Spatiotemporal Changes of the Herpetofaunal Community in Mount Resaca and Luis Peña Cay, Culebra National Wildlife Refuge, Culebra, Puerto Rico[1]

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Abstract: Culebra, which is an archipelago that forms part of the Puerto Rican Bank, has had a limited scope of biological studies, provided the basis for this work. Culebra's terrestrial resources were disturbed since the early 1900's until the 1970's. Since the 1970's, a natural reserve, called the Culebra National Wildlife Refuge, has been managed by the United States Fish and Wildlife Service. The purpose of this research is to update the species list of reptiles and amphibians on the Island as well as to examine how spatial and temporal changes affect the diversity and abundance of its herpetofauna. Twenty species of reptiles and amphibians placed in thirteen families were identified. Two new records for Mount Resaca are *Eleutherodactylus coqui* Thomas, 1966 and *Eleutherodactylus cochranae* Grant, 1932. Meanwhile, *Anolis pulchellus* Duméril and Bibron, 1837 is a new record for the Luis Peña Cay. Mount Resaca has greater species richness, ten more species than the Luis Peña Cay, three species of amphibians and seven species of reptiles. The differences in herpetofaunal biodiversity (e.g. Shannon Wiener, Simpson's Index and Margalef's Index) between Mount Resaca and the Luis Peña Cay were statistically significant. Abiotic factors, such as temperature and humidity, and biotic factors, such as vegetation and the presence of other animal species, possibly influence the relative abundances within these communities.

Key Words: Culebra Island, Culebra National Wildlife Refuge, herpetofauna, biodiversity, ecology, spatiotemporal changes, Mount Resaca, Luis Peña Cay

Introduction

Terrestrial reptiles and amphibians are important organisms of many ecosystems due to their total numbers, biomass and how they affect ecosystem functions through complex trophic interactions (Dodd 2010, Ríos-López et al. 2015). However, these taxa are sensitive to the changes in terrestrial ecosystems occurring worldwide. The herpetofauna is susceptible to sudden environmental changes (Sala et al. 2000, Cushman 2006), and these changes can either reduce their populations or, in extreme cases, lead to extinctions.

A few critical factors responsible for these changes are land use, such as agriculture, recreational space, urban sprawl and the development of areas for military training; all leading to habitat fragmentation (Gibbons 2000, Thrush 2008). In such cases, many amphibians and reptiles cannot escape from the area

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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 extant species (IUCN 2012) 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 on islands are much higher than in their continental counterparts (Henderson 1992, Vitousek 1990).

Ecological studies can provide insights about factors limiting the distribution and abundance of susceptible species. This information is critical for habitat management (Rutherford and Gregory 2003) and enables proper delimitation of regions that need to be protected (Burt 1943, Litzgus and Mousseau 2004). More importantly, the persistence of many species depends upon the effectiveness of strategies for conserving biodiversity in human dominated landscapes (Vandermeer and Perfecto 2007). Spatiotemporal studies may yield ecological data of great value to conservation ecology and biology.

One tool of ecological studies is a spatial focus on organisms. 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 constitute an important axis where different species may coexist in different niches (Buckley 2005, Millar 2011).

Another tool, temporal studies, are important for understanding the fluctuations in populations, studying correlations between climatic variables, such as precipitation, temperature, humidity, that can affect abundance and diversity of the herpetofauna. 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 to be physiologically active (Hillman et al. 2009). We can assume that during dry seasons, the abundance of frogs will decrease, while the wet season will favor an increase in frog's abundance. In addition, temperature can influence habitat humidity and can cause heat stress in animals. Dry seasons can decrease the amount of food available. Changes in temperature and humidity may vary the conditions of the habitat in which animal populations thrive. All of these factors can reduce the abundance and decrease biodiversity (Toft 1980), which in the case of the often endemic Caribbean herpetofauna.

Puerto Rico lies within the Caribbean biosiversity hotspot (Cox and Moore 2000). Its extant biodiversity consists of approximately 26,410 species of plants, fungi, and animals (Joglar 2005). The 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 has been mostly centered on the main island, Puerto Rico, excluding neighboring islands, such as the Culebra Archipielago (Pregill 1981).

The herpetofauna of the main Culebra Island was only been listed in 1930 (Grant 1932a) and has been mostly neglected ever since, due to potential problems, such as access to areas, and historical reasons, concerning the presence of the United States military. Only 12 species were reported in Grant's work. Among these species is the Culebra Giant Anole, *Anolis roosevelti* Grant, 1931, a species that is now believed to be extinct (Ojeda 2010). There is also the Virgin Islands' Boa, *Chilabotrus granti* (Stull, 1933), a federally-listed endangered species (USFWS 2009). In addition to Grant's work, Rivero (1998) cited eight species of lizards [*Anolis critatellus wileyae* Grant, 1931; *Anolis stratulus* Boulenger, 1885; *Anolis pulchellus* Duméril and Bibron, 1837; *Ameiva exsul* Cope, 1862; *Spondilurus culebrae* Hedges and Conn, 2012; *Sphaerodactylus macrolepis* Günther, 1859; *Anolis roosevelti* Grant, 1931; *Iguana iguana* (Linnaeus, 1758)] and three species of snakes [*Boriquenophis richardii* Grant, 1946; *Typhlops richardii* Duméril and Bibron, 1844 and *Magliophis exigum* (Cope, 1863), Table 1].

Herpetofaunal studies at the Culebra Archipielago are scarce due in part to the military activities that were conducted by the United States Marine Corps in what now constitutes refuge areas. 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 Island began protests, known as the Navy-Culebra protests, advocating the removal of the U.S. Marine Corps from the Island. Four years later, in 1975, the use of the Culebra Archipielago 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 United States Fish and Wildlife Service (Feliciano 2001). These areas were kept restricted to the public and a minimum of environmental and ecological studies has been conducted ever since.

The purpose of this study is to document how abundance and diversity of reptiles and amphibians changes in spatial and temporal scales. Changes in elevation, location, vegetation, seasonality, temperature, precipitation and humidity were taken into consideration. Lastly, we considered it necessary to update the current herpetofaunal diversity for the Culebra Archipielago.

Methods

Study Sites. The main island of Culebra is located at 18º 18' 18" N: 65º 18' 05" W, approximately 17 miles (27 km) east from the main island of Puerto Rico, 12 miles (19 km) west of St. Thomas (United States Virgin Islands) and 9 miles (14 km) north from the northernmost tip of Vieques. It comprises the main island of Culebra and 23 smaller islands or cays. This study took place in two protected areas within the U.S. Fish and Wildlife Service Refuge System: Mount Resaca in the main island of Culebra and the Luis Peña Cay to the west (Figure 1). These areas were transferred in 1976 (Román et al. 2012) to the U. S. Fish and Wildlife Service when the Navy left the island in 1975. Since then, these areas have been relatively undisturbed, giving time to native and endemic species to recolonize.

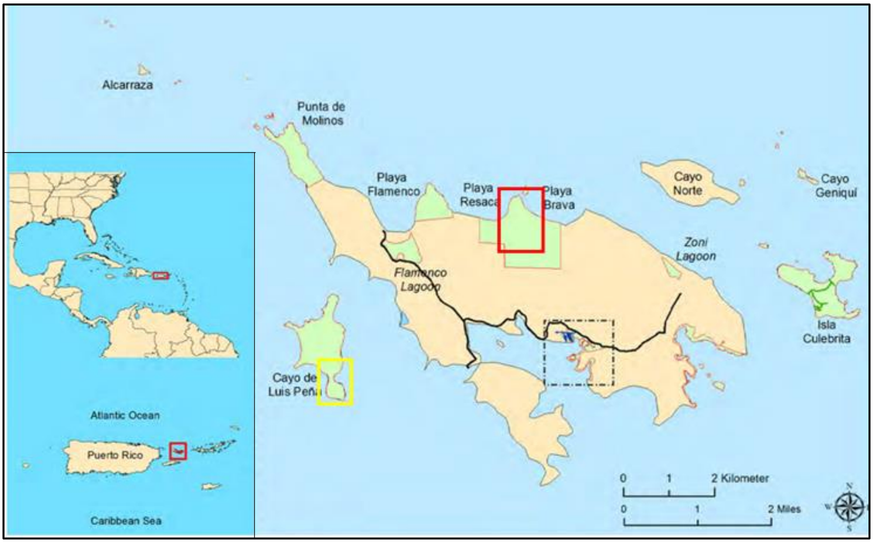

Figure 1. Culebra Archipielago with sampling areas of this study. The Mount Resaca area is denoted with a red rectangle and Luis Peña Cay area with a smaller yellow rectangle. Pale green areas denote the Culebra National Wildlife Refuge. Insert represents the Culebra Archipelago in the context of the Americas and Puerto Rico. Images taken from the *Culebra National Wildlife Refuge Comprehensive Conservation Plan* (Román et al. 2012).

