.0 m above the sea level (Figures 4-5). Systematic transect searches were performed to make estimates about the spatial status of amphibian and reptile populations (Anderson *et al*., 1976; Magurran 2004; Manzanilla, 2000; Stiling, 2002; Stork, 1995; Yoccoz, 2001). For Luis Peña Cay searches during the night were not performed due to illegal hunting activities that threatened personal safety. Also, no data were taken on the Cay on October and December 2010 because of transportation logistics. The total area sampled per transect was 375.0 m^2, making a total sampled area of 1,500m^2 per site, and a total of 3,000 m^2 sampled in Culebra Island. In addition, I used the time effort to express the abundance per unit effort (Bury and Raphael, 1983).

Autonomous Recording Unit (ARU)

An automated acoustic monitoring of amphibians was performed using an Autonomous Recording Unit (ARU) Song Meter 2 developed by Wildlife Acoustics. This company specializes in manufacturing bioacoustics equipment for research (http://www.wildlifeacoustics.com). The equipment was set to record for six weeks (between August, 2010 thru February, 2011), 1:00 minute every hour, from 6:00pm to 6:00am at 1,600Hz and 16 bits (2 channels). The data were recorded during the wet season when amphibians were more active. The data was analyzed to estimate the activity in each recording using simple listening skills and the amphibian species were corroborated by spectrographs prepared using Raven Pro® 1.4 software. The spectrographs allow the identification of the species by their specific frequency in kHz (Pellet, 2004). This information was organized and put into a graph to determine the peaks/hour in which each species were more active.

Visual Encounter Surveys (VES)

Visual Encounter Surveys (VES) were used to identify the species. These surveys were conducted from 6:00am to 1:00pm to look mainly for reptiles, and from 6:00pm to 2:00am for amphibians. These data were collected twice a month for one year (2010-2011). Additionally, some individuals were captured to verify their identity using taxonomic keys (Rivero, 1998). The scientific names used to identify species were the ones included in Rivero (2006), Smith and Chiszar (2006) and Hedges (2010, 2012).

Temperature and humidity data were also documented at the beginning, the mid-section and the end of each transect. For this, a Kestrel® 3000 Pocket Weather Station was used. These data were important to correlate temperature and humidity with species richness. The data sheet used to collect information in the field is shown in Appendix A, Table I.

Vegetation analysis

A vegetation analysis was made using the same transects of the surveys. Each transect was divided in twelve points, each separated by 10.0 m. In each point layer analysis, canopy cover, tree density and basal area were determined. The layer analysis was performed using a PVC pipe 2.0 m high. Every time a leaf touched the pipe was counted and identified, the height where it touched was also recorded. This information was used to categorize the structure of the understory. The canopy cover was presented as percentage using visual estimation. At each sampling point, a two meter diameter circle was marked and every plant species was identified to assess diversity. Also, diameter to the breast high (DBH) was measured to obtain basal area, and counted to obtain density of the plant populations (Matos, 2006). The species that could not be identified at the site were collected and taken to the Herbarium of the University of Puerto Rico at Mayaguez (MAPR) for further information.

Statistical models

For this work, four programs were used to analyze the data: PAST v. 2. 04©, Microsoft Excel©, InfoStat© and Estimate©; and seven statistical analyses were used:

Shannon-Wiener Index - This function of species diversity is based on information theory. The main objective of information theory is to measure the amount of order or disorder contained in a system (Margalef, 1958). This formula treats species as symbols and their relative population sizes as the probability. The values reach from 0 (low diversity) incrementing up to 5 (high diversity) in biological communities (Washington, 1984).

Simpson Index - This non-parametric measure suggests that diversity is inversely related to the probability that two individuals picked randomly belong to the same species for an infinite population (Krebs, 1998). When the value is zero it means that all species are equally present and when the value is one it means that one species completely dominates.

Margalef Index (M) - Is a measure of species diversity and is calculated from the total number of species present and the abundance or total number of individuals. The ranges used to determine diversity where: $M < 2.0$- low diversity, $2.0 > M < 5.0$-moderate diversity, and $M > 5.0$- high diversity.

Analysis of Similarity (ANOSIM) - A similarity analysis was used to determine the difference in herpetofaunal composition and abundance between Luis Peña Cay and Mount Resaca. The parameters used were dry/wet season and low/high elevation.

Similarity Percentage (SIMPER) - Is a simple method for assessing which taxa are primarily responsible for an observed difference between groups of samples (Clarke, 1993). These groups were the community on Mount Resaca and Luis Peña Cay. This statistical method uses abundance data to analyze the percentage of species contribution in an area.

Species Accumulation Curve - This curve analyzes the plot of the cumulative number of species collected, S(n), against a measure of the sampling effort (n). The sampling effort can be measured in many different ways; some examples are the number of quadrants taken, the total number of animals handled and the hours of observation. In this case, our curve was prepared using abundance and total of animals handled. As effort increases, gradually more species living in a habitat will be caught, until eventually only the rarest species or occasional visitors remain unrecorded. When this occurs, increased effort will not increase the recorded number of species. Thus species accumulation curve will have reached an asymptote.

Spearman Correlation - This matrix is used to assess the amount of co-linearity in a set of independent variables (McCune and Melford, 1997; Lyman and Longnecker, 2001). This method was used to observe the co-linearity between humidity, temperature and species abundance.

Lineal Regressions- Linear regressions are used to model a relation between variables. There are two types of variables, one dependent and one or more explanatory variables. The dependent variable represents the output or effect, or the one that is tested to see if there is an effect. The explanatory variables are the ones to be used by the formula to make comparisons. For this study, this correlations were use to observe if there is a relation between biotic factors such as canopy cover, leaf litter and DBH and compare it to animal abundances.

RESULTS

Surveys

The herpetofauna of Culebra was composed of nine lizards, four snakes and two amphibians. In this study, 7 species were added to the herpetofauna, and increment of 46.7%. These represent an increment of 25.0 % for the species reported for Culebra Island. During the current survey a total of 14 species were found in the refuge; *Anolis cristatellus wileyi* and *Eleutherodactylus antillensis* were the most abundant species. Mount Resaca has a habitat structure made of different layers that provide abundant of perches to *Anolis cristatellus wileyi* for living. Four sub-species of *Sphaerodactylus macrolepis* and one unidentified species of *Sphaerodactylus* were found during the study period. In addition, *Hemidactylus angulatus* was found during the night in tree trunks.

A frog species, one lizard and one snake are newly reported. Two species (*Leptodactylus albilabris* and *Rhinella marina*) were found outside the sampling area. A possible reason why both species were not detected during the surveys is the absence of fresh water bodies on the surveyed areas. Two more species of lizards, *Ameiva exsul* and *Iguana iguana* were found outside the studied area, these two species were widely distributed throughout the island. Two snakes were found outside the research area: *Typhlops hypomethes* and the Virgin Islands tree boa (*Epicrates monensis granti*). Abundance of these species can be affected by abiotic variables such as climate (Toft, 1980). The mean humidity in Mount Resaca during the day was 82.0 % with a mean temperature of 27.78°C. Night mean humidity was 84.8%, which was 2.0% higher than during the day, and the mean temperature was 26.05°C. The highest abundance of the herpetofaunal community was in July when the temperature and humidity were 28°C and 86.6 % respectively. These values are higher than the mean values for both parameters (Figure

6). Temporal conditions such as precipitation, temperature and humidity for Mount Resaca were relatively constant throughout the year. The constant climate means that the populations do not reproduce at different seasons.

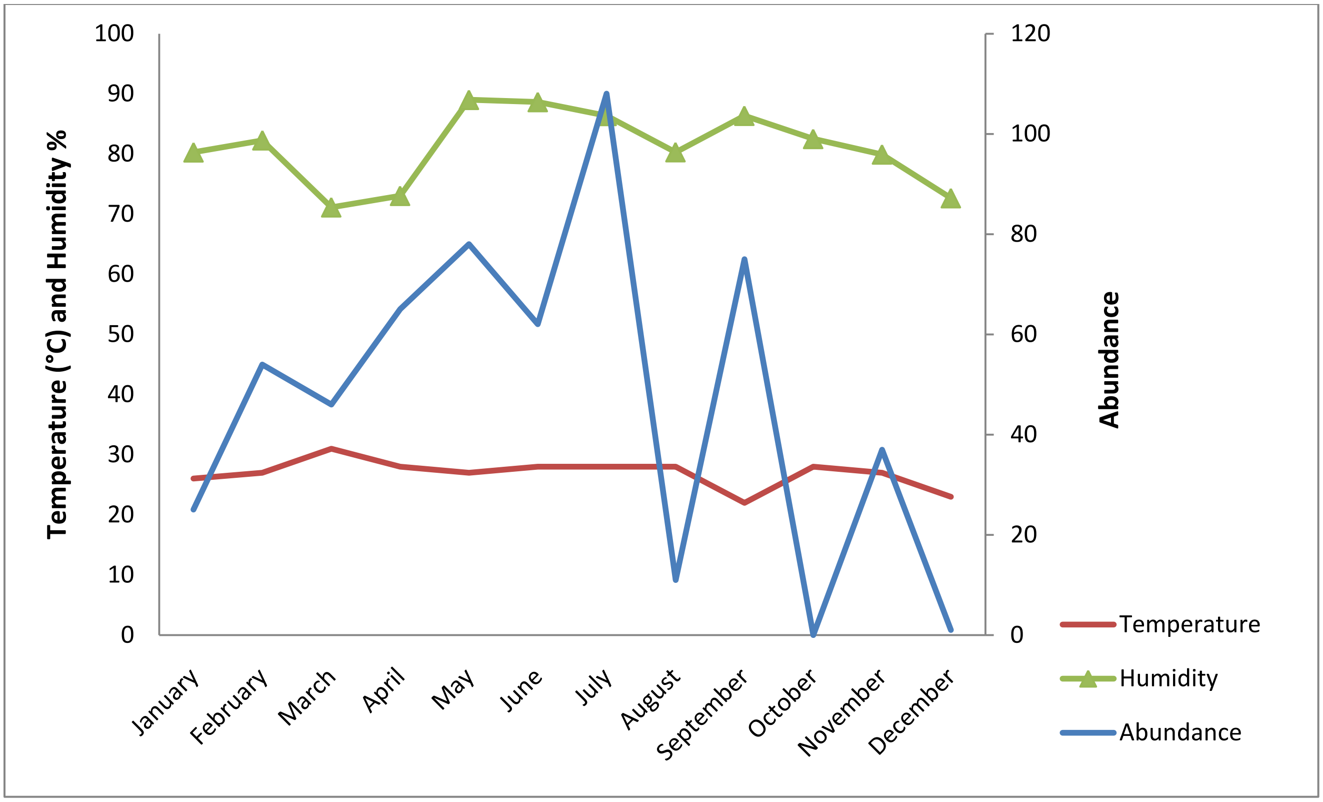

Figure 6. Monthly variation of the abundance of the herpetofaunal community in relation of temperature (°C) and humidity (%) at Mount Resaca, CNWR.

Precipitation data collected at the Fish and Wildlife Refuge, suggested that the wet season started in May and ended in November, 2010. The month with the highest precipitation was November with 26.54 cm of rain, followed by July with 25.96 cm of rain. The dry season started in December and ended in April, 2010. The driest month was February with 0.58 cm of rain. As the year 2010 progressed, the data showed that it was an atypical year. In fact, it was a very wet year, where rain peaks were higher than 25.4 cm in one month (Appendix A, Figure 7). The years 2006 and 2009 showed a mean of 6.45 and 7.49 centimeters of rain respectively. This means that in average, 2010 had 7.4 cm above the rain that usually can be observed on Culebra island.

