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DISTRIBUTION AND HABITAT STATUS OF THE COQUÍ GUAJÓN *ELEUTHERODACTYLUS COOKI*

In parcial fulfillment of the requirements for the degree of
Masters in Science in Environmental Management
in Conservation and Management of Natural Resources

By
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DEDICATION

To my family and beloved wife,
for carving the person I am today and for all your support.

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ABSTRACT

Coquí Guajón (*Eleutherodactylus cooki*) is a threatened amphibian limited to Sierra Pandura Mountain Range in southeast Puerto Rico. It is a habitat specialist that utilizes caves formed from large granite boulders or crevices and grottoes in rocky streams. This research has produced new insights about this species that can be useful for its conservation. The major finding of this study was that of the 108 sampled localities, only five were found within 100 m of the USFWS critical habitat areas, meaning that 103 (95.4%) of the localities are new records for this species. The PRGAP Analysis model proved to be a useful tool for locating new populations of *E. cooki*. Due to the data collected using the PRGAP model, our new habitat model of *E. cooki* acquired more accuracy for predicting the presence of this species in Puerto Rico. The efficiency of the new model was tested by determining the percent of error in commissions and omissions, to evaluate if it predicted accurately the absence and presence of individuals at each site sampled. The new model had a low percent in commission errors with 34% (53/158), and a percent of error in omissions of only 27% (3/11). The percent of error in omissions of the models differed significantly (p=0.048), the PRGAP model had a 62% of error compared to the 27% of the new model. This study also revealed the current habitat status for this species of Eleutherodactylid frog. We found that municipalities with higher quantities of land development cases had lower habitat availability. Results of this study provide government agencies new management tools to ensure the conservation of this threatened species of frog.

RESUMEN

El Coquí Guajón (*Eleutherodactylus cooki*) es un anfibio que se encuentra amenazado y con distribución limitada a la Sierra de Pandura en el sureste de Puerto Rico. Es considerada como una especie especialista que utiliza cuevas y cavidades formadas por piedras de gran tamaño que se encuentran adyacentes o sobre quebradas rocosas. Este estudio ha producido avances sobre esta especie que serán útiles para su conservación. El hallazgo más importante de este estudio fue que de las 108 muestras tomadas, solo cinco de ellas se encontraban a una distancia de 100m de un hábitat crítico del USFWS, significando que 103 (95.4%) de las muestras son informes nuevos de presencia para la especie. El modelo del PRGAP demostró ser un instrumento útil para localizar nuevas poblaciones de *E. Cooki*. Gracias a los datos obtenidos utilizando al modelo del PRGAP, nuestro modelo adquirió más precisión para predecir la presencia de esta especie en Puerto Rico. La eficiencia del modelo nuevo fue probada al determinar el porciento de error en comisiones y omisiones, para poder evaluar si logró predecir correctamente la presencia o ausencia de individuos en cada muestra tomada. El modelo nuevo obtuvo un porciento bajo en errores de comision con un 34% (53/158), y un porciento de error en omisiones de sólo 27% (3/11). El porciento de error en omisiones de los modelos se diferenciaron significativamente ($p=0.048$), el modelo del PRGAP tuvo un 62% de error comparado con el 27% del modelo nuevo. Este estudio también reveló el estado actual del hábitat de esta especie de rana Eleuterodactílida. Encontramos que los municipios con mayores cantidades de casos radicados para desarrollo tenían menor disponibilidad de hábitat. Los resultados de este estudio proveerán a las agencias gubernamentales nuevas recomendaciones de manejo que aseguren la conservación de esta especie amenazada.

CHAPTER I

INTRODUCTION

Background

Amphibian declines are a well documented global phenomenon (Houlahan et al., 2000). The term "enigmatic declines" has been used to describe this phenomenon when it occurs in places where appropriate habitat is available, and there are no evident causes for these declines (Stuart et al., 2004). Possible causes may include: pollution, invasive species, pathogens, habitat loss and modification, increase in ultraviolet rays, climate change and synergisms between these (Alford & Richards, 1999; Blaustein & Kiesecker, 2002; Collins & Storfer, 2003; Kats & Ferrer, 2003). However, climate change and a disease caused by a chytridiomycete fungus, *Batrachochytrium dendrobatidis* (*Bd*), are the most commonly referred threats for rapidly declining species (Stuart et al., 2004; Pounds et al., 2006; Lips et al., 2006).