Mount Resaca (latitude 18º19'33.2" N, longitude 65º18'2.3" W; elevation 1850 m above sea level) is located in northern Culebra Island, on a peninsula approximately 1.0 km long by 1.5 km wide. Mount Resaca has a dry subtropical forest type known as a boulder forest (Román et al. 2012), an ecosystem characterized by the pronounced presence of boulders, which fosters constant vegetational changes depending on the seasonal temperature, humidity and rainfall. Additionally, its soils are composed of about 70% to 80% volcanic rock. This particular boulder forest brings within its structure different kinds of microhabitats, such as intermittent streams, bromeliad clusters, thorny bushes, leaf litter, boulders and tall trees that provide shade and maintains high soil humidity (United States Fish and Wildlife Service 1982, Román et al. 2012).

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* Britton (Piperaceae), another federally-listed species, and the Sebucán cactus, *Leptocereus grantianus* Britton (Cactaceae). On the other hand, animals such as Virgin Island Tree Boa, *Chilabotrus granti* (Stull, 1931), 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 in 1930 (United States Fish and Wildlife Service 1982).

The second study site was located at the Luis Peña Cay. The study area is about 2.2 km long by 1.0 km wide, and it is composed of a subtropical dry forest with a mean temperature and humidity of 86.47°F and 74.25%, respectively. It is located to the west side of Culebra Island (latitude 18°18'05.2" N: longitude 65°19'51.1" W). Compared to Mount Resaca, the second study area was drastically deforested by the US Navy. Currently, the Luis Peña Cay has a concrete road that crosses the island's lower part in the southwest to the highest point in the center. Currently, the Luis Peña Cay has a young secondary forest comprised mainly of thorny bushes (*Acacia* spp. Fabaceae). Seedlings are not common in the area; however, when present, they appear to be under constant herbivory (Ríos-Franceschi, personal observations). The Cay appears to have a high concentration of invasive species, such as domestic goats, *Capra hircus* Linnaeus, 1758 (Ríos-Franceschi, personal observations) and, ocassionally, white-tailed deer, *Odocoileus virginianus* Zimmermann, 1780 as observed by another colleague (Teodoro Torres, personal communication).

Survey. Four transects of 125 meters each were established at each study site from January 2010-11 (Figure 2). Transects were selected randomly with respect to their exact location. However, 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 (Figure 15, page 289), the highest transect was located at 163.0 m above the sea level and the lowest transect was located at 11.0 m above the sea level. At Luis Peña Cay, the highest transect was located at 63.0 m above sea level and the lowest at 3.0 m above the sea level. The considerably greater difference in elevational difference in Mount Resaca was taken in consideration for the herpetofaunal community analysis.

Systematic transect searches were performed by at least two researchers to estimate the spatial distribution of amphibian and reptile populations (Anderson et al. 1976, Stork 1995, Manzanilla 2000, Yoccoz 2001, Stiling 2002, Magurran 2004). These surveys were conducted from 6:00 am to 1:00 pm to look mainly for reptiles, and from 6:00 pm to 2:00 am for amphibians. These data were collected twice a month for one year (2010-2011). Some individuals were captured to verify their identity using taxonomic keys (Rivero 1998). The scientific names used to identify species are 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. With these, we are able to correlate temperature and humidity with species richness. Abundance of these species can be affected by abiotic variables, such as the weather (Toft 1980). 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 and Luis Peña Cay. In addition, we used time effort to express the abundance per unit effort (Bury and Raphael 1983). Nocturnal surveys at the Luis Peña Cay were not performed due to illegal hunting that threatened our personal safety. Moreover, no data were taken on the Cay in October and December 2010 because of transportation limitations.

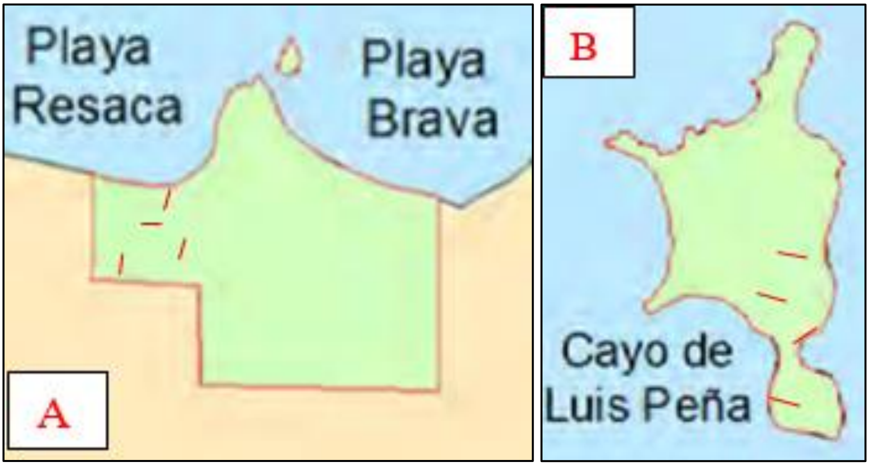

Figure 2. Sampling sites. A. Mount Resaca B. Luis Peña Cay. Each site has four transects, marked by red lines. Images taken form the Culebra National Wildlife Refuge Comprehensive Conservation Plan (Román et al. 2012).

Acoustic Activity. Automated acoustic monitoring of amphibians was performed using an Autonomous Recording Unit (ARU) Song Meter® 2 developed by Wildlife Acoustics (http://www.wildlifeacoustics.com/). The equipment was set to record for six weeks (between August 2010 and February 2011), 1:00 minute every hour, from 6:00pm to 6:00am at 16,000Hz and 16 bits (two channels). The data were recorded during the wet season when amphibians tend to be more active. The data were analyzed to estimate the activity in each recording using human listening skills; the species identity of the amphibians was 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 placed into a histogram to determine the peaks/hour in which each species were more active.

Vegetation Analysis. In 2012, a vegetation analysis was made on the same transects of the herpetological surveys. These data are important as the distribution of amphibians and reptiles is affected by the vegetation (Araújo 2006, Wake 2007). Each transect was divided in twelve points, each separated by 10 m. In each point, canopy cover, tree density and basal area were measured. The layer analysis, which is used to determine canopy and vertical forest structure, was performed using a PVC pipe 2 m high. Plants were included in the sample plot, and identified every time a leaf touched the pipe, 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 human visual estimation. At each sampling point, a two meter diameter circle was marked and every plant species was identified to assess diversity. Diameter at the breast high (DBH) was measured to obtain basal area, and counted to obtain density of the plant populations (Matos 2006). Samples of any plant species that could not be field identified were collected and taken to the Herbarium of the University of Puerto Rico at Mayaguez (MAPR) for identification to lowest possible taxonomic level. All identifications were confirmed by Ms. Jeanine Vélez-Gavilán (Herbarium Curator University of Puerto, Mayagüez Campus). Botanical nomenclature follows Axelrod (2011).

Statistical Analyses. Four programs were used to analyze the data: PAST v. 2.04©, Microsoft Excel©, InfoStat© (Di Rienzo 2008), and Estimate©. The following eight statistical tests were performed.

First, the Shannon-Wiener Index was used 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). The formula is given below,

$$\mathbf{H = -\sum_{i=1}^{n} p_i \ln (p_i)} ,$$

where p_i = proportion of individuals found in the species, i.

Second, the Simpson Index is a non-parametric measure that 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. The formula is given below,

$$D = \sum_{i=1}^{n} (n / N)^2 ,$$

where n = the total number of organisms of a particular species (i) and N = the total number of organisms of all species.

Third, the Margalef Index (M) was used to measure species diversity and it is calculated from the total number of species present and the abundance or total number of individuals (Magurran 2004). 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. The formula is given below,

$$D_M = (S-1) / \ln (N) ,$$

where N = the total number of individuals in the sample and S = the number of species recorded.

Fourth, an Analysis of Similarity (ANOSIM) was used to determine the difference in herpetofaunal composition and abundance (Field and Mcfarlane 1968) between Luis Peña Cay and Mount Resaca. The parameters used were dry/wet season and low/high elevation.

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

Sixth, an Species Accumulation Curve analyzes the plot of the cumulative number of species collected, S(n), against a measure of the sampling effort (n) (Ugland et al. 2003). 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.

Seventh, the Spearman Rank-order Correlation Coefficient Correlation (rs), better known as the Spearman Crrelation was 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.

Eight, linear regressions were used to model a relation between biotic factors such as canopy cover, leaf litter and DBH and compare it to animal abundances.