Mount Resaca

Visual Encounter Surveys

Data obtained in the field showed that two species of amphibians and seven species of reptiles were found in the dry season (December-April) (Appendix B; Table 2). Pictures of each species can be seen in Appendix A (Figures 8-12).

As for the wet season (May-November), the mean temperature was 28.21°C and the mean humidity was 87.2%. Two species of amphibians and nine species of reptiles were documented during this period in Mount Resaca (Appendix B, Table 2).

Diversity was higher during the dry season. According to the Simpson's index (0.833), the population is not governed by the dominance of a single species, indicating that there is variability in the herpetofaunal community. This information was separated by taxa to determine if there were changes between wet and dry periods. Amphibian's diversity was higher in the wet season; while, in reptiles, diversity was higher in the dry season. In addition, the Simpson's Index indicated that in both seasons the amphibian and reptile taxa shows dominance of one species (*E. antillensis* and *A. cristatellus wileyi* respectively). Although there were no significant differences between diversity indexes (diversity. t-test, p=0.435) (Appendix B, Table 3).

Another parameter for comparing both areas was elevation. Transects were divided into two categories: low lands (11.0m-72.0m) and high lands (137.0m-162.0m). At low elevation, the mean temperature was 27.6°C and the mean humidity was 83.4%. Two amphibian species and nine reptile species were found (Appendix A, Figure 8-12; Appendix B, Table 4) at this elevation. On the other hand, at high altitudes, the mean temperature was 27.0 °C and the mean humidity was 85.9%. Three amphibian species and ten reptile species were found there (Appendix A, Figure 8-12; Appendix B, Table 4). Some species were found only at a specified elevation, as it was the case of *Eleutherodactylus coqui* and the *Hemidactylus angulatus*. However, this does not mean that they are not present across the elevation range. Data from Mount Resaca showed that the more offshore a transect is located, there is a slightly greater diversity found; although there were no significant differences.

According to Simpson's index (0.81), the community is not governed by the dominance of a single species, indicating that there is variability in Mount Resaca. This information was separated by taxa to see if there were changes between them in elevation. Amphibian and reptile's diversity was higher at higher elevation. Furthermore, for the amphibian taxon the Simpson's Index showed dominance of one species in both altitudes. Although there were no significant differences between these data (diversity t-test, p= 0.757) (Table 5).

During daytime, *Eleutherodactylus coqui* was found hiding in a flagging tape on a tree (Table 7). Diversity was higher during the day. This is because reptiles were the most abundant taxa in Culebra Island and they are diurnal. In terms of species contribution to a habitat, *Eleutherodactylus antillensis* was the species that contribute the most and a dominant species between the amphibian taxa (Simpson's Index, 0.51). Reptiles are more diverse for which there was no dominance of one species over another, although *Anolis cristatellus* was the mayor contributor to ecosystem (Simpson's Index, 0.82). This was because it was the most abundant species throughout the area. It was seen from the ground to the tree trunks successfully competing and displacing other species.

One group that posed some problems for identification in Mount Resaca were the geckos, of the genus *Sphaerodactylus*. As some *Sphaerodactylus* are still unidentified, that might change some biodiversity values; however models were performed in which species were included as existing and new species, and changes were not significant. Specialized dichotomic keys and genetic analyses are required. In total, six families were encountered in Mount Resaca, in which the genus *Sphaerodactylus* (Shaerodactylidae) was the most abundant with 36.0% relative abundance, the other families sampled were Eleutherodactylidae (Leptodactylidae), Gekkonidae, Dactyloidae (Polychrotidae), Dipsadidae (Colubridae), Mabuyidae (Scincidae) (Appendix A, Figure 13).

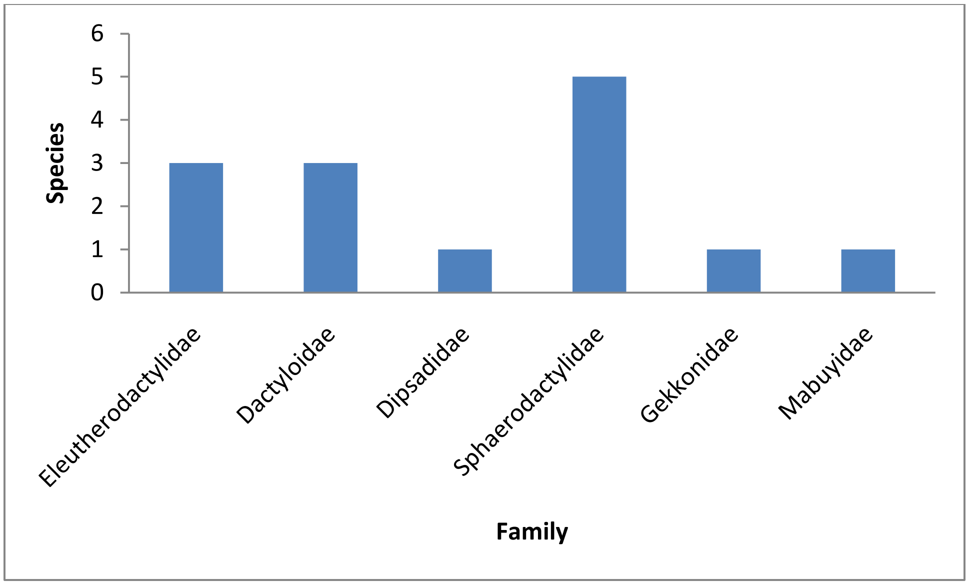

Figure 13. Species richness per family found in Mount Resaca, CNWR

Amphibians are dependent on constant water resources to reproduce. Mount Resaca does not provide this resources, instead it has intermittent streams that form when rain drops. This factor could be the responsible for the absence of *Rhinella marina* and *Leptodactylus albilabris*. In addition, *Trachemys stejnegeri stejnegeri* was not found within the federal boundaries. Another species that were not found, were the Culebra Giant Anole (*Anolis roosevelti)* and the Virgin Islands Tree Boa (*Epicrates monensis granti*) (Appendix B, Table 17). Overall, time effort was determined by the time in which two people observed each transect. The time effort for this area was 48 hours per transect/person with a total of 384 hours for the whole area. This effort was analyzed by the species accumulation curve. The curve reflects that there are species that were not encountered due to the fact that there was not enough time effort and it may require more visits to determine species richness with higher precision (Bersier, 2001) (Figure 14).

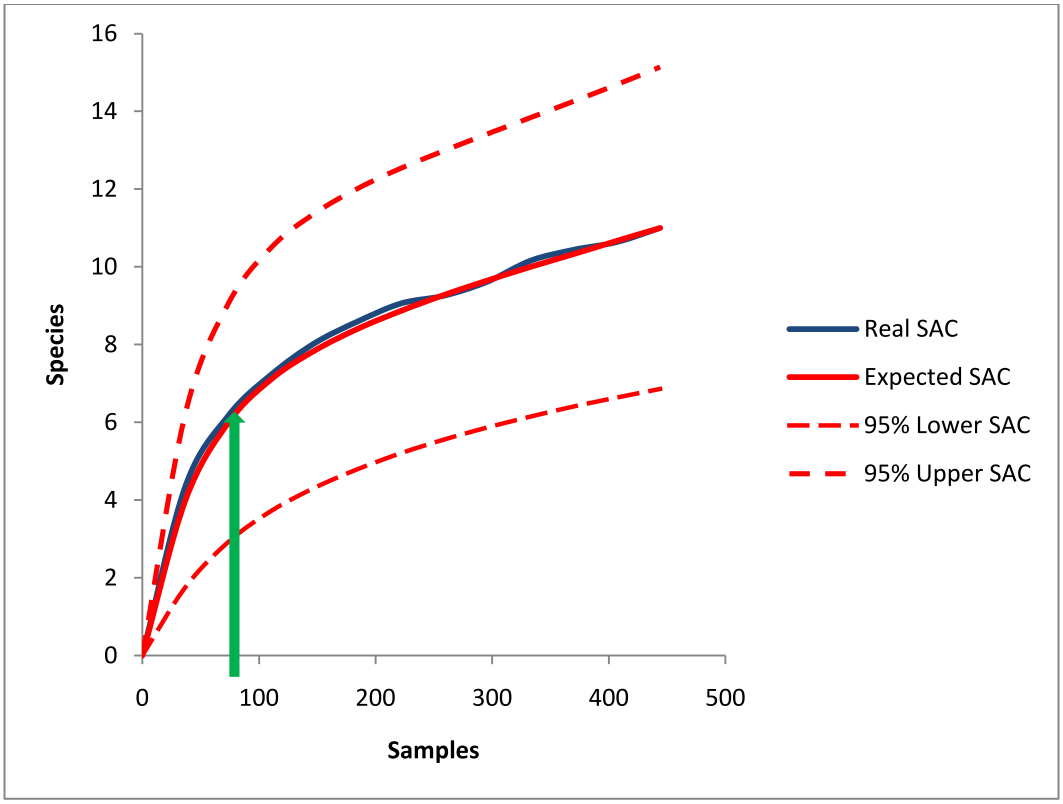

Figure 14. Species accumulation curve (SAC) for Mount Resaca, Culebra NWR.

The analysis of similarity (ANOSIM) showed that diversity patterns did not changed between wet and dry seasons within Mount Resaca (R= 0.5321, p=>0.05) (Appendix B,Table 8).

Autonomous Recording Unit (ARU)

The Song Meter gathered 143.7 hours of data. The recordings confirmed the presence of *Eleutherodactylus cochranae*. This species was not previously found in field surveys, giving relevance to the automated acoustic monitoring. Furthermore, it demonstrated that *E. antillensis* has a peak of activity between 6:00pm-8:00pm; from 8:00pm-4:00am it remains relatively constant at a low level of activity and raises its activity again between 4:00 -6:00am. On the other hand, *E. cochranae* has its highest activity between 6:00pm-8:30pm, decreases its activity throughout the night, but increases its activity by a little between 3:00am-4:00am (Appendix A, Figure 15). The most common species, *E. antillensis,* had a lower frequency between 1,800 kHz-3,250 kHz (Figures 16, 18) *E. cochranae* had a higher frequency between 3,900 kHz-4,000 kHz (Appendix B: Figures 17, 18).

Plant Diversity

During the surveys 30 species from 23 families of plants were encountered in Mount Resaca, in which *Randia aculeata* (Rubiaceae) was the most abundant (Appendix B, Table 13). Diversity in Mount Resaca was moderate with a Shannon-Wiener index (2.47) and a Margalef's Index (3.80). Dominance by one species was not present (Simpson's Index-0.883), indicating that the plant community is even in terms of spatial diversity. In addition, species diversity did not change significantly by elevation. The SIMPER analysis demonstrated that *Plumeria alba* (with 12.18 %), *Gymnantes lucida* (with 10.19 %) and *Pisonia subcordata* (9.54 %) were the three species with major abundance contribution to the composition of the plant community. Mean canopy cover was 75.84% providing a habitat with moisture retention. This area being less disturbed by humans, the vegetation seems to be older and taller increasing canopy coverage by mean of 10%. The shadows created by these trees decrease the growth of grasses, decreasing the possibility of encountering grass dwelling species. According to Simpson, Shannon-Weiner and Margalef indexes, biodiversity was moderate and there was no dominance of one species over another, rather they suggest homogeneity in the area.