The Caribbean is considered one of the geographical regions with most threatened species. According to the Global Amphibian Assessment (GAA), Puerto Rico ranks as the fifth country with highest percentage of threatened amphibians, with 72.2% of its species threatened (IUCN et al., 2006). These findings are of concern, and have motivated the scientific community to study events that may lead to the mass extinction of not only species, but a possible extinction of an entire class.

In the last 30 years, Puerto Rico has possibly lost three of its endemic species of coquis, while six other species are declining at El Yunque (Burrowes et al., 2004; Joglar et al., 2007). These reported declines are occurring in protected areas, where suitable habitat is still available (Burrowes et al., 2004). Synergies between climate change and *Bd* are suggested as the culprit of declines and local extinctions on highlands above 600 meters (m) on the island, while lowland species are not being affected (Burrowes et al., 2004; 2008; Joglar et al., 2007).

Of all endemic species of *Eleutherodactylus* in Puerto Rico, *Eleutherodactylus cooki* is the species which none of its habitat was protected for the longest period of time (Joglar, 1998). Threats affecting other highland congenerics such as chytridiomycosis, a disease caused by *Bd*, and climate change have not been found in *Eleutherodactylus cooki* (Burrowes et al., 2008). Although, changes on climatic variables such as temperature and precipitation as reported at El Yunque by Burrowes et al. (2004), may affect the reproductive success of this species. *Eleutherodactylus cooki* is a habitat specialist that utilizes caves formed from large granite boulders or crevices and grottoes in rocky streams (Rivero, 1998; Vega-Castillo, 2000). This riparian ecosystem constantly changes due to prolonged dry periods and heavy rains that create ephemeral and perennial streams within its habitat (Vega-Castillo, 2000). These events influence the reproductive activity of this species, causing a reproductive peak during the rainy season, while in the dry season this activity is reduced considerably (Joglar et al., 1996; Joglar, 1998). Adult males have two peaks of vocal activity; the first is between 1400 and 1900 hours and the second close to 2100 hours (Drewry & Rand, 1983; Joglar et al., 1996; Joglar, 1998).

Eleutherodactylus cooki, is in a vulnerable condition because of its limited distribution, and lack of knowledge of its population status (Rivero, 1998; Joglar 1998).

Its present distribution is in two predominant life zones (Ewel & Whitmore, 1973), which are the subtropical moist and subtropical wet forest within the Sierra Pandura Mountain Range (USFWS, 2007). The current distribution of the Guajón is highly fragmented due to habitat loss caused by urban and agricultural development, and this is presently regarded as the mayor threat of its populations (Hedges et al., 2004). The current elevations where it has been found are limited to intermediate elevations of 91–400 m above sea level (Burrowes & Joglar, 1999; Burrowes et al., 2004; Joglar, 1998; Rivero, 1998). Habitat fragmentation can specially affect this species by reducing or even eliminating areas that may provide habitat cover for foraging, because it occurs outside its reproductive habitat (Burrowes & Joglar, 1999; Burrowes et al., 2004; Joglar et al., 1996; Joglar, 1998; Marsh & Pearman, 1997). Changing habitat quality, as a consequence of fragmentation, may affect this species indirectly by introducing elements that were not present in the past or simply were not a factor of concern before these changes (Marsh & Pearman, 1997). Isolation created by fragmentation could also reduce genetic variability, due to its reproductive dependence on streams to maintain gene flow (Burrowes & Joglar, 1999; Burrowes, 2000).

Various studies have been carried out for the conservation of this species, which include studies of its reproduction, population ecology, habitat characterization, population genetics, predation and a few more ecology related studies (Burrowes & Joglar, 1999; Joglar et al., 1996; Joglar, 1998; Vega-Castillo, 2000). Local, federal and international efforts include the designation as a vulnerable species by the Department of Natural and Environmental Resources (DNER), and as a threatened species by the United States Fish and Wildlife Service (USFWS). However, a more recent designation by the

International Union for the Conservation of Nature and Natural Resources (IUCN) considers the species as endangered (Hedges et al., 2004). The USFWS has also issued recently a Recovery Plan for the species (USFWS, 2004), and a Designation of Critical Habitat of 105.6 hectares (ha), which at this time land acquisition efforts have not yet begun (USFWS, 2007). Private Non-profit Organizations (NGO's) like the Conservation Trust of Puerto Rico have also made important contributions for this species by purchasing and protecting lands for the first time to conserve the species. Proyecto Coquí, another NGO, has contributed in educating the public and studying this species to insure its conservation.