Results

Visual Encounter Surveys

The herpetofaunal species found in this survey of the Culebra Archipielago (Mount Resaca and Luis Peña Cay) was composed of thirteen species of reptiles (nine species of lizards and four species of snakes) as well as two species amphibians (Table 1). Seven species were added to the herpetofauna of Culebra Island, an increment of 46.7% to the previous list (Grant 1931). This represents an increment of 25.0% for the herpetofauna reported for Culebra Archipelago. During these surveys a total of 14 species were found between both sites (Table 1); *Anolis cristatellus wileyi* and *Eleutherodactylus antillensis* were the most abundant species in Mount Resaca and *A. cristatellus wileyi* in Luis Peña Cay.

Table 1. Species found in Mount Resaca and Luis Peña Cay at Culebra National Wildlife Refuge.

Class: Order	**Family**	**Species and Authorship**
Amphibia: Anura	Eleutherodactylidae	▲ *Eleutherodactylus coqui* Thomas, 1966
		▲ *Eleutherodactylus antillensis* Reinhardt and Lutken, 1863
		▲ *Eleutherodactylus cochranae* Grant, 1932
	Leptodactylidae	* *Leptodactylus albilabris* Gunther,1859
	Bufonidae	* *Rhinella marina* Chaparro, Pramuk, and Gluesenkamp, 2007
Reptilia: Squamata	Dactyloidae	▲■ *Anolis cristatellus wileyi* Grant, 1931
		▲■ *Anolis pulchellus* Duméril and Bibron, 1844
		▲ *Anolis stratulus* Boulenger, 1885
	Dipsadidae	▲■ *Borikenophis portoricensis richardi* Reinhardt and Lutken, 1862
	Boiidae	* *Chilabothrus granti* Reynolds, 2014
	Sphaerodactylidae	▲■ *Sphaerodactylus macrolepis macrolepis* Gunther, 1859
		▲ *Sphaerodactylus macrolepis iñigoi* Thomas and Schwartz, 1966
		▲ *Sphaerodactylus macrolepis* spp.
		▲ *Sphaerodactylus* sp.

	Gekkonidae	▲ *Hemidactylus angulatus* Hallowell, 1854
	Mabuyidae	▲ *Spondilurus culebrae* Hedges and Conn, 2012
	Typhlopidae	* *Typhlops richardi* Duméril and Bibron, 1844
	Iguanidae	* *Iguana iguana* (Linnaeus, 1758). See Low (2015:290, this issue) for an explanation of the nomenclature of this taxon.
	Teiidae	* *Ameiva exsul* Cope, 1862
	Emydidae	* *Thachemys stegnejeri stegnejeri* Schmidt, 1928

* Found in the Culebra National Wildlife Refuge but the outside of the sampling area. ▲Found in Mount Resaca. ■ Found in Luis Peña Cay.

Mount Resaca has a multilayered habitat structure that provides abundant perches to *Anolis cristatellus wileyi*. Three sub-species of *Sphaerodactylus macrolepis* (one unknown) and one unidentified species of *Sphaerodactylus* were found during the study period. In addition, *Hemidactylus angulatus* was found during the night on tree trunks. A species of frog, *E. coqui*, one species of lizard, *A. pulchellus*, and one species of snake, *B. richardii*, are new records for Mount Resaca NWR.

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 relatively permanent bodies of freshwater 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 species of snake were found outside the research area *Typhlops richardi* and the Virgin Islands tree boa, *Chilabotrus granti*), as was one species of semiaquatic turtle, *Trachemys stejnegeri stejnegeri*. None of the previous species were included in the statistical analyses.

The mean humidity and temperature in Mount Resaca were similar during the day and night hours. During the day hours the mean humidity was 82.0% with a mean temperature of 27.78°C; night mean humidity was 84.8% (only 2.0% higher), and the mean temperature was 26.05°C (only 1.73% higher). The highest abundance of the herpetofaunal community was in July (Figure 3) when the temperature and humidity were 28.00°C and 86.6%, respectively. These values are higher than the mean values. Temporal conditions, such as precipitation, temperature and humidity for Mount Resaca were relatively constant throughout the year. The constant climate suggests that the populations do not reproduce seasonally. Precipitation data collected at the Culebra National Wildlife Refuge pluviometer located 2.6 km from Mount Resaca and 7.6 km from Luis Peña Cay, suggests that the wet season began in May and ended in November 2010. The month with the highest precipitation was November with an accumulation of 265.4 mm of rain, followed by July with 259.6 mm of rain. The dry season began in December and ended in April 2010. The driest month was February with only 5.8 mm 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 254 mm in one month (Figure 4). The years 2006 and 2009 showed a mean of 64.5 and 74.9 millimeters of rain respectively. Thus, on average, 2010 had 74 mm above the rain that usually can be observed on Culebra Island.

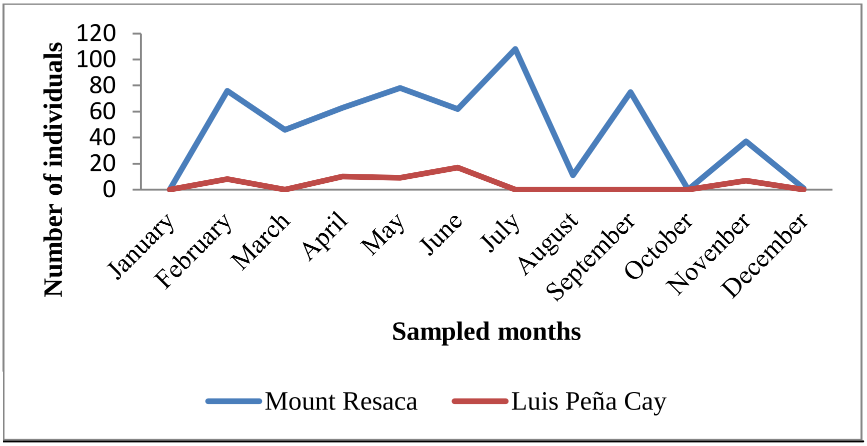

Figure 3. Number of individuals of the herpetofaunal community sampled at each month at Mount Resaca and Luis Peña Cay at Culebra Island in 2010. Vertical bars represent the standard error.

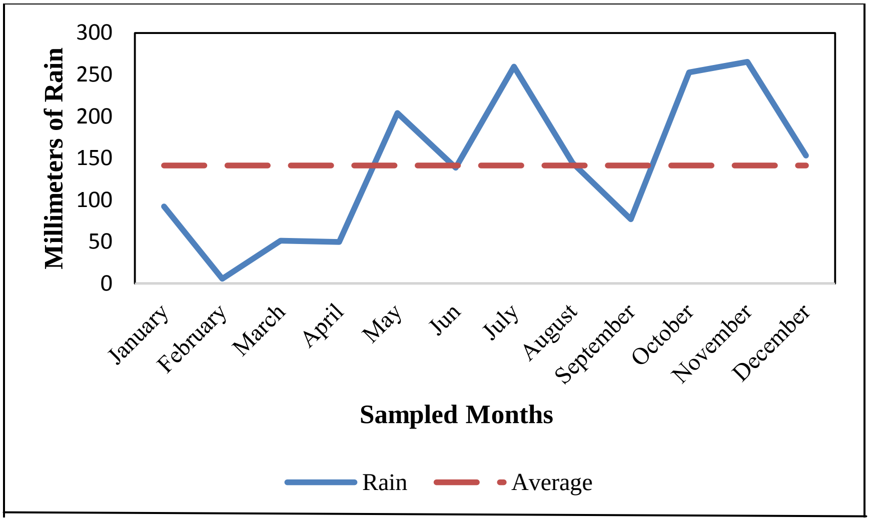

Figure 4. Rain activity in the Culebra National Wildlife Refuge during 2010. The mean precipitation for the year 2010 was 141 mm, denoted with the dashed red line.

Mount Resaca. *Seasonality*. We documented two species of amphibians and seven species of reptiles (Figures 5-9) during the dry season (December-April) with a mean temperature and humidity of 30.7 °C and 67.8% respectively. 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.