The forest layer analysis reflected that the forest present with a variety of layers including grasses, woodland, and shrubs in different stages.

Luis Peña Cay

Visual Encounter Surveys (VES)

Mean diurnal humidity in Luis Peña Cay was 74.25 % with a mean temperature of 30.9°C. The highest abundance of the herpetofaunal community was in June were the temperature and humidity was 30.7°C and 72.6 %, respectively (Figure 19). Temporal conditions such as precipitation, temperature and humidity for Luis Peña Cay were relatively constant throughout the year.

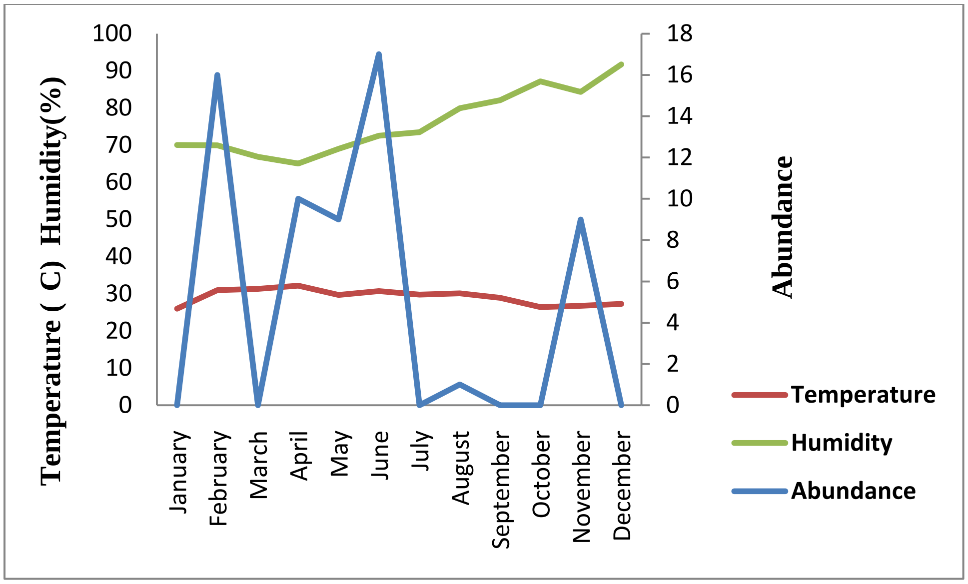

Figure 19. Monthly variation of the abundance of the herpetofaunal community in relation of temperature (°C) and humidity (%) at Luis Peña Cay, CNWR.

During the dry season, mean temperature was 30.7 °C and mean humidity was 67.8%. Four reptile species were found (Appendix B, Table 2). During the wet season, mean temperature was 28.8 °C and the mean humidity was 80.7 % and three reptile species were found (Table 2). The biodiversity Simpson's index (0.713) showed that the community is not governed by the dominance of a single species, indicating that there is variability in the area. Diversity indexes showed no significant statistical differences (Table 8).

At low elevation (<30.0 m), mean temperature was 29.2 °C and the mean humidity was 75.3% and four reptile species were found (Appendix B, Table 4). On the other hand, at high elevation (>30.0 m), mean temperature was 31.3°C and mean humidity was 73.3% and only two species were found (Appendix B, Table 5). The Simpson's index (0.713) also indicated that the community is not governed by the dominance of a single species. However, Margalef's diversity index (1.062) showed that diversity was low. Still, biodiversity indexes showed that reptile diversity was higher at low elevations. The data were statistically different ($p= 0.043$, $df= 3.400$) (Appendix B, Table 9). On the other hand, the upper part shows dominance by one species (Simpson's Index-0.480). According to Simpson, Shannon-Wiener and Margalef indexes, diversity was low but even throughout the area, except for high elevations, which were dominated by *S. macrolepis macrolepis*. No amphibian was seen on site, but *Leptodactylus albilabris* was heard one time near the lagoon at morning. Seasonal changes did not affect the diversity an abundance of the community, but an increment in temperature seems to influence abundance negatively. The species accumulation curve showed that the area was highly sampled, but night surveys are needed to examine further amphibian presence. The SIMPER analysis shows that *Anolis pulchellus* is the species with the largest abundance, with 13.42 % (Appendix B, Table 14). Three reptile families were found, half of the individuals were from the family

Dactyloidae, and the others to Sphaerodactylidae and Dipsadidae. Overall, time effort was measured by the time in which two persons observe each transect. The time effort for this Luis Peña Cay was 20 hours per transect/person with a total of 160 hours for the whole area. This effort was analyzed by the species accumulation curve. The curve reflects that the habitat was monitored exhaustively (Bersier, 2001), (Figure 20).

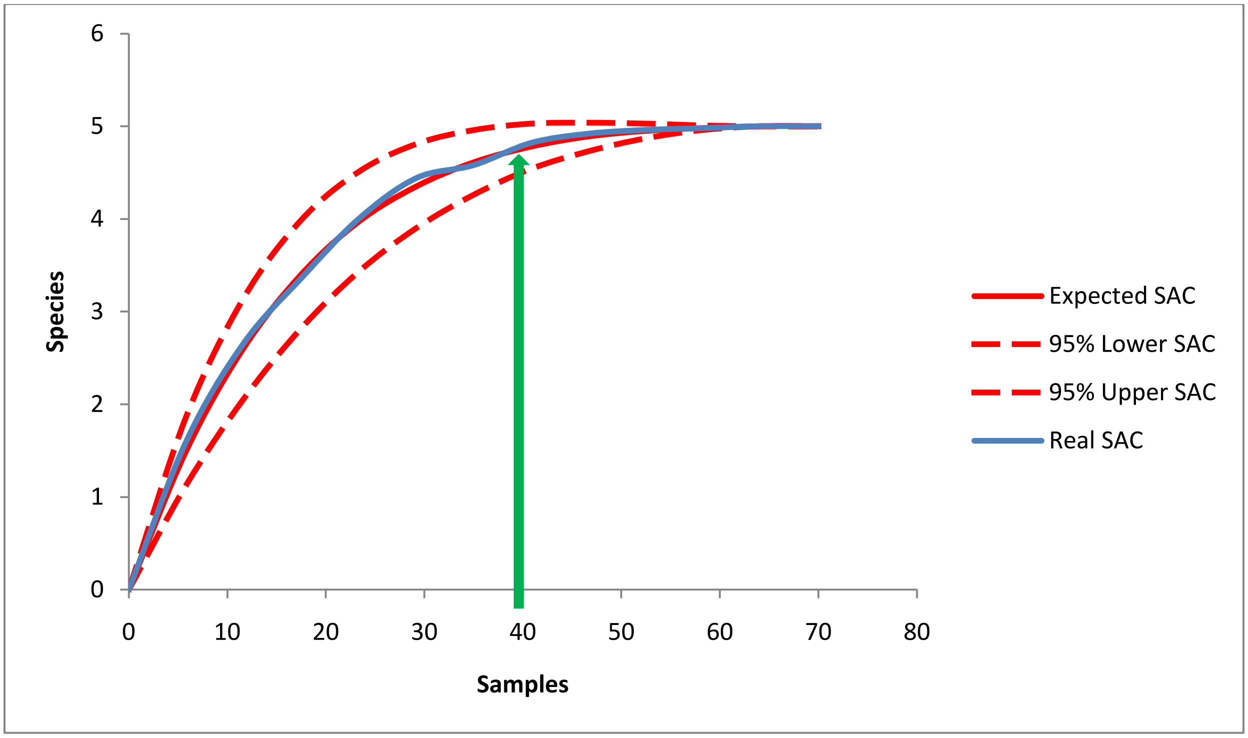

Figure 20. Species accumulation curve for Luis Peña Cay, Culebra NWR. The green arrow represents the samples done in the area.

Autonomous Recording Unit (ARU)

Recordings were taken at only one point on the transect above 30.0 m, transportation logistics were fundamental for the retrieval of the equipment. A total of 18.66 hours of data were recorded and no amphibian species were detected.

Plant Diversity

During the surveys 19 plant species from 14 families were encountered among Luis Peña, in which *Randia aculeata* (Rubiaceae) was the most abundant (Appendix B, Table 10). Diversity was moderate with a Shannon-Wiener Index of 2.21 and a Margalef's Index of 2.78 (Stoyanova, 2010). Dominance by one species was not indicated (Simpson's Index-0.862) suggesting that the plant community is even in terms of spatial diversity. In addition, species diversity did not change across elevation. The SIMPER analysis demonstrated that *Bursera simaruba* (with 14.15%), *Pisonia subcordata* (12.47%) and *Randia aculeata* with (11.46%) were the three species with major abundances (Appendix B, Table 11). Mean canopy cover was 65.4% allowing sunlight to penetrate and, thus, creating a drier habitat. The forest layer was composed of vegetation 2.0 m high and above. No vegetation was measured under 2.0 m and under. Lack of seedlings was prominent.

Comparison among Sites

The highest abundance for Mount Resaca was recorded in July, with 108 individuals and the lowest abundances were detected during the dry season in general. Indeed, a peak in abundance was recorded in June for Luis Peña Cay (Figure 21).

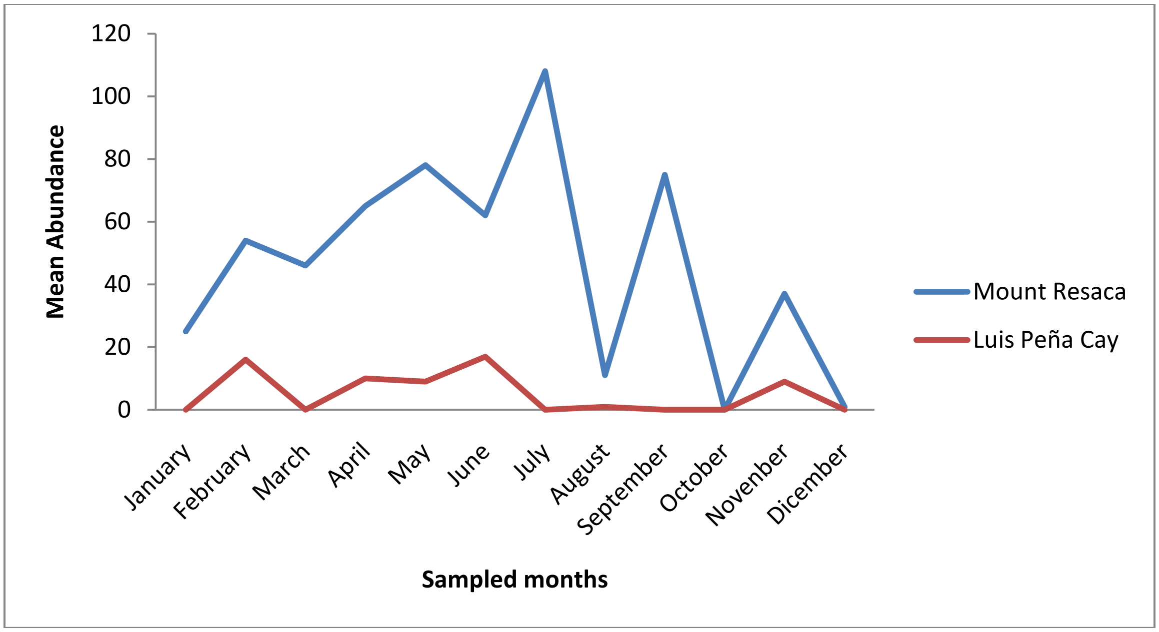

Figure 21. Mean abundance for the herpetofaunal community at Mount Resaca and Luis Peña Cay at Culebra Island.