Problem Statement

The Coquí Guajón (*Eleutherodactylus cooki*) is a threatened amphibian limited to Sierra Pandura Mountain Range in southeast Puerto Rico. It is a habitat specialist that utilizes caves formed from large granite boulders or crevices and grottoes in rocky streams (Rivero, 1998; Vega-Castillo, 2000). Spatial analysis models are commonly developed to determine species potential distributions and effects of habitat loss and fragmentation (Cushman, 2006; Neckel-Oliviera & Gascon, 2006). Local efforts have been made using these type of methods, for example the Puerto Rico Geographical Approach to Planning (GAP) Analysis Project is a comprehensive assemblage of information on Puerto Rico's landcover, vertebrate occurrences and natural history information, and land stewardship (Gould et al., 2007). The GAP Analysis Project is an important contribution for the conservation of Puerto Rican biodiversity and it is an effective tool for implementing well thought out management plans. Generating these types of models also has its trade-offs. In some cases when very little information is available for a particular species, all of the possible variables that determine distribution are not taken into account. This can create small or large margins of error, and for this reason empirical data is needed for verification (Cushman, 2006). Many models have been used to predict species distribution, but in many instances the results of these models are not validated in the field, because of time and/or budget limitations, among others. The GAP Analysis Project has developed a predicted distribution map for the Coquí Guajón, based on data of historical localities where it was present provided by literature and expert advise. It is almost certain that many locations where the species is currently found were not delimited in this map, due to the poor available knowledge of its distribution, and the obtained results have not been confirmed. Therefore, we strive to increase the available knowledge of the distribution of this species and confirm initial efforts of the PR GAP model.

The U.S Fish and Wildlife Service (USFWS) recently issued a critical habitat designation for this species and a recovery program, because of the threats to its habitat which are confined to private owned lands (Joglar, 1998). Interest for conserving the species by USFWS is much-admired, but some issues in the designation are still in need of improvement. For example, the delimitation of buffer zones for the species should extend from the water source more than 30 m contrary to what was proposed by designation. The USFWS knowingly ignored recent studies that have demonstrated that narrow buffer zones in riparian habitats are not as effective as wide zones (Houlahan & Findlay, 2003; Semlitsch & Bodie, 2003). The first priority of the Coquí Guajón Recovery Program is to determine the distribution and population status within the available habitat, but this has not yet been done. This basic biogeographic information is needed to develop a management plan for the conservation of this species.

Justification

Amphibians are vulnerable to complex synergistic factors (Burrowes, 2004; Houlahan et al., 2000). Habitat loss and fragmentation are among the highest threats of amphibian populations, and the Coquí Guajón is a good example of this (Cushman, 2006; deMaynadier & Hunter, 1998; Hedges, 2004; Houlahan & Findlay, 2003; Marsh & Pearman, 1997; Rothermel & Semlitsch, 2002; Rothermel & Semlitsch, 2006, Ríos-López & Thomas, 2007). Studying patterns of distribution and abundance of species is key for addressing and understanding measures that have to be taken in establishing effective management strategies that addresses these threats (Cushman, 2006). Results obtained by this research revealed in detail the distribution patterns of the Guajón, and provided information necessary to expand its known distribution. It was useful for identifying localities that were viable for Guajón sustainability, other than the ones already characterized, and could possibly become candidates for designation as critical habitats. Information for improving development of spatial analysis models that predict its distribution was obtained. This was be achieved by taking into account possible variables that could have been neglected or overlooked in the past development of this kind of analysis. Furthermore, this will promote an emphasis of validating the results of spatial analysis models with fieldwork and empirical data.

Another benefit in obtaining a complete distribution data was that researchers will be able to examine the habitat status of the species. Effective measures which are necessary for conserving the species, can be taken into consideration and assess priorities for conservation. A landscape analysis is needed to address some of the most important conservation issues like agricultural and urban development risks for the species and areas that maintain connectivity among subpopulations by studying land use history (Rothermel & Semlitsch, 2002; deMaynadier & Hunter, 1998; Manel et al. 2000; Funk et al. 2005; Houlahan & Findlay, 2003; Helmer, 2004; Helmer et al. 2002; Grau, 2003). Efficient buffer zones can be designed and designated with the data obtained, taking into account optimal conditions proposed from recent studies in riparian amphibian conservation (Semlitsch & Bodie, 2003; Semlitsch, 1998; Crawford & Semlitsch, 2007). The data collected provided the necessary information for sustaining the importance of corridors for this species, and the habitat characteristics that are critical for its dispersal and gene flow (Burrowes & Joglar, 1999; Burrowes, 2000). Since little is known about the abundance of individuals (all age classes considered) throughout the distribution of *E. cooki*, the data supplied by this study provided a snapshot of the population status at all localities sampled. In general, a broad scope of what has to be done to ensure the well being of the species will be given to governmental authorities, the scientific community and the general public, which have the responsibility of conserving this species.