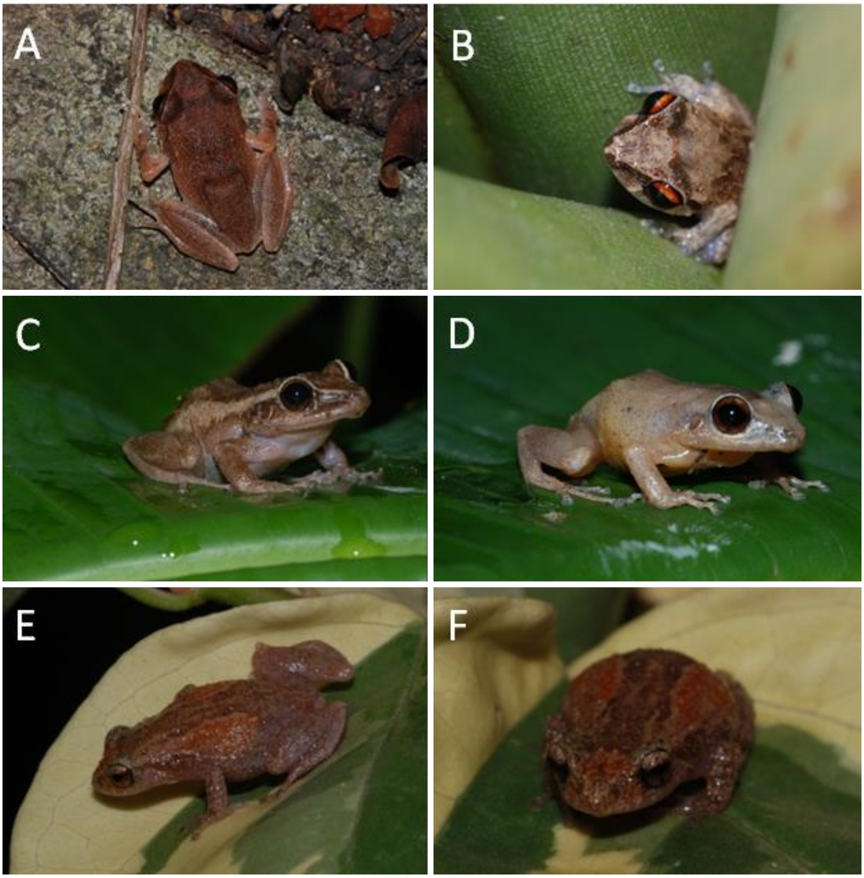

Figure 5. Amphibians (Eleutherodactylidae) found in Culebra Island. A. Dorsal view of *Eleutherodactylus antillensis*, found in Mount Resaca. B. *Eleutherodactylus antillensis*, showing reddish eye color. C and D. *Eleutherodactylus coqui,* lateral view, found in Mount Resaca under a flagging tape and Dewey (town) respectively. Note coloration variability. E. *Eleutherodactylus cochranae,* dorsolateral view. F. *Eleutherodactylus cochranae* dorsal view emphasizing orange coloration.

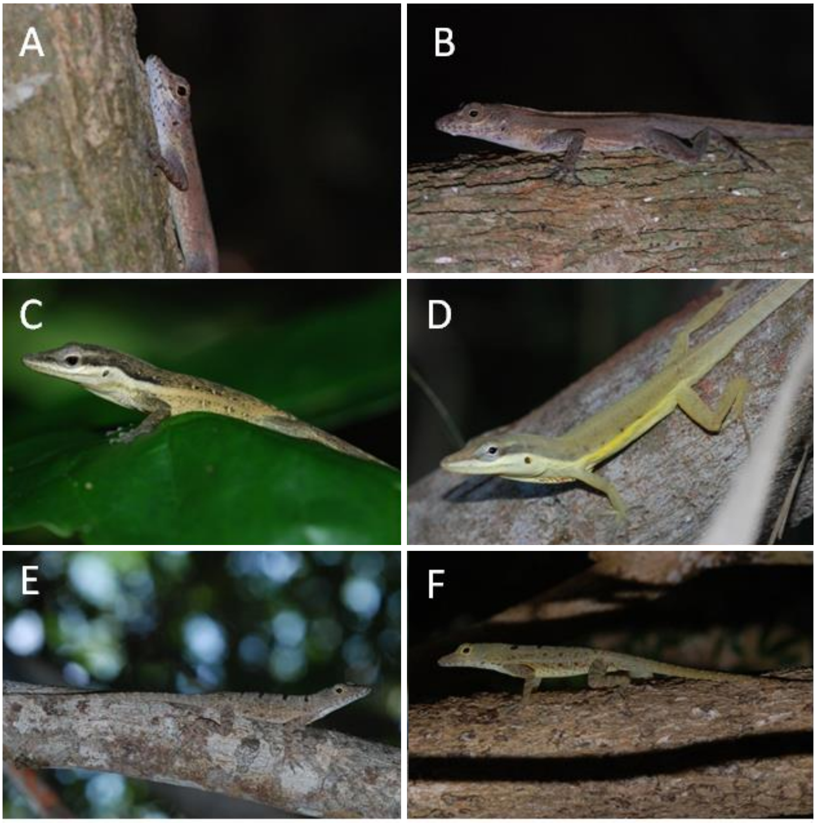

Figure 6. Anoles (Dactyloidae) found at Mount Resaca and Luis Peña Cay at CNWR. A and B. *Anolis cristatellus wileyi*, lateral views. C and D. *Anolis pulchellus,* lateral and dorsolateral views, respectively. E and F. *Anolis stratulus*, lateral views. In all cases, note color variability.

Figure 7. Snake (Dipsadidae) found at Mount Resaca and Luis Peña Cay at CNWR. A. *Borikenophis portoricensis richardi.* B. Dorsal scales of *Borikenophis portoricensis richardi.*

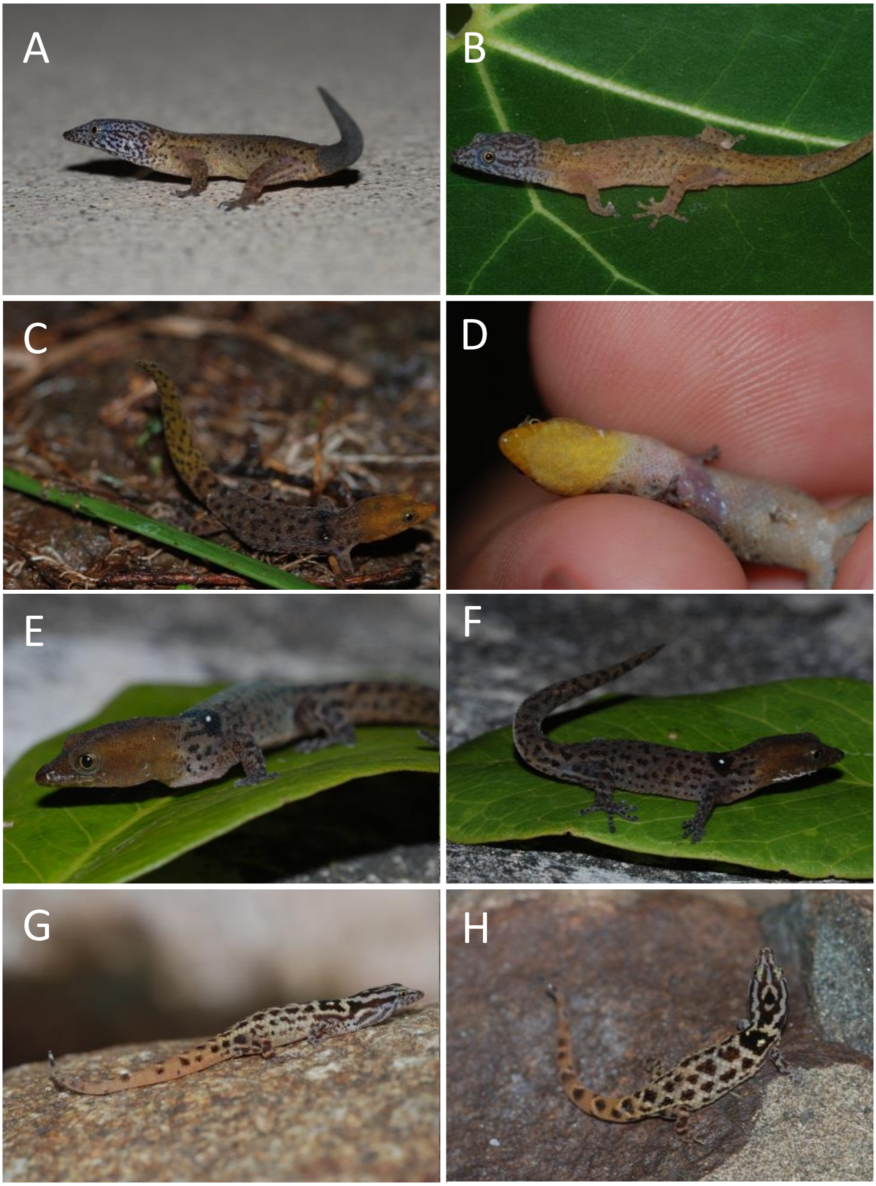

Figure 8. *Sphaerodactylus* (Sphaerodactylidae) found in Mount Resaca at CNWR. A and B. *Sphaerodatylus* sp., lateral and dorsolateral views, respectively. C and D. *Sphaerodatylus macrolepis* ssp. dorsolateral and ventral views, respectively. E and F. *Sphaerodactylus macrolepis inigoi*, lateral and dorsolateral views, respectively. G and H. *Sphaerodatylus* sp., lateral and dorsal views, respectively.