The Analysis of Similarity (ANOSIM) did not show significant differences between dry and wet seasons within Mount Resaca and Luis Peña Cay; suggesting that there is no spatial pattern in structure and composition between both seasons. In addition, differences between seasons among Mount Resaca and Luis Peña Cay, confirms a seasonal pattern in the community structure between these two areas. This means that the spatial structure of species in each area varies independently within the dry and wet season ($R = 0.5321$; $p= <0.0001$) (Table12).

The SIMPER analysis demonstrated that , *Eleutherodactylus antillensis* (11.47 %), and *Anolis cristatellus wileyi* (6.27%) were the species with the highest abundances in Mount Resaca, while *A. pulchellus*, showed the highest abundance Luis Peña Cay (Appendix B, Table 13).

The Spearman correlation results indicated that there is no relation between herpetofaunal abundance and temperature in Mount Resaca; however, there is a positive relation between abundance and humidity ($r_s=0.608$, $p<0.01$) for the amphibians. Luis Peña Cay had a positive relation between reptile abundance and temperature ($r_s=0.761$, $p<0.01$). Temperature seemed to directly affect the abundance of reptiles in Luis Peña Cay. On the other hand, humidity did not correlate with reptile abundances (Table 14).

Lineal regressions showed that in the case of Luis Peña Cay, animal diversity and abundance was affected positively by plant diversity at low elevations ($R^2=0.36$, $p=<0.001$, $n=13$). Canopy cover also affected diversity at high elevations ($R^2=0.26$, $p=<0.001$, $n=17$).

Table 14. Spearman correlation coefficient between the herpetofaunal abundance of Mount Resaca and Luis Peña Cay with temperature and relative humidity.

Study Area	Taxa	Temperature (°F)	Relative Humidity (%)
		Correlation Coefficient	
		Spearman's rs	
Mount Resaca	Amphibian	0.109	0.608*
	Reptile	0.242	0.396
Luis Peña Cay	Reptile	0.761*	0.274

* Statistically significant (p= <0.001)

Plant Diversity

In general, diversity in Luis Peña Cay appears to be lower than Mount Resaca. Dominance by a single species was not detected (Simpson's Index- 0.883). Plant species composition seems to be even throughout the sampled area. Luis Peña Cay seems to be more affected by the military practices and the presence of goats (*Capra hirca*) (North *et.al*, 1986 and Bullock, 2001) (Table 15).

Table 15. Diversity index values for the Shannon-Wiener, Simpson and Margalef diversity indexes for plants (Family) in Mount Resaca and Luis Peña Cay.

Sampling Area	Shannon-Wiener	Simpson's Index	Margalef	
Mount Resaca	2.472	0.883	3.802	p =0.0039 (Between Sites)
Luis Peña Cay	2.209	0.862	2.782	

Mean canopy cover was 10.0% higher at Mount Resaca than in Luis Peña Cay ($t=20.72$, $SD=24$, $p=<0.0001$), as in Luis Peña Cay the values for mean DBH and leaf litter were larger than Mount Resaca; however, these were not statistically significant ($t= 14.12$, $SD= 10.53$, $p=>0.05$) between localities (Figure 23). Furthermore, for Mount Resaca, leaf litter ($p=>0.05$, $n= 41$) and canopy cover ($p=>0.05$, $n= 41$) were not affected by elevation but DBH was higher in lower elevations ($p=<0.0001$, $n= 330$). On the other hand, in Luis Peña Cay, leaf litter ($p=>0.05$, $n= 24$), canopy cover ($p=>0.05$, $n= 24$) DBH ($p=>0.05$, $n= 122$) were not affected by elevation. (Figure 22)

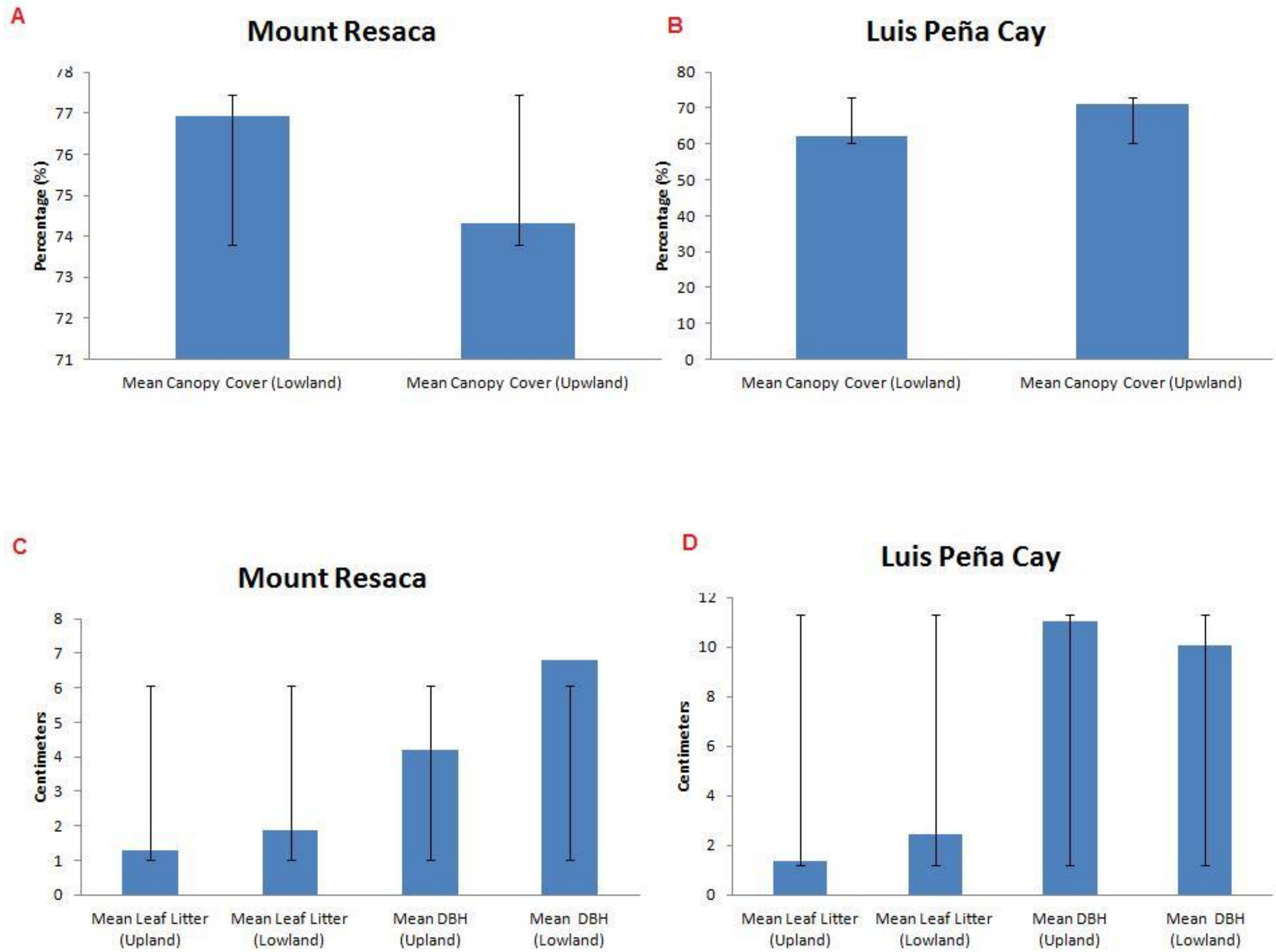

Figure 22. (A) Mean canopy cover for lowlands and uplands in Mount Resaca with Standard Deviation; (B) Mean canopy cover for lowlands and uplands in Luis Peña Cay with Standard Deviation; (C) Mean leaf litter and DBH for lowlands and uplands in Mount Resaca with Standard Deviation; (D) Mean leaf litter and DBH for lowlands and uplands in Luis Peña Cay with Standard Deviation.

Correlations

At each locality; abundance, canopy cover, diameter at breast high (DBH) and leaf litter were correlated to herpetofaunal abundance at two elevations (low/high). For Resaca, none of the parameters measured were significantly correlated.

For Luis Peña Cay the diversity of the herpetofauna was positively related to vegetation diversity at low elevations (R^2=0.36, p=<0.001, n=13). Canopy cover was negatively related to the diversity of herpetofaunal species (R^2=0.21, p= <0.001, n=17) (Appendix B, Table 16).

DISCUSSION

As previously stated, herpetofaunal studies on Culebra Island are scarce due to former military activities that were carried out in the present refuge areas. The USFWS species checklist of 2012 was incomplete; species that were present in the area were not included because ecological studies have not been done. Nevertheless, this study is intended to provide a baseline that will allow the developing and conducting of future advance studies. This is important because within an archipelago, islands are not true replicates; they differ in size, elevation, habitat, geological age, history, distance to colonization sources, human land use and climate. These factors affect the number and identity of species and distribution patterns change with spatial resolution in response to these variables (Buckley, 2005; Case and Bolger, 1991; Gaston, 2003; Kotliar and Wiens, 1990). Spatial changes such as elevation can be measured to assess differences in a community of the given area (Millar, 2011).

Mount Resaca

Visual Encounter Survey

This area as it is has not been perturbed since the NAVY left, giving a chance for ecological succession to run its natural course. Some species previously reported such as *A. roosevelti*, *E. monensis granti* and *S. townsendi* could not be found in the vicinities of the surveyed area. This could be explained by the secretive habits and preferred foraging places (Herrera, 2010). *Anolis roosevelti* was founded in the past in *Ficus* sp. and *Bursera simaruba* trees (Dodd and Campbell, 1982), *E. monensis granti* prefers tall trees like *Bursera simaruba* and coastal vegetation (Tolson, 2005) and *S. townsendi* has preference for coastal leaf litter

(Rivero, 1998). Amphibians are scarce in Culebra Island because of its dry climate. However, *Eleutherodactylus antillensis* has managed to survive and become the most contributing amphibian in the habitat.

In Mount Resaca, *A. cristatellus wileyi* was the most abundant species during the dry and wet seasons, due to its adaptations to deal with altered habitat (Herrera, 2010; Henderson and Powell, 2009).

Species diversity seems to be independent from seasonality in both areas. This may be because in tropics, seasonality has no marked changes, as there is in temperate areas. Toft (1980) found that in some cases, the season of lower food abundances may change both, absolute and relative abundances, and similarity in diet among species was reduced at that time.

In spatial terms, some species were abundant at different elevations, such was the case of *A.pulchellus* that was more abundant in high elevations and of *A. cristatellus wileyi* that was more abundant at lower elevations. Diamond (1973) suggested that species at different elevations develop canopy-height specialization, which subsequently enables range expansion and local spatial coexistence (Buckely, 2005).

Invasive species such as rats (*Rattus rattus*) and feral cats (*Felis catus*) were seen about 50% of surveys on the site. These species are known to predate anoles since they are more arboreal (Case and Bolger, 1991; Henderson, 1992). One of the most common patterns in lizard biogeography is the association of high lizard densities with low predator abundance. Small islands without mammalian predators have high density of lizards compared to the mainland or larger islands with mammalian predators (Case and Bolger, 1991). Also, Gibbons and Watkins

(1982) suggest that cats may have been even more damaging than mongooses to arboreal reptiles.

Autonomous Recording Unit (ARU)

Vocalization evolves as the result of a variety of selection pressures such as the environment (Drewry and Rand, 1983). The *genus Eleutherodactylus* is one of the few that can use the same notes to do courtship and advertisement calls rearranging the notes (Stewart and Rand, 1991; Stewart and Bishop, 1994). A study conducted on the genus *Eleutherodactylus* in the main island showed that *E. antillensis* had an activity peak call during midnight and low intensity at dusk and dawn (Drewry and Rand, 1983). In Culebra Island, the activity was different; this species was more active during dusk and dawn. These differences may function in defense of a calling territory to other males (Ovaska and Caldbeck, 1997). In the case of Culebra Island, the frequency of calls by *E. antillensis* was broader in range compared to the same species at El Yunque Rain Forest (Drewry and Rand, 1983), being 1.05 kHz higher.

On the other hand, *E. cochrane* showed a difference in spectral length from the population in the main island. The population activity in the main island was relatively constant during all night, but in Culebra Island, the population was more active during dusk and its intensity diminished almost to no calling individuals and remained so throughout the night until dawn. The same occurs in the Virgin Islands, which have almost the same type of forest as Culebra (Ovaska and Caldbeck, 1997). Their spectral signature is so dissimilar from the main island that they differ by frequency (kHz), up to 2.0 kHz higher, and shorter note length. Interestingly both *E. cochranae* and *E. antillensis* have similar courtship calls (Michael, 1996).

It is known that frogs can modify the amplitude of the call depending of the environment, depending on how open or closed is their habitat space and the intensity of interspecific competitors (Drewry and Rand, 1983; Alcock, 2005). Competition studies can be done to examine why *E. coqui* is so unsuccessful when *E. antillensis* is present in an area. Spectrographs showed that *E. antillensis* usually use trill (aggressive) calls, which are used in defense of a territory (Ovaska and Caldbeck, 1997). It is well known that these two species share the same habitat, thus may compete for the same resources. Narins (1995) mentioned that frogs resort to time-sharing and some of them restrict their calls to particular times of day. This event does not seem to be occurring in Mount Resaca because both species were recorded calling at the same time in almost every recording. Autonomous monitoring proved to be a success, since the researcher does not have to be in the area, minimizing disturbance and allowing a more natural behavior of the species inhabiting the sampled area.

Plant Diversity

Mount Resaca has an homogeneous plant diversity throughout the area. However, there are differences in forest structure. In the lowlands the DBH tends to be higher, indicating that the forest is denser and this was confirmed as both, the litter and vegetation cover are greater.

Luis Peña Cay

Visual Encounter Survey

Luis Peña Cay is composed of a drier forest that was affected directly by the military activities (Feliciano, 2001).These activities destroyed most of the forest, so this forest is in a younger state (pers. obs.). It is known that areas that are perturbed by humans are not suitable for native or endemic species, which could explain the low diversity in the area (Dodd and Campbell, 1982; Germano *et al.*, 2003). These perturbed areas are susceptible and are targets to exotic species, such as domestic goats (*Capra hircus*). Goats were widely spread through the island destroying the coastal vegetation that some lizards and snakes use as lair (pers. obs.). In Round Island of the Republic of Mauritius, a place similar in size to Luis Peña Cay, goats have caused the probable extinction of one snake species in just a few decades after their introduction (Bullock, 2001). In addition, the Helmeted Guinea fowl (*Numida meleagris*) was seen on site eating *Sphaerodactylus* sp.

For the Luis Peña Cay, *A. pulchellus* was a new report, located at low elevations this species was abundant, living in shrubs near the coast. In addition, it was the most abundant throughout the lower parts of the Cay. At higher elevations, *A. pulchellus* was not encountered; this could be because the area that seems to be more suitable for the species was not surveyed because it had limited access due to the Unexploded Ordinance, or better known by its acronym, UXO.

Spatial change had an influence in reptile abundance as well (Buckley, 2005). Biotic factors such as vegetation were correlated to animal abundance in the elevation gradient. For the lower part, as vegetation abundance increased, so did animal abundance. Vegetation creates biomass which, at a microhabitat scale, produces an increase of leaf litter that benefits dwelling species such as *B. portoricensis richardi*, *S. macrolepis* and *A. cristatellus wileyi*. At high elevations, canopy cover influences reptile abundance by decreasing the population individuals of *A. cristatellus wileyi* and *S.macrolepis macrolepis*. The reasons for these results are not yet clear. Henderson and Crother (1989) suggested that lower areas are more suitable for reptiles. In this particular case, spatial contour measure by vegetation was homogeneous throughout the area.

Plant Diversity

This Cay is highly disturbed by various factors previously mentioned. Human impact has destroyed this refuge in a way that most of the trees seem young creating less dense vegetation (pers. obs.). This provokes the invasion of grasses that limits the propagation of seedlings (Callaway and Aschehoug, 2000). Another impact cause by humans is the introduction of goats (*Capra hirca*), this herbivore prevented tree recruitment, destroyed the hardwood forest, and promoted the progressive ecological degradation (Vinson, 1964; North, 1986). The area sampled lacked of seedling stage creating a succession problem and reducing habitats needed for crawling species (Bullock, 2001).

Comparison among sites

Species richness of the herpetofaunal community did not change during the seasons within each area. However, there was a difference between Mount Resaca and Luis Peña Cay diversities within the community, indicating a spatial species differentiation. Each habitat contains a different microclimate. Shifts in landscape and elevation correspond to change in relative species abundance at the landscape space (Buckley, 2005). For example, Mount Resaca tends to be more humid and cooler than Luis Peña Cay is, but in the last one temperature tends to raise a lot more. In addition, vegetation itself is different in terms of structure and species between both localities. This means that the spatial structure of the community in each area varies within the dry and wet season independently.

In general, diversity in both sites was moderate to low. Between them, Mount Resaca showed major diversity. This area is richer in terms of fresh water resources and vegetation diversity, providing with more niches that can accommodate additional species. Amphibian diversity seems to be higher in Vieques Island, but Culebra Island had higher reptile diversity, yet with an accumulation species curve indicating that the area in Culebra was not sufficiently monitored. Diversity in amphibians and reptiles could be higher if more surveys are performed (Herrera, 2010).

Regarding to biotic factors, vegetation does not seem to influence diversity and abundance in Mount Resaca. In fact, the only parameter that correlated with diversity was the humidity. At Luis Peña Cay's low elevations, the vegetation is greatly affected by goats (*Capra hirca*) (pers. obs.). Seedling density is extremely low, thus, reducing important habitat for juvenile reptiles (Lieberman, 1982). The greater the canopy covers, the lesser species found. At these elevations, vegetation does not seem to be as damaged as at low elevations. In this area, the biodiversity was correlated with temperature, which suggests that reptile species could be affected by heat stress. Further analysis should be performed in the future to observe if competition with non-native species could be affecting this plant community. Both areas have woody trees and tallgrass which are fuel for intentional fires. These fires are common in the dry season when people start them with no reason. These fires already affected the USFWS Culebra Refuge. It is well known that fire suppress woody vegetation, removes the litter layer, alters vegetation composition and productivity (Cavitt, 2000), thus affecting animal relative abundance.

Recommendations

This work intended to analyze the spatial and temporal composition of herpetofaunal communities in two areas of the Culebra National Wildlife Refuges. The results demonstrated moderate species diversity in both areas. Abiotic parameters such as temperature and humidity were correlated to the spatial pattern of the communities. Based on the results, I would like to make the following recommendations:

1. Increase the coverage of study sites in order to develop long term monitoring programs for herpetofaunal communities to assess the status of species that were not found, such as *E. monensis granti*, *Anolis roosevelti* and *S. townsendi*. Some of the areas are closed due to Unexploded Ordinance (UXO) but removal of these artifacts is in schedule. These studies can help the management of these areas and the conservation of these species.
2. For these studies, the use of traps may be useful to assess small reptiles such as geckos and blind snakes. Because an estimate of population size could not be made, a mark-recapture study may be held to assess anoles and snakes in the refuge areas.
3. Invasive species, like Rats (*Rattus rattus*), feral cats (*Felis catus*) and White-tailed deer (*Odocoileus virginianus*), were common in the same areas that *Epicrates monensis granti* and *Anolis roosevelti* inhabit. The domestic goat (*Capra hircus*) and the Helmeted Guinea fowl (*Numida meleagris*) were observed in Luis Peña Cay; goats, in particular, were seen in the area damaging the vegetation foliage. Eradication programs are imperative to these areas to help the recovery of threaten native species and restore the habitat to its natural form.

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APPENDIX A

Figure 1. The Giant Culebra Island Anole (*Anolis roosevelti*) is a large brownish-gray lizard that grows to about 16 cm (snout-vent length), and has a light spoton its temple, and two light lines on each side. One line runs from the ear to the eyelids and the posterior quarter of its dewlap are yellow, and the tail is yellowish brown with the edge of the tail fin deeply scalloped (Grant, 1931b; Dodd and Campbell, 1982; Williams, 1962; Rivero, 1998). Photo by: University of Harvard.

Figure 2. Virgin Islands Boa (*Epicrates monensis granti*): The adult body color is light plumbeus brown with darker blotches partially edged with black. The dorsal blotches are angulate and frequently reach the ventral scales and its surface has a general blue-purple iridescence. The ventral surface is greyish-brown speckled with darker spots. In contrast to the adult coloration, neonate dorsal ground color is light grey punctuated with black blotches. It has an extremely disjunctive distribution indicative of a long history of population decline and extirpation (Mayer and Lazell, 1988; Nellis *et al.,* 1983; Tolson, 1984).

Figure 3. Culebra Island with sampling area. Mount Resaca marked with a red square and Luis Peña Cay marked with a yellow square.

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Figure 4. Representation of the four transects surveyed in Mount Resaca. Each transect is 125 meters long.

Figure 6. Representation of the four transects surveyed in Luis Peña Cay. Each transect is 125 meters long.

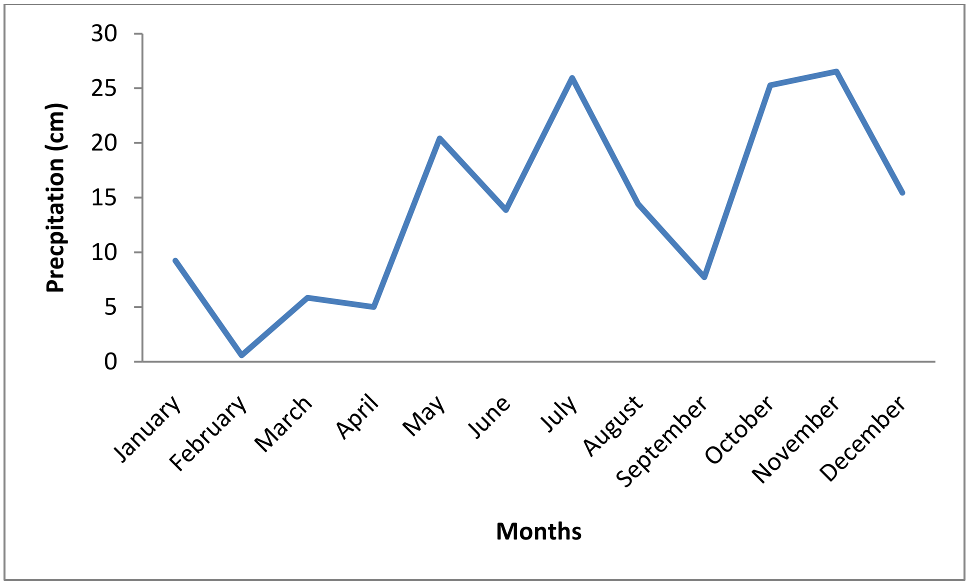

Figure 7. Rain activity in the Culebra National Wildlife Refuge during 2010. The mean precipitation for the year 2010 was 13.9 cm.