Figure 9. Skink (Mabuyidae) found at Mount Resaca, CNWR. A and B. *Spondilurus culebrae*, lateral view and closeup of the head.

Herpetofaunal diversity was higher at Mount Resaca during the dry season. There was variability in the herpetofaunal community (Simpson's index = 0.833). 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 (Table 2) indicated that, in the wet season, the amphibian, *E. antillesis*, was dominant (more abundant) while, in the dry season, the reptile, *A. cristatellus wileyi* was dominant (more abundant). However there were no significant differences between diversity indexes (diversity t-test, p = 0.435).

Table 2. Diversity Indexes for the Dry and Wet seasons at Mount Resaca NWR, Culebra Island.

Diversity Indexes	**Dry Season (both taxa)**	**Wet Season (both taxa)**	**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	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

Elevation above sea level. Another parameter for comparing both areas was elevation. Transects were divided into two categories: lowlands (11.0 - 72.0 m) and highlands (137.0 -162.0 m). At low elevations, the mean temperature was 27.6°C and the mean humidity was 83.4%. Two species of amphibians and nine species of reptiles were found in lowlands. At higher elevations, the mean temperature was 27.0°C and the mean humidity was 85.9%. Three species of amphibians and ten species of reptiles were found there. Some species were found only at a specific 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 suggests that more inland transects had slighly greater (slightly) diversity although statistical analyses indicated that the differences were not significant.

Hepetofaunal Diversity. The herpetofaunal community at Mount Resaca was not dominated by a single species (Simpson's Index = 0.81. This information was separated by taxa to see if there were changes in species composition by elevation. Amphibian and reptile diversity was higher at higher elevation. Furthermore, although the amphibian *Eleutherodactylus antillensis* dominated the community at both elevations, there were no significant differences in amphibian diversity between the two compared elevations (diversity t-test, p = 0.757). During the daytime, *Eleutherodactylus coqui* was found hiding under a flagging tape on a tree. This was the only indivivual recorded in Mount Resaca.

Herpertofaunal diversity was higher during the day, perhaps because reptiles, being diurnal, were most abundant than amphibians in Mount Resaca. In terms of species contribution to the community in a habitat, *Eleutherodactylus antillensis* was the species that contributed the most to the community and was a dominant species among the amphibians (Simpson’s Index = 0.51). Reptiles are more diverse and *Anolis cristatellus wileyi* was the major contributor to the ecosystem’s herpetofaunal community (Simpson’s Index = 0.82). This species was seen from the ground to the tree trunks, perhaps competing and displacing other species.

One group that posed some problems for identification in Mount Resaca was the geckos of the genus *Sphaerodactylus*. Due to the lack of updated taxonomic keys, some *Sphaerodactylus* could not be identified. Recent genetic work on these taxa completed by Dr. Graham Reynolds (unpublished data) has yielded possible new species for Culebra Island. Although this might change some biodiversity values herein reported, new biodiversity calculations were computed in which the possible new species were included; changes were not statistically significant (t-test, p = 0.435).

In total, five families were found in Mount Resaca, with the genus *Sphaerodactylus* (Sphaerodactylidae) being the most relatively abundant (36.0%). Other sampled families were Eleutherodactylidae, and Leptodactylidae (Amphibia), Gekkonidae, Dactyloidae, Polychrotidae, Dipsadidae, Mabuyidae, and Scincidae (Reptilia). *Trachemys stejnegeri stejnegeri* (Emydidae) was not found within the Federal boundaries. Another species that were not found within the study area, were the Culebra Giant Anole, *Anolis roosevelti*, which is presumed extinct throughout the island, and the Virgin Islands Tree Boa, *Chilabotrus grantii* (Table 1).

Overall, time effort was determined by the time in which two people observed each transect. The time effort for the Mount Resaca transects 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 10). The analysis of similarity (ANOSIM) suggested that diversity patterns did not change between wet and dry seasons within Mount Resaca ($R = 0.5321$, $p \geq 0.05$).

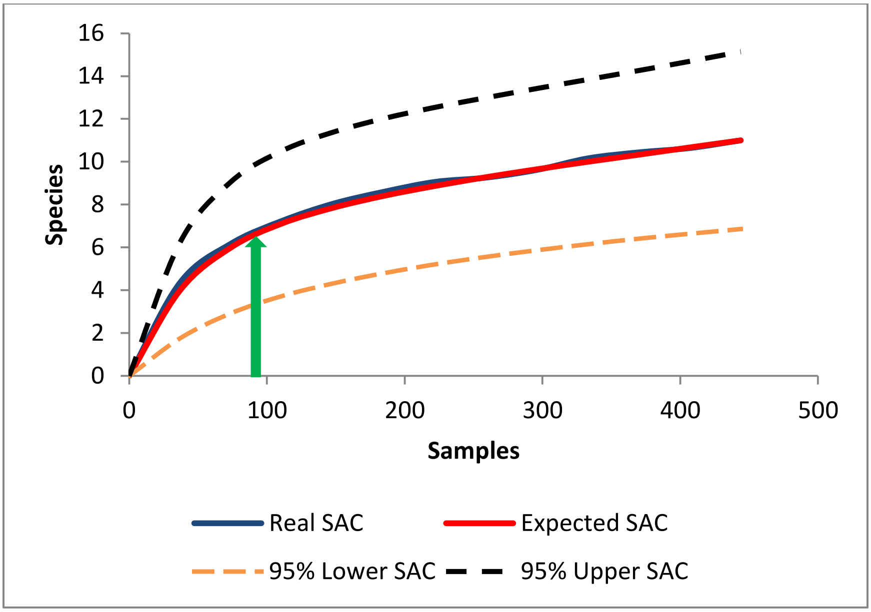

Figure 10. Species accumulation curve (SAC) for Mount Resaca, Culebra NWR. The green arrow represents the number of samples taken (n= 96).

Luis Peña Cay. *Seasonality*. 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 were 30.7°C and 72.6%, respectively. Temporal conditions such as precipitation, temperature and humidity for Luis Peña Cay were relatively constant throughout the year. During the dry season, the mean temperature was 30.7 °C and the mean humidity was 67.8%. Four species of reptiles were found. During the wet season, the mean temperature was 28.8 °C and the mean humidity was 80.7 % and three species of reptiles were found. The biodiversity Simpson's index (0.713) suggests that the community is not dominaned of a single species or that there is variability in the area. Diversity indexes showed no significant statistical differences (t test, p = 0.245).

Elevation above sea level. At low elevations (< 30.0 m), the mean temperature was 29.2 °C and the mean humidity was 75.3%; four species of reptiles were found. At higher elevations (> 30.0 m), the mean temperature was 31.3°C and the mean humidity was 73.3%; only two species were found.

Hepetofaunal Diversity. The Simpson's index (0.713) also indicated that the community is not dominated by a single species. However, Margalef's diversity index (1.062) confirmed that diversity was low. Biodiversity indexes indicated that reptile diversity was higher at low elevations (p = 0.043, df = 3.40). The higher elevations are dominated by *A. cristatellus wileyi* (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 7:00AM. 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 suggested that the area was highly sampled, but night surveys are needed to examine further amphibian presence. The SIMPER analysis revealed that *Anolis pulchellus* is the species with the largest abundance, with 13.42 %. In total, 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 observed 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 (Figure 11) reflects that the habitat was monitored exhaustively (Bersier 2001).

Acoustic Activity

Mount Resaca. 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 of Mount Resaca, but elsewhere in Culebra (Rivero and Joglar, 1979), giving relevance to the use of automated acoustic monitoring. Furthermore, it demonstrated that *E. antillensis* peak occurs 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 (Figure 12). On the other hand, *E. cochranae* has its highest activity between 6:00pm - 8:30pm; decreases its activity throughout the night, with a small increase in acoustic activity between 3:00am - 4:00am (Figure 12). The most common species, *E. antillensis*, had a frequency range between 1.80 kHz – 3.25 kHz and *E. cochranae* had a frequency range between 3.90 kHz – 4.00 kHz.

Luis Peña Cay. Recordings gathered in Luis Peña Cay 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 species of amphibians were detected.