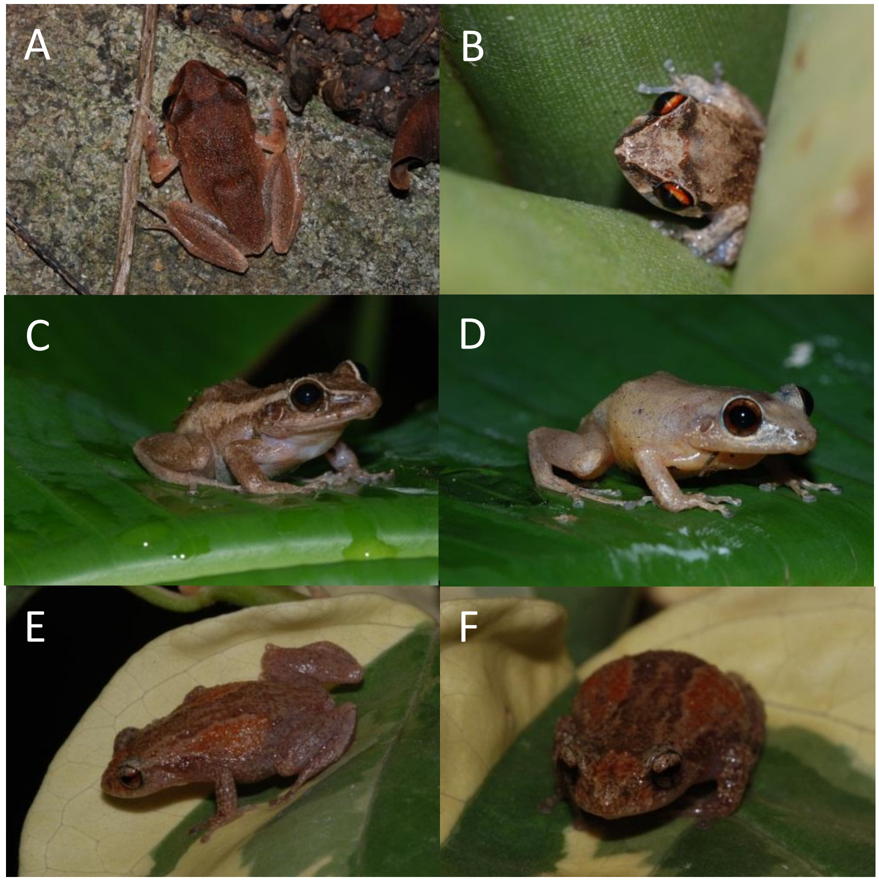

Figure 8. Amphibians (Eleutherodactylidae) found in Culebra Island. (A) Dosal view of *Eleutherodactylus antillensis*, found in Mount Resaca; (B) *Eleutherodactylus antillensis*, red eye coloration; (C),(D) *Eleutherodactylus coqui*, lateral view, found in Mount Resaca and Dewey (town);(E) *Eleutherodactylus cochranae* dorsolateral view (F) *Eleutherodactylus cochranae* dorsal orange coloration.

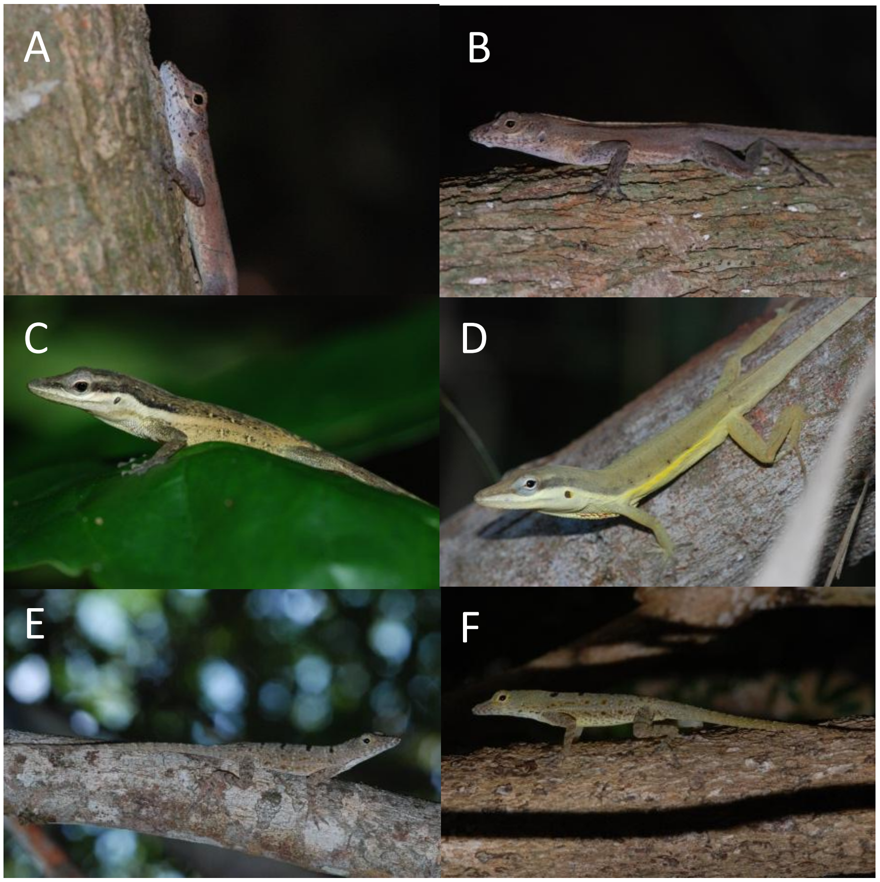

Figure 9.Anoles (Dactyloidae) found at Mount Resaca and Luis Peña Cay at CNWR. (A),(B) *Anolis cristatellus wileyi* lateral view*;* (C) *Anolis pulchelus* lateral view; (D) *Anolis pulchellus* dorsal view*;* (E), (F) *Anolis stratulus*, lateral view.

Figure 10. Snake (Dipsadidae) found at Mount Resaca and Luis Peña Cay at CNWR. (A) *Borikenophis portoricensis richardi;* (B) dorsal scales of *Borikenophis portoricensis richardi.*

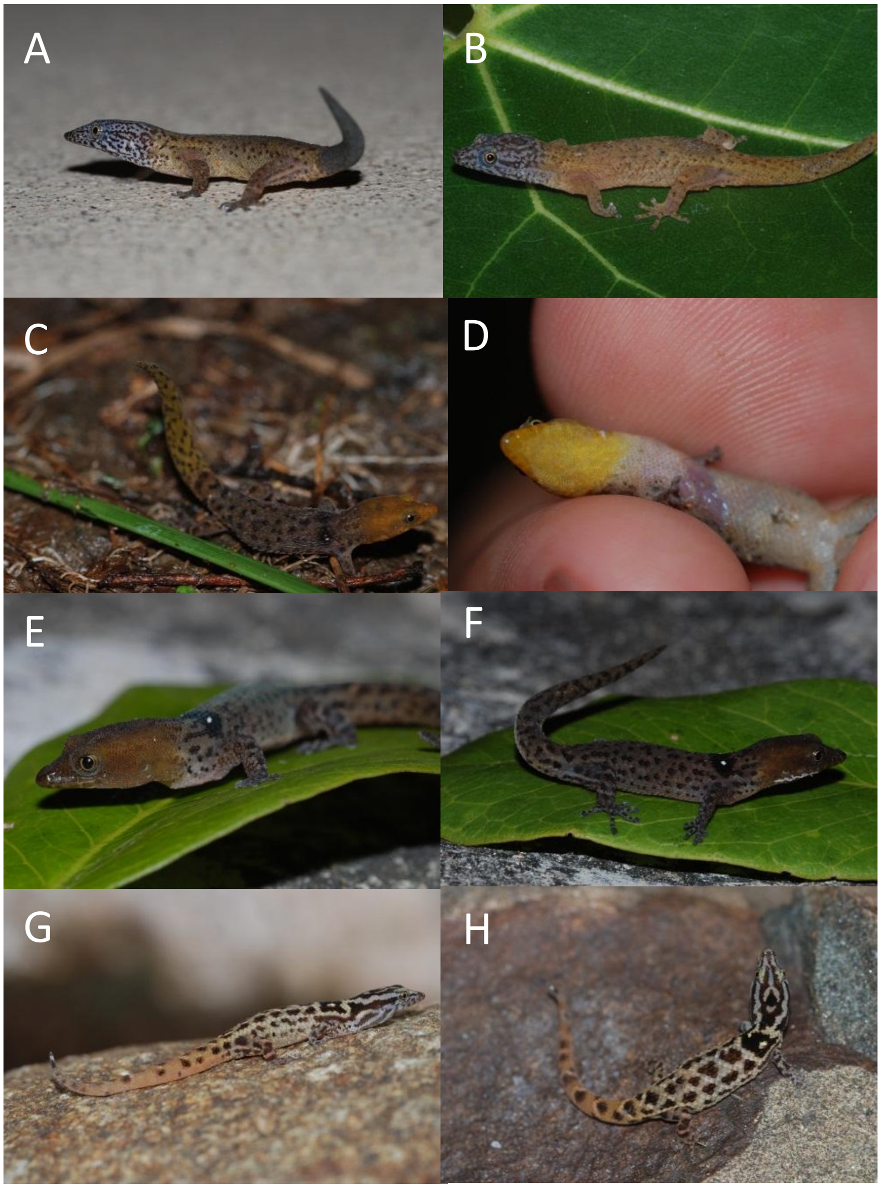

Figure11. *Sphaerodactylus* (Sphaerodactylidae) found in Mount Resaca at CNWR.(A),(B) *Sphaerodatylus macrolepis macrolepis*; (C) *Sphaerodatylus macrolepis ssp*. dorsal view*;* (D) *Sphaerodatylus macrolepis ssp.,* ventral view;(E),(F) *Sphaerodactylus macrolepis inigoi;* (G),(H) *Sphaerodatylus sp.*

Figure 12. Skink (Mabuyidae) found at Mount Resaca,CNWR. (A) *Spondilurus culebrae*, lateral view; (B) *Spondilurus culebrae* zoom of the head.

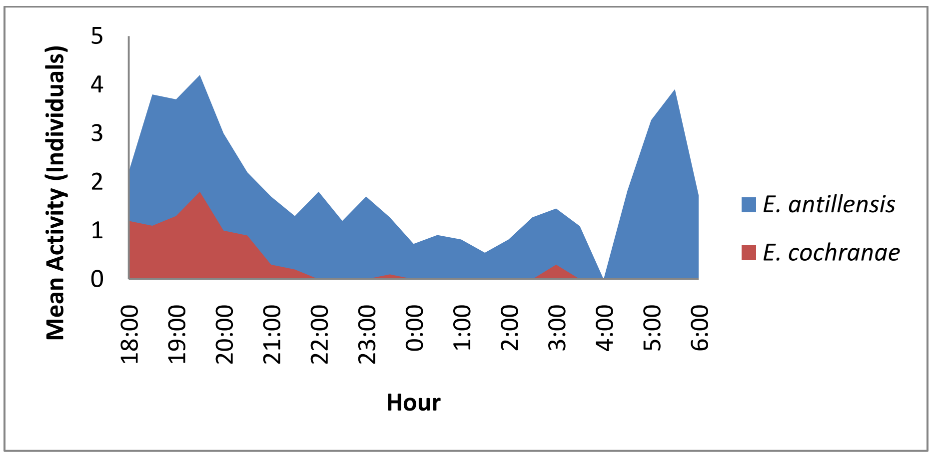

Figure 15. Frog activity during the night at Mount Resaca (n= 8,622), CNWR.