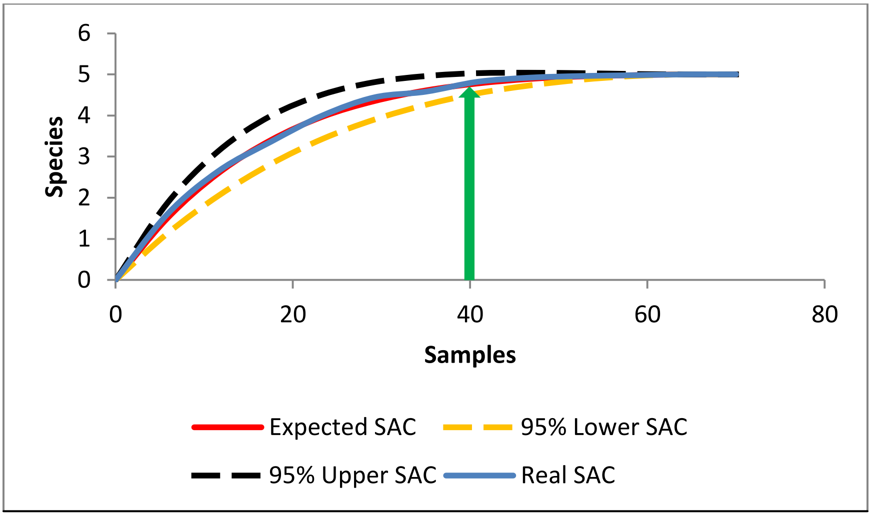

Figure 11. Species accumulation curve for Luis Peña Cay, Culebra NWR. The green arrow represents the number of samples taken (n = 40).

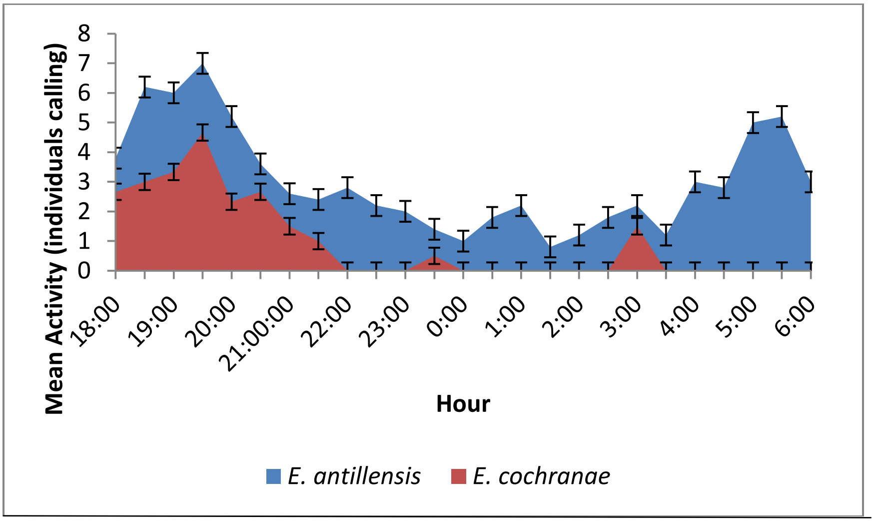

Figure 12. Frog activity during the night at Mount Resaca, CNWR (n = 8,622). Vertical bars represent standard error.

Vegetation Analysis

For Mount Resaca, 30 species belonging in 23 families of plants were encountered (Table 3). Diversity in Mount Resaca was moderate (Shannon-Wiener Index = 2.47, Margalef's Index = 3.80). No plant species was overwhelmingly dominant (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 (p = 0.404). The SIMPER analysis demonstrated that *Plumeria alba* L. (relative abundance 12.18%), *Gymnanthes lucida* Sw. (10.19 %) and *Pisonia subcordata* Sw. (9.54 %) were the three most abundant species of the Luis Peña Cay plant community. Mean canopy cover was 75.84% providing a habitat with greater moisture retention.

Table 3. Species found in the sample transects in Mount Resaca and Luis Peña Cay at Culebra National Wildlife Refuge.

Family	**Species**	**Mount Resaca**	**Luis Peña Cay**
Acanthaceae	*Avicennia germinans* L.	X	
Arecaceae (Palmae)	*Thrinax morrisii* H. Wendl.	X	
Apocynaceae	*Plumeria alba* L.	X	X
Boraginaceae	*Bourreria* spp.		X
Bromeliaceae	*Tillandsia* spp.	X	
Burseraceae	*Bursera simaruba* (L.) Sarg.	X	X
Cactaceae	*Leptocereus quadricostatus* (Bello) Britton & Rose	X	X
Capparaceae	**Cynophalla flexuosa* (L.) J. Presl	X	
	Quadrella cynophallophora (L.) Hutch.	X	
	**Quadrella indica* (L.) Iltis and Cornejo	X	X
	Morisonia americana L.	X	
Celastraceae	*Schaefferia frutescens* Jacq.	X	X
Clusiaceae	*Clusia rosea* Jacq.	X	
Erythoxylaceae	*Erythroxylum brevipes* DC.	X	
Euphorbiaceae	*Croton flavens* L.	X	X
	Euphorbia petiolaris Sims		X
	Gymnanthes lucida Sw.	X	
Fabaceae	*Acacia* spp.	X	X

	Pictetia aculeata (Vahl) Urb.		X
	Pithecellobium unguis-cati (L.) Mart.	X	X
Lauraceae	*Nectandra coriacea* (Sw.) Griseb.	X	
Malpighiaciae	*Malpighia woodburyana* Vivaldi	X	X
Malvaceae	Unidentified malvacean	X	
Meliaceae	*Trichilia hirta* L.	X	
Mimosoideae	*Leucaena leucocephala* (Lam.) de Wit		X
Moraceae	*Ficus citrifolia* Mill.	X	
Myrtaceae	*Eugenia rhombea* Krug and Urb.	X	X
Nyctaginaceae	*Guapira fragrans* (Dum. Cours.) Little	X	
Phyllanthaceae	*Savia sessiliflora* (Sw.) Willd.		X
Piperaceae	**Peperomia wheeleri* Britton	X	
Poaceae	**Megathyrsus maximus* (Jacq.) B. K. Simon and S. W. L. Jacobs	X	
Polygonaceae	*Coccoloba microstachya* Willd.	X	X
Rubiaceae	*Exostema caribea* (Jacq.) Roem. and Schult.	X	
	Psychotria brownei Spreng.	X	X
	Randia aculeata L.	X	X

*New report for each site by: Ms. Jeanine Vélez-Gavilán, (Herbarium Curator, University of Puerto Rico, Mayagüez Campus). Nomenclature follows Axelrod (2011).

With restricted general access to Mount Resaca, the vegetation seems to be older and taller, increasing canopy coverage by a mean of 10% (Figure 13). The forest layer analysis reflected a structural variety compromised of grasses, woodland, and shrubs in different life stages.

On the other hand, Luis Peña Cay had 19 plant species from 14 families, in which *Randia aculeata* L. (Rubiaceae) was the most abundant (Table 4). 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 evident (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.

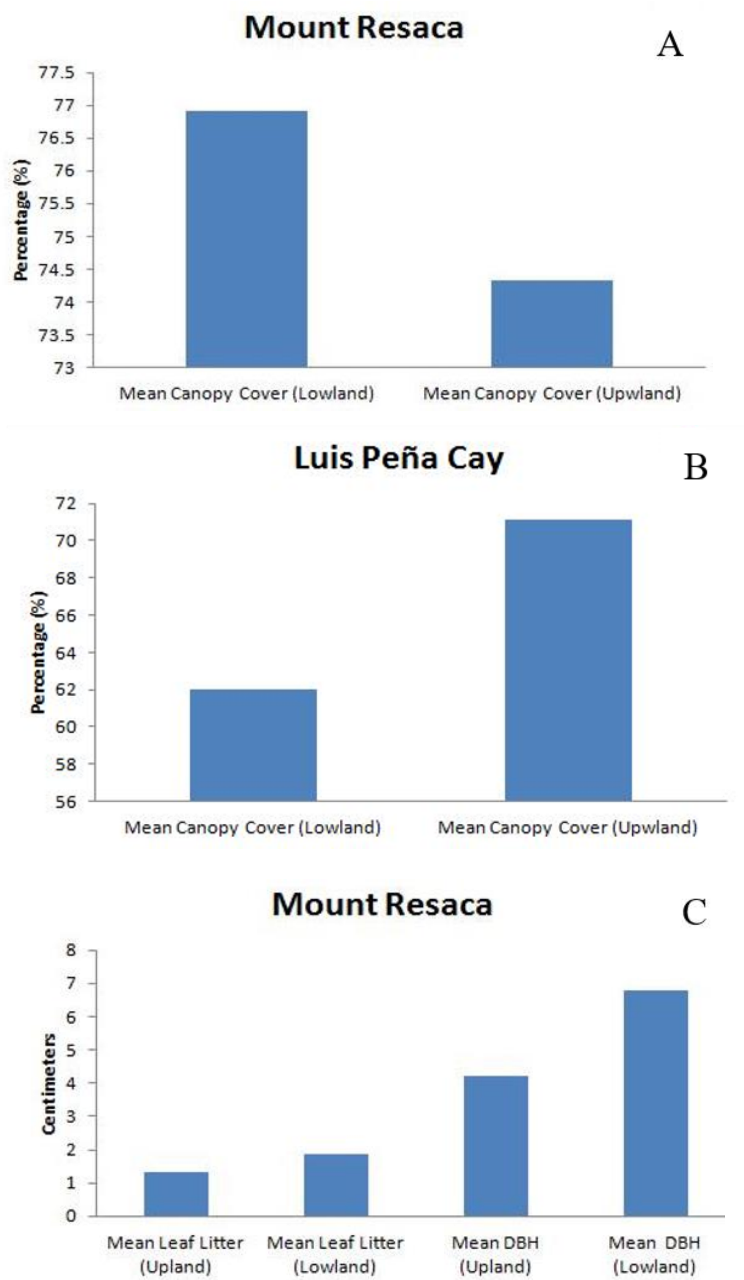
Mount Resaca
A
Percentage (%)
77.5
77
76.5
76
75.5
75
74.5
74
73.5
73
Mean Canopy Cover (Lowland)
Mean Canopy Cover (Upwland)
Luis Peña Cay
B
Percentage (%)
72
70
68
66
64
62
60
58
56
Mean Canopy Cover (Lowland)
Mean Canopy Cover (Upwland)
Mount Resaca
C
Centimeters
8
7
6
5
4
3
2
1
0
Mean Leaf Litter (Upland)
Mean Leaf Litter (Lowland)
Mean DBH (Upland)
Mean DBH (Lowland)

Figure 13. A. Mean canopy cover for lowlands and uplands in Mount Resaca. B. Mean canopy cover for lowlands and uplands in Luis Peña Cay. C. Mean leaf litter and DBH for lowlands and uplands in Mount Resaca. D. Mean leaf litter and DBH for lowlands and uplands in Luis Peña Cay. Panels A-C on page 275.

The SIMPER analysis (Table 4) demonstrated that *Bursera simaruba* (L.) Sarg (with 14.15%), *Pisonia subcordata* (12.47%) and *Randia aculeata* with (11.46%) were the three most abundant species. Mean canopy cover was 65.4% allowing sunlight to penetrate and, thus, creating a drier habitat. The forest layer was composed of vegetation 2 m high and above. No vegetation was measured under 2.0 m and under. Lack of seedlings was prominent. In general, diversity in Luis Peña Cay appears to be lower than at Mount Resaca.

Table 4. SIMPER analysis of indicator species at Mount Resaca and Luis Peña Cay at Culebra National Wildlife Refuge.

Taxa Authorship	**Contribution (%), relative abundance**	
	Mount Resaca	**Luis Peña**
Plumeria alba L.	12.18	1.37
Gymnanthes lucida Sw.	10.19	7.74
Guapira fragrans (Dum. Cours.) Little	9.54	12.47
Eugenia rhombea Krug and Urb.	5.23	1.79
Quadrella indica (L.) Iltis and Cornejo	5.02	2.64
Randia aculeata L.	4.17	11.46
Morisonia americana L.	3.66	absent
Acacia sp.	3.55	absent

Bursera simaruba (L.) Sarg.	3.19	14.15
Leptocereus quadricostatus (Bello) Britton and Rose	2.65	absent
Thrinax morrisii H.Wendl	2.64	absent
Erythroxylum brevipes DC.	2.53	absent
Pithecellobiumunguis-cati (L.) Mart.	1.84	absent
Ficus citrifolia Mill.	1.76	absent
Croton flavens L.	1.72	2.74
Trichilia hirta L.	1.64	absent
Quadrella cynophallophora (L.) Hutch.	1.37	absent
Malpighia woodburyana Vivaldi	1.02	1.00
Ficus citrifolia Mill.	0.81	absent
Megathyrsus maximus (Jacq.) B.K. Simon and S.W.L. Jacobs	0.70	absent
Avicennia germinans L.	0.70	absent
Clusia rosea Jacq.	0.58	absent
Malvaceae spp.	0.48	0.93
Peperomia wheeleri Britton	0.48	absent
Tillandsia spp.	0.48	absent
Cynophalla flexuosa (L.) J. Presl	0.35	1.65
Nectandra coriacea (Sw.) Griseb.	0.31	absent
Exostema caribea (Jacq.) Roem. and Schult.	0.31	absent
Bourreria spp.	0.29	6.18
Schaefferia frutescens Jacq.	0.21	8.58
Psychotria brownei Spreng.	absent	2.74
Savia sessiliflora (Sw.) Willd.	absent	4.41
Pictetia aculeata (Vahl) Urb.	absent	0.95
Amyris elemifera	absent	0.48
Euphorbia petiolaris Sims	absent	absent
Coccoloba microstachya Willd.	absent	2.36
Leucaena leucocephala (Lam.) de Wit	absent	absent

Dominance by a single species was not detected in either Mount Resaca or Luis Peña Cay (Simpson's Index = 0.883). Plant species composition seems to be even throughout the sampled areas. However, Luis Peña Cay seems more affected by the military practices and the presence of goats, *Capra hircus* (North et al. 1986, Bullock 2001). Mean canopy cover was 10.0% higher at Mount Resaca than in Luis Peña Cay (t = 20.72, sd = 24, p = 0.049). Mean DBH (6.61 cm) and leaf litter (2.42 cm) were larger at the Luis Peña Cay than in Mount Resaca with a DBH (3.85 cm) and leaf litter (1.84 cm), however, those values were not statistically significant (t = 14.12, sd = 10.53, $p \geq 0.05$) between the localities. Furthermore, for Mount Resaca, leaf litter (p = 0.078, n = 41) and canopy cover (p = 0.363, n = 41) were not affected by elevation but DBH was higher in lower elevations (p = 0.006, n = 330). At the Luis Peña Cay, leaf litter ($p \geq 0.05$, n = 24), canopy cover (p = 0.168, n = 24) DBH (p = 0.345, n = 122) were not affected by elevation.

Linear Regressions. 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 Mount Resaca, none of the parameters measured were significantly correlated (Table 5). For Luis Peña Cay herpetofauna diversity was positively related to vegetation diversity at low elevations (R^2 = 0.36, p = 0.0292, n = 13). Canopy cover was negatively related to the diversity of herpetofaunal species (R^2 = 0.21, p = 0.0356, n = 17, Figure 14).

Table 5. Linear regressions for Mount Resaca and Luis Peña Cay. Asterisks (*) denote statistically significant values.

Parameter	**Resaca**		**Luis Peña**	
	R^2	**p value**	**R^2**	**p value**
Herpetofaunal abundance x Vegetation abundance	0.006	0.816	0.038	0.427
Herpetofaunal abundance x Vegetation abundance at high elevation	0.04	0.500	0.002	0.909
Herpetofaunal abundance x Vegetation abundance at low elevation	0.01	0.704	0.364	0.029*
Herpetofaunal abundance x DBH	0.02	0.426	0.03	0.378

Herpetofaunal abundance x DBH at high elevation	0.000	0.979	0.19	0.134
Herpetofaunal abundance x DBH at low elevation	0.06	0.271	0.03	0.573
Herpetofaunal abundance x Canopy	0.02	0.367	0.15	0.055
Herpetofaunal abundance x Canopy at high elevation	0.001	0.894	0.26	0.035*
Herpetofaunal abundance x Canopy at low elevation	0.055	0.339	0.06	0.420
Herpetofaunal abundance x Leaf litter	0.001	0.892	0.04	0.345
Herpetofaunal abundance x Leaf litter at high elevation	0.002	0.852	0.02	0.617
Herpetofaunal abundance x Leaf litter at low elevation	0.02	0.529	0.18	0.146

Comparisons between Mt. Resaca and Luis Peña Cay

Abundance and Seasonality. The highest number of individuals for Mount Resaca was recorded in July, with 108 individuals, and the lowest abundances (1-10 individuals) were detected during the dry season in general. Peak abundance was recorded in June for Luis Peña Cay (Figure 3). 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 structural or compositional pattern difference between both seasons and sites. In addition, the differences between seasons among Mount Resaca and Luis Peña Cay, confirm 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 ($R^2 = 0.5321$; $p \leq 0.0001$). The SIMPER analysis demonstrated that *Eleutherodactylus antillensis* (abundance contribution = 11.47%), and *Anolis cristatellus wileyi* (abundance contribution = 6.27%) were the species with the highest abundances in Mount Resaca, while *A. pulchellus*, was the most abundant species at the Luis Peña Cay (Table 6).