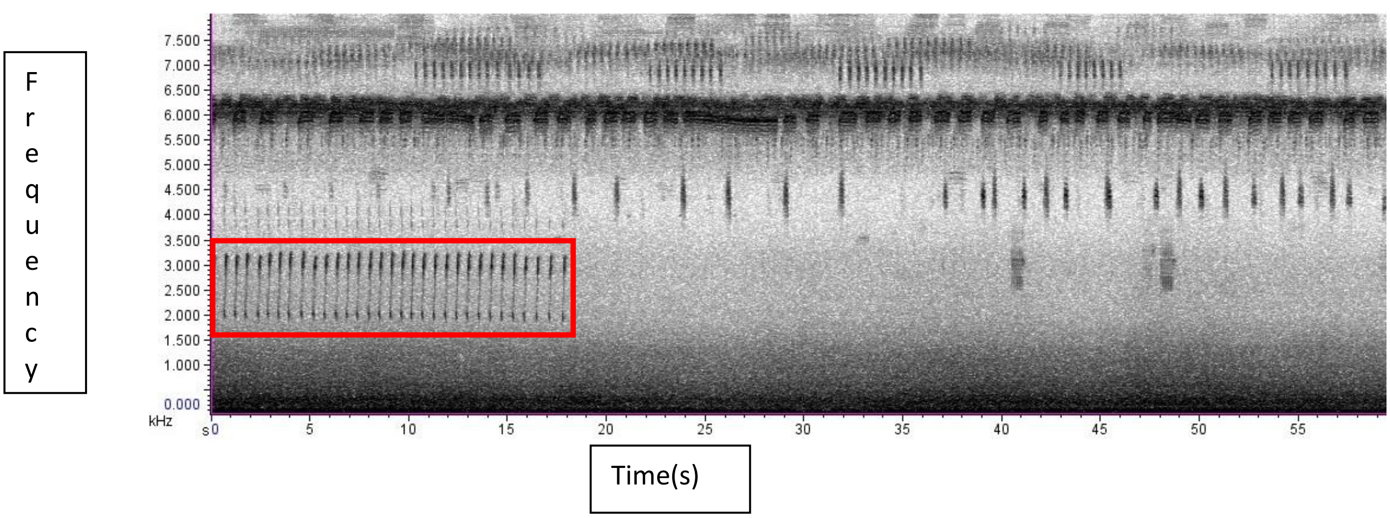

Figure 16. *E. antillensis* sound spectrogram in red square

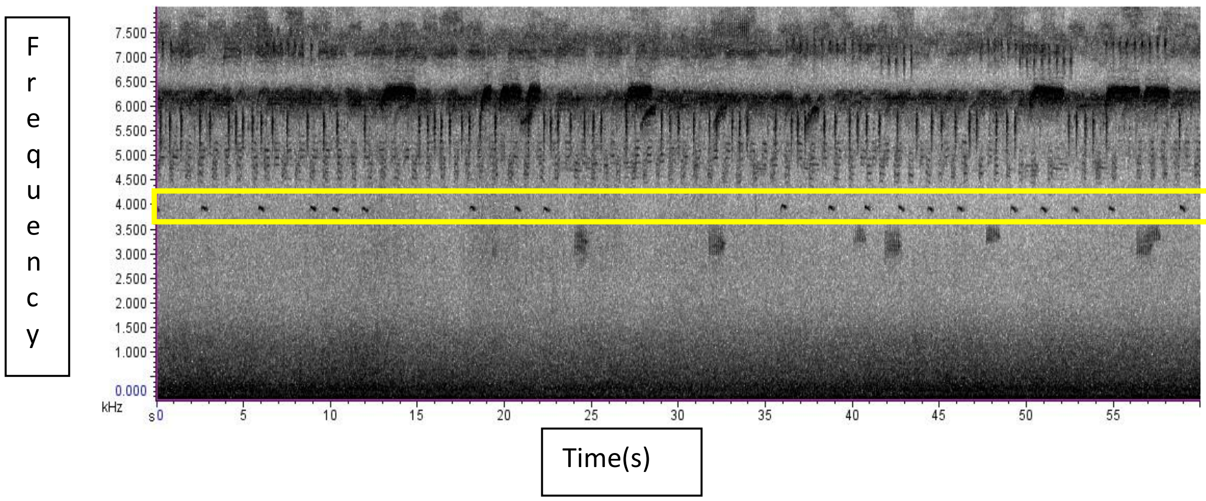

Figure 17. *E. cochranae* sound spectrogram in yellow square

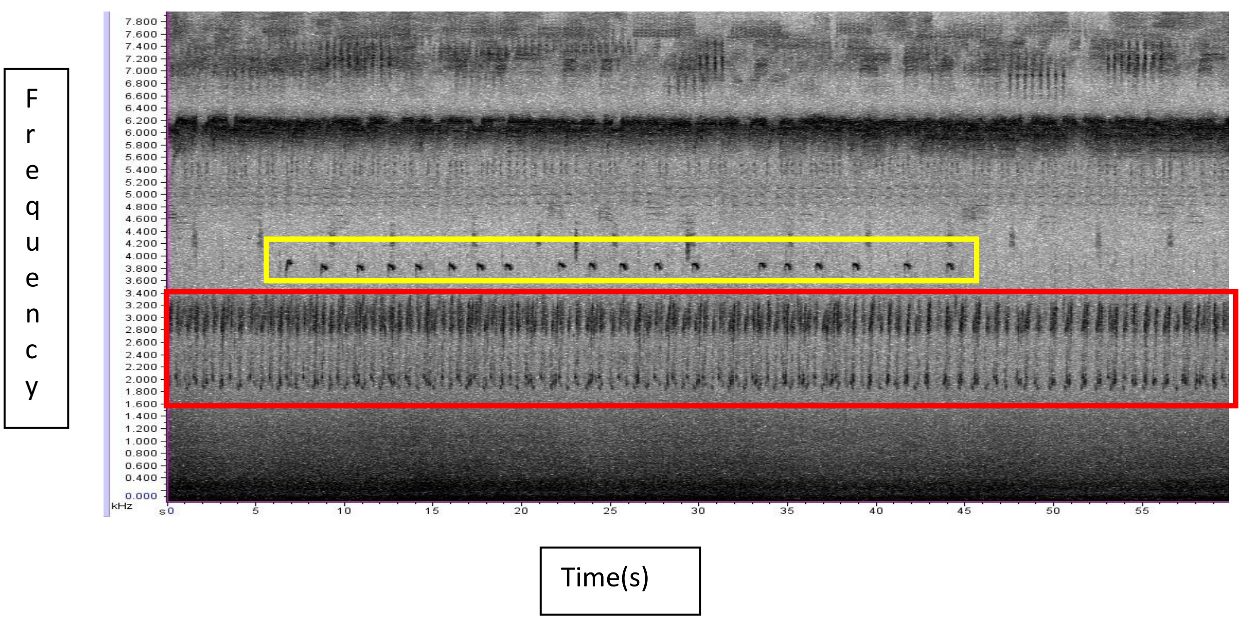

Figure 18. *E.antillensis* (Red) and *E. cochranae* (Yellow) sound spectrograms calling at the same time.

APPENDIX B

Table 1. Sheet used to organize the data in twelve categories.

Date: ___________

Day/Night

Dist. (m)	Species	Ind.	Number of photo	Coord.		Pres. (m)	Elev. (m)	Hour	Temp. ° F	Humidity (%)	Obs.
0											
10											
20											
30											
40											
50											
60											
70											
80											
90											
100											
110											
125											

Note:
The coordinate's reference system is on NAD 83.
n.o. : Not present

Table 2. Mean abundances of amphibians and reptiles during wet and dry seasons in Mount Resaca and Luis Peña Cay, over the year 2010.

	Mount Resaca		Luis Peña Cay	
Parameter	Species	Abundance	Species	Abundance
Dry season	*Anolis cristatellus wileyi*	7.78	*Anolis cristatellus wileyi*	4.00
	Anolis stratulus	7.57	*Sphaerodactylus macrolepis macrolepis*	4.00
	Anolis pulchellus	3.5	*Borikenophis portoricensis richardi*	2.00
	Borikenophis portoricensis richardi	2.6	*Anolis pulchellus*	6.50
	Sphaerodactylus macrolepis macrolepis	1.25		
	Sphaerodactylus macrolepis inigoi	1.67		
	Hemidactylus angulatus	1.00		
	Eleutherodactylus coqui	2.00		
	Eleutherodactylus antillensis	7.75		
Wet season	*Eleutherodactylus antillensis*	15.71	*Anolis cristatellus wileyi*	2.83
	Eleutherodactylus cochranae	7.65	*Sphaerodactylus macrolepis macrolepis*	3.60
	Anolis cristatellus wileyi	11.46	*Anolis pulchellus*	1.00
	Anolis stratulus	6.20		
	Anolis pulchellus	2.83		
	Borikenophis portoricensis richardi	2.00		
	Sphaerodactylus macrolepis macrolepis	4.50		
	Sphaerodactylus macrolepis inigoi	2.00		
	Sphaerodactylus sp.	1.00		

Table 3. Diversity Indexes for the Dry and Wet seasons at Mount Resaca NWR, Culebra Island.

Diversity Indexes	Dry Season	Wet Season	Reptiles (Dry Season)	Reptiles (Wet Season)	Amphibian (Dry Season)	Amphibian (Wet Season)
Shannon-Wiener	1.949	1.904	1.685	1.675	0.500	0.632
Simpson's Index	0.833	0.820	0.779	0.769	0.326	0.441
Margalef	2.248	2.012	1.856	1.764	0.4391	0.3174

Table 4. Mean abundances of amphibians and reptiles in high and low elevations in Mount Resaca and Luis Peña Cay.

	Mount Resaca		Luis Peña Cay	
Parameter	Species	Abundance	Species	Abundance
Low Elevation	*Eleutherodactylus coqui*	1.00	*Anolis cristatellus wileyi*	3.71
	Eleutherodactylus antillensis	11.00	*Sphaerodactylus macrolepis macrolepis*	4.67
	Anolis cristatellus wileyi	13.33	*Borikenophis portoricensis richardi*	2.00
	Anolis statulus	6.67	*Anolis pulchellus*	6.50
	Anolis pulchellus	2.00		
	Borikenophis portoricensis richardi	6.00		
	Sphaerodactylus macrolepis macrolepis	2.50		
	Sphaerodactylus macrolepis inigoi	1.00		
	Sphaerodactylus macrolepis ssp.	1.00		
High Elevation	*Eleutherodactylus antillensis*	16.83	*Anolis cristatellus wileyi*	1.33
			Sphaerodactylus macrolepis macrolepis	2.00
	Eleutherodactylus coqui	1.00		
	Eleutherodactylus cochranae	7.65		
	Anolis cristatellus wileyi	8.07		
	Anolis pulchellus	3.38		
	Sphaerodactyluys macrolepis inigoi	2.00		
	Anolis stratulus	7.00		
	Borikenophis portoricensis richardi	1.33		
	Sphaerodactylus macrolepis macrolepis	3.67		

Table 5. Diversity Indexes for high and low elevations at Mount Resaca NWR, Culebra Island.