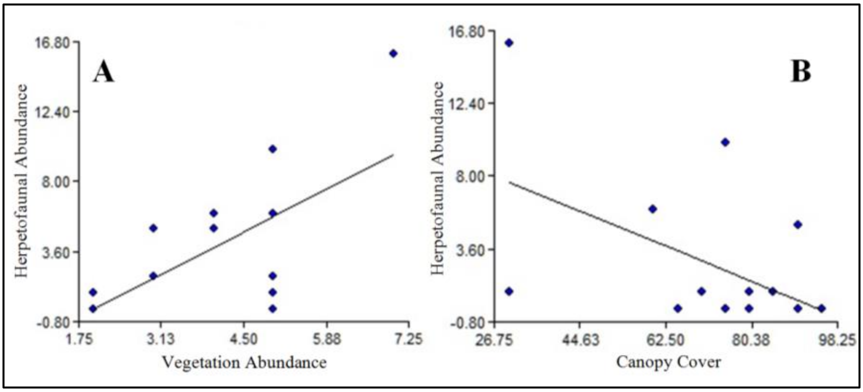

Figure 14. Linear Regressions. A. Positive correlation between herpetofaunal abundance and vegetation abundance at low elevations in Luis Peña Cay. B. Negative correlation between herpetofaunal abundance and canopy cover at high elevations in Luis Peña Cay.

Abundance and environmental parameters. The Spearman correlation results indicated that there is no relationship between herpetofaunal abundance and temperature in Mount Resaca; however, there is a positive relation between abundance and humidity (rs = 0.608, $p < 0.01$) for the amphibians. Luis Peña Cay had a positive relation between reptile abundance and temperature (rs = 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 abundance. Linear regressions suggested that in the case of Luis Peña Cay, animal diversity and abundance was affected positively by plant diversity at low elevations ($R^2 = 0.36$, $p \leq 0.001$, n = 13). Canopy cover also affected diversity at high elevations ($R^2 = 0.26$, $p \leq 0.001$, n = 17).

Discussion

Herpetofaunal studies on the Culebra Archipielago are scarce due to former U.S. military activities carried out in the present refuge areas. This study provides a baseline to facilitate future studies. This is important because within the Culebra 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 possible differences in a community of the given area (Millar 2011).

Visual Encounter Surveys

***Mount Resaca*.** As it is has not been heavily disturbed since the United States Navy left in 1975, ecological succession has been progressing since that time. Some species previously reported such as *A. roosevelti*, *C. granti* and *S. townsendi* could not be found in the survey area or its vicinity. This could be explained by the secretive habits and preferred foraging places (Herrera 2010). *Anolis roosevelti* was founded in the past in *Ficus* spp. and *Bursera simaruba* trees (Dodd and Campbell 1982), *C. 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 dependent on constant water resources to reproduce. Mount Resaca does not provide this resource; instead it has intermittent streams that form with the sporadic precipitation. This factor could be the responsible for the absence of *Rhinella marina* and *Leptodactylus albilabris*. Overall, amphibians are scarce in Culebra Island because of its dry climate. However, *Eleutherodactylus antillensis* has managed to survive and become the most abundant amphibian in the habitat. In Mount Resaca, *A. cristatellus wileyi* was the most abundant species in the reptile taxa during the dry and wet seasons, due to its adaptations to deal with altered habitat (Herrera 2010, Henderson and Powell 2009).

Temporal Patterns. Species diversity seems to be independent of seasonality in both areas. This may be because in tropics, seasonality is not as drastically different as 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.

Spatial Patterns. Some species were abundant at different elevations, such as *A. pulchellus*, which 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 black rats, *Rattus rattus* (Linnaeus, 1758), and feral cats, *Felis catus* Linnaeus, 1758, were seen in 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.

Acoustic Activity. Vocalization evolves as the result of a variety of selection pressures in 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 by rearranging the notes (Stewart and Rand 1991, Stewart and Bishop 1994). A study conducted on the genus *Eleutherodactylus* at El Yunque National Forest, Puerto Rico presented 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 Culebra Island, the calls by *E. antillensis* were broader in frequency compared to conspecifics at the El Yunque Rain Forest (Drewry and Rand 1983), being 1.05 kHz higher.

On the other hand, *E. cochrane* displayed a difference in spectral length from the population in Puerto Rico's main island. The population activity Puerto Rico's main island was relatively constant during all night, but in Culebra Island, *E. cochrane* 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 Puerto Rico's main island that they differ in frequency (kHz) by up to 2.0 kHz higher, and shorter note length.

It is known that frogs can modify the amplitude of the call depending of the environment, 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 homogeneous plant diversity throughout the area. However, there are differences in forest structure. In the lowlands, the DBH tends to be higher, which could be due to higher soil organic matter due to accumulation, indicating that the forest is denser and this was confirmed as both, the litter and vegetation cover are greater.

Luis Peña Cay. 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, with the current vegetation developing as a secondary forest (Ríos-Franceschi, personal observation). Areas that are disturbed by humans tend not to be 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 to exotic species, such as domestic goats, *Capra hircus*. Goats were widespread through the cay destroying the coastal vegetation that some lizards and snakes use as lair (Ríos-Franceschi, personal observation). 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 the snake, *Bolyeria sp.*, a few decades after their introduction (Bullock 2001). In addition, the Helmeted Guineafowl, *Numida meleagris* (Linnaeus, 1758), was seen near one of Luis Peña Cay's beaches eating one *Sphaerodactylus* sp.

For the Luis Peña Cay, *A. pulchellus* is a new record. At low elevations, this species was abundant, living in shrubs near the coast. In addition, it was the most abundant reptile throughout the lower parts of the Cay. At higher elevations, *A. pulchellus* was not encountered perhaps because the area that seems more suitable for the species was not surveyed. This area, is located in the western part of the cay and is restricted (Unexploded Ordnance, better known by its acronym, UXO) because there may be live, unexploded weapons.

Temporal Patterns. Seasonal patterns in the herpetofaunal community of the cay could not be identified do to the lack of seasonal information. Although, species richness and abundance in the reptile taxa where higher during the dry season but there were not sufficient data to make conclusions.

Spatial Patterns. Spatial changes influence reptile abundance (Buckley 2005). Biotic factors, such as vegetation, were correlated to animal abundance in the elevation gradient (Table 5). 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 the snake *B. portoricensis richardi*, the dwarf gecko *S. macrolepis* and the lizard, *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. Luis Peña Cay is a highly disturbed island. Past and recent activities such as military excersises and current civilian activities such as goat introduction for species recruitment, these impacts have generated an area where most of the trees are young and sparsely located (Ríos-Franceschi, personal observation). This promotes the invasion of grasses (Poaceae) and weedy vegetation that limits the propagation of tree seedlings (Callaway and Aschehoug 2000). The introduction of goats, *Capra hircus*, by humans for personal comsumption and sale prevents tree recruitment, destroys the hardwood forest, and promotes ecological degradation (Vinson 1964, North 1986). The area sampled lacked sufficient seedlings decelerating ecological succession and reducing habitats needed for crawling species (Bullock 2001).

Comparisons between Mt. Resaca and Luis Peña Cay

Species richness of the herpetofaunal community did not change during the seasons within each area. However, there was a difference in the herpetofaunal diversity between Mount Resaca and Luis Peña Cay, indicating 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 latter temperatures tend to be higher. In addition, the vegetation is different in structure and species composition. This means that the spatial structure of the community in each area varies independently within the dry and wet season.

Diversity in both sites was relatively moderate to low, yet Mount Resaca is more diverse herpetologically. This area has more sources of freshwater and is more botanically diverse, providing with more niches that can accommodate additional species. Amphibian diversity seems to be higher in neighboring and much larger Vieques Island, but Culebra Island has higher reptile diversity, yet with an accumulation species curve indicating that Culebra has not yet been sufficiently monitored. Diversity of amphibians and reptiles in Culebra could be higher if more surveys are performed.

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 hircus* (Ríos-Franceschi, personal observation). 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 analyses should be performed to observe if competition with non-native species could be affecting Luis Peña Cay's plant community. Both areas have woody trees and tallgrass which can become fuel for human induced fires. These fires are frequent in the dry season, these fires have already affected the USFWS Culebra Refuge by suppressing woody vegetation, removing leaf litter layer, altering vegetational composition and productivity (Cavitt 2000). Ultimately, these fires affect the local herpetofauna.

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Figure 15. Mount Resaca, area where one of the study sites was located. Cayo Norte can be seen on the background. Photo by Alejandro Ríos-Franceschi.