Diversity Indexes	Low elevation	High Elevation	Reptiles (Low Elevation)	Reptiles (High Elevation)	Amphibian (Low Elevation)	Amphibian (High Elevation)
Shannon-Wiener	1.818	1.884	1.586	1.621	0.287	0.762
Simpson's Index	0.802	0.812	0.774	0.777	0.153	0.472
Margalef	2.108	2.035	1.724	1.545	0.402	0.618

Table 6. Mean abundances of amphibians and reptiles during day and night in Mount Resaca and Luis Peña Cay.

	Mount Resaca		Luis Peña Cay	
Parameter	Species	Abundance	Species	Abundance
Day	*Eleutherodactylus coqui*	1.00	*Anolis cristatellus wileyi*	3.71
	Anolis cristatellus wileyi	14.64	*Shaerodactylus macrolepis macrolepis*	4.67
	Anolis statulus	7.29	*Borikenophis portoricensis richardi*	2.00
	Anolis pulchellus	3.57	*Anolis pulchellus*	7.50
	Borikenophis portoricensis richardi	1.86		
	Sphaerodactylus macrolepis macrolepis	2.17		
	Sphaerodactylus macrolepis inigoi	1.50		
	Sphaerodactylus macrolepis ssp.	1.00		
	Sphaerodactylus sp.	1.00		
	Spondilurus culebrae	1.00		
Night	*Eleutherodactylus antillensis*	21.77		
	Eleutherodactylus coqui	1.00		
	Anolis cristatellus wileyi	3.6		
	Sphaerodactylus macrolepis. macrolepis	1.75		
	Sphaerodactylus macrolepis ssp.	2.00		
	Anolis pulchellus	2.00		
	Sphaerodactylus macrolepis inigoi	3.00		
	Anolis stratulus	1.15		
	Borikenophis portoricensis richardi	1.50		
	Hemidactylus angulatus	1.00		

Table 7. Diversity Indexes during day and night at Mount Resaca NWR, Culebra Island.

Diversity Indexes	Day	Night	Reptiles (Day)	Reptiles (Night)	Amphibian (Day)	Amphibian (Night)
Shannon-Wiener	1.793	1.607	1.712	1.996	0	0.180
Simpson's Index	0.760	0.659	0.746	0.853	0	0.084
Margalef	2.531	2.461	2.268	2.525	0	0.320

Table 8. Reptile Diversity Indexes for the Dry and Wet seasons at Luis Peña Cay NWR, Culebra Island.

Diversity Indexes	Dry Season	Wet Season
Shannon-Wiener	1.310	0.999
Simpson's Index	0.713	0.602
Margalef	1.070	0.997

Table 9. Reptile Diversity Indexes for high and low elevations at Luis Peña Cay NWR, Culebra Island.

Diversity Indexes	Low elevation	High Elevation
Shannon-Wiener	1.310	0.673
Simpson's Index	0.713	0.480
Margalef	1.062	0.831

Table 10. Summary of species found in Mount Resaca and Luis Peña Cay at Culebra National Wildlife Refuge.

Family	Genus	Species
Avicenniaceae	*Avicennia*	*germinans*
Arecaceae (Palmae)	*Thrinax*	*morrisii*
Apocynaceae	*Plumeria*	*alba*
Boraginaceae	*Bourreria*	sp.
Bromeliaceae	*Tillandsia*	sp.
Burseraceae	*Bursera*	*simaruba*
Cactaceae	*Leptocereus*	*quadricostatus*
Capparaceae	*Cynophalla*	*flexuosa*
	Quadrella	*cynophallophora*
	Quadrella	*indica*
	Morisonia	*americana*
Celastraceae	*Schaefferia*	*frutecens*
Clusiaceae	*Clusia*	*rosea*
Erythoxylaceae	*Erythroxylum*	*brevipes*
Euphorbiaceae	*Croton*	*flavens*
	Euphorbia	*petiolaris*
	Gymnantes	*lucida*
Fabaceae	*Acacia*	sp.
	Pictetia	*aculeata*
	Pithecellobium	*unguis-cati*
Lauraceae	*Nectandria*	*coriacea*
Malpighiaciae	*Malpighia*	*woodburyana*
Malvaceae	-----	-----
Meliaceae	*Trichilia*	*hirta*
Mimosoideae	*Leucaena*	sp.
Moraceae	*Ficus*	sp.
	Ficus	*citrifolia*
Myrtaceae	*Eugenia*	*rhombea*
Nyctaginaceae	*Pisonia*	*subcordata*
Phyllanthaceae	*Savia*	*sessiliflora*
Piperaceae	*Peperomia*	*wheeleri*
Poaceae	*Megathyrsus*	*maximus*
Poligonaceae	*Coccoloba*	sp.
Rubiaceae	*Exostoma*	*caribaea*
	Psychotria	*brownei*
	Randia	*aculeata*

Table 11. SIMPER analysis of indicator species at Mount Resaca and Luis Peña Cay at Culebra National Wildlife Refuge.

Taxa	Contibution (%)	
	Resaca	Luis Peña
Plumeria alba	12.18	1.37
Gymnantes lucida	10.19	7.74
Pisonia subcordata	9.54	12.47
Eugenia rhombea	5.23	1.79
Quadrella indica	5.02	2.64
Randia aculeata	4.17	11.46
Morisonia americana	3.66	0.00
Acacia sp.	3.55	0.00
Bursera simaruba	3.19	14.15
Leptocereus quadricostatus	2.65	0.00
Thrinax morissii	2.64	0.00
Erythroxylum brevipes	2.53	0.00
Pithecellobium unguis-cati	1.84	0.00
Ficus sp.	1.76	0.00
Croton flavens	1.72	2.74
Trichilia hirta	1.64	0.00
Quadrella cynophallophora	1.37	0.00
Malpighia woodburyana	1.02	1.00
Ficus citrifolia	0.81	0.00
Megathyrsus maximus	0.70	0.00
Avicennia germinans	0.70	0.00
Clusia rosea	0.58	0.00
Malvaceae (Family)	0.48	0.93
Peperomia wheeleri	0.48	0.00
Tillandsia	0.48	0.00
Cynophalla flexuosa	0.35	1.65
Nectandria coriacea	0.31	0.00
Exostoma caribaea	0.31	0.00
Bourreria	0.29	6.18
Schaefferia frutecens	0.21	8.58
Psychotria brownei	0.00	2.74
Savia sessiliflora	0.00	4.41
Pictetia aculeata	0.00	0.95
Amyris elemifera	0.00	0.48
Euphorbia petiolaris	0.00	0.00
Coccoloba sp.	0.00	2.36
Leucaena sp.	0.00	0.00

Table 12.Analysis of Similarity (ANOSIM). Pairwise Comparison between Dry and Wet Season within Mount Resaca and Luis Peña Cay and between the two areas sampled.

Pairwise tests-GroupComparison	p-value	R-value
Resaca-Dry/Luis Peña Dry*	0.0014	0.5321
Resaca-Dry/Luis Peña Wet*	0.0053	
Resaca-Wet/Luis Peña Dry*	0.0012	
Resaca-Wet/Luis Peña Wet*	0.0026	
Luis Peña-Wet/Luis Peña Dry	0.4131	
Resaca-Wet/Resaca Dry	0.9567	

* = SignificantDifference

Table 13.SIMPER analysis of indicator species at Mount Resaca and Luis Peña Cay at Culebra National Wildlife Refuge.

Taxa	Contibution (%)	
	Resaca	Luis Peña
Eleutherodactylus antillensis	11.47	
Anolis cristatellus wileyi	6.27	2.30
Eleutherodactylus cochranae	6.16	
Anolisstratulus	3.55	
Borikenophis portoricensis richardi	2.49	4.13
Sphaerodactylus macrolepis inigoi	1.83	
Sphaerodactylus macrolepis macrolepis	1.60	9.48
Hemidactylus angulatus	1.27	
Anolis pulchellus	0.92	13.42
Sphaerodactylus sp.	1.27	
Sphaerodactylus macrolepis ssp.	1.27	
Eleutherodactylus coqui	0.97	
Sphaerodactylus macrolepis ssp.	0.83	
Spondilurus culebrae	0.81	
Average Disimilarity %	40.57	29.34

Table 16. Lineal regressions for Mount Resaca and Luis Peña Cay.

Parameter	Resaca		Luis Peña	
	R^2	p value	R^2	p value
Herpetofaunal abundance/ Vegetation abundance	0.006	0.816	0.038	0.427
Herpetofaunal abundance/ Vegetation abundance/ High elevation	0.04	0.500	0.002	0.909
Herpetofaunal abundance/ Vegetation abundance/ Low elevation	0.01	0.704	0.364	0.029*
Herpetofaunal abundance/ DBH	0.02	0.426	0.03	0.378
Herpetofaunal abundance/ DBH/ High elevation	0.000	0.979	0.19	0.134
Herpetofaunal abundance/ DBH/ Low elevation	0.06	0.271	0.03	0.573
Herpetofaunal abundance/ Canopy	0.02	0.367	0.15	0.055
Herpetofaunal abundance/ Canopy/ High elevation	0.001	0.894	0.26	0.035*
Herpetofaunal abundance/ Canopy/ Low elevation	0.055	0.339	0.06	0.420
Herpetofaunal abundance/ Leaf litter	0.001	0.892	0.04	0.345
Herpetofaunal abundance/ Leaf litter / High elevation	0.002	0.852	0.02	0.617
Herpetofaunal abundance/ Leaf litter / Low elevation	0.02	0.529	0.18	0.146

Table 17. Summary of species found in Mount Resaca and Luis Peña Cay at Culebra National Wildlife Refuge.

Class	Order	Family	Genus	Species	Sub-species
Amphibia	Anura	Eleutherodactylidae	*Eleutherodactylus*	*coqui*	-----
			Eleutherodactylus	*antillensis*	-----
			Eleutherodactylus	*cochranae*	-----
*		Leptodactylidae	*Leptodactylus*	*albilabris*	-----
*		Bufonidae	*Rhinella*	*marina*	
Reptilia	Squamata	Dactyloidae	*Anolis*	*cristatellus*	*wileyi*
			Anolis	*pulchellus*	-----
			Anolis	*stratulus*	-----
		Dipsadidae	*Borikenophis*	*portoricensis*	*richardi*
*		Boiidae	*Epicrates*	*monensis*	*granti*
		Sphaerodactylidae	*Sphaerodactylus*	*macrolepis*	*macrolepis*
			Sphaerodactylus	*macrolepis*	*iñigoi*
			Sphaerodactylus	*macrolepis*	*unknown*
			Sphaerodactylus	*macrolepis*	*unknown*
			Sphaerodactylus	*unknown*	*unknown*
		Gekkonidae	*Hemidactylus*	*angulatus*	-----
		Mabuyidae	*Spondilurus*	*culebrae*	-----
*		Typhlopidae	*Typhlops*	*hypomethes*	-----
*		Iguanidae	*Iguana*	*iguana*	-----
*		Teiidae	*Ameiva*	*exxul*	-----

*Found outside of sampling area