Research Questions

1. What is the current distribution of the Coquí Guajón *(Eleutherodactylus cooki)*?
2. What is the habitat status of the Coquí Guajón *(Eleutherodactylus cooki)*?

Goals

Determine the current distribution, habitat and population status of the Coquí Guajón (*Eleutherodactylus cooki*) to assess adequate conservation measures for its recovery and management.

Objectives

1. Determine the present distribution of the Coquí Guajón (*Eleutherodactylus cooki*) using Geographical Information Systems.
2. Evaluate current habitat status according to the conservation needs of the species.
3. Collect baseline data to provide a snapshot of the population status using individual counts at all localities sampled.

CHAPTER II

LITERATURE REVIEW

Background

Eleutherodactylus cooki was discovered on January 24, 1932 by Chapman Grant, and was described as the most elusive species discovered (Joglar et al., 1996). The Guajón is the largest extant species of *Eleutherodactylus* in Puerto Rico, if we take into consideration that *E. karlschmidti* is probably extinct (Joglar, 1998). It is a habitat specialist that utilizes caves formed from large granite boulders or crevices and grottoes in rocky streams (Rivero, 1998; Vega-Castillo, 2000). This specialization has influenced the evolution of this species, giving it physical characteristics that are optimal for this kind of habitat, such as large eyes, largest digital disk diameter and largest tibia length of any *Eleutherodactylus* in Puerto Rico (Joglar, 1983). Due to this degree of specialization the distribution of the species has been confined to the habitat described, which can only be found within the Sierra Pandura Mountain Range (Joglar, 1998; USFWS, 2007).

The Coquí Guajón is in a vulnerable state because of its limited distribution, and poor knowledge of its population status (Rivero, 1998; Joglar 1998). Efforts that have been made for its conservation include studies of its reproductive biology (Burrowes & Joglar, 1999; Joglar, et al., 1996), population ecology (Joglar et al., 1996, Vega-Castillo, 2000), habitat characterization (Joglar et al., 1996, Vega-Castillo, 2000), populations genetics (Burrowes & Joglar, 1999), predation (Joglar, 1998) and a few more ecology related studies. Local and federal efforts include the designation of most of the area where the

Guajón is believed to be distributed as a Critical Wildlife Area by the DNER (DNER, 2005). The USFWS has also issued recently a Recovery Plan for the species (USFWS, 2004), and a Designation of Critical Habitat of 105.6 hectares (ha) (USFWS, 2007; Appendix A).

Conceptual framework

The reason that motivated this study is that amphibians are declining worldwide (Stuart et al. 2004, Houlahan et al. 2000). It is very important to understand also that Puerto Rico is not excluded from this global phenomenon, since we rank as the fifth country with highest percentage of threatened amphibians with 72.2% of its species (Burrowes et al. 2004; IUCN et al., 2006; Joglar et al., 2007). Among the concepts that are critical to understand for the conservation of this species are the negative effects that fragmentation and habitat loss have on amphibians (Cushman, 2006; deMaynadier et al., 1998; Hedges, 2004; Houlahan & Findlay, 2003; Marsh & Pearman, 1997; Rothermel & Semlitsch, 2002; Rothermel & Semlitsch, 2006; Ríos-López & Thomas, 2007). These effects were relevant to this study because the current distribution of *Eleutherodactylus cooki* is highly fragmented due to habitat loss caused by urban and agricultural development, and this is presently regarded as the mayor threat of its populations (Hedges et al., 2004). To protect the habitat of *E. cooki*, a landscape analysis must be carried out in which the distribution, habitat status, and development threats are all taken into account by studying land use history. By doing so, this will facilitate the development of an effective management plan that follows proper measures for amphibian conservation (Rothermel & Semlitsch, 2002; deMaynadier et. al., 1998; Manel et al. 2000; Funk et al. 2005; Houlahan & Findlay, 2003; Helmer, 2004; Helmer et al.

2002; Grau, 2003; Semlitsch & Bodie, 2003; Semlitsch, 1998; Crawford & Semlitsch, 2007). Another concept to consider is species distribution modeling, and how it can be used as a functional tool for finding new populations of *E. cooki*. This study will broaden our knowledge of the actual distribution of this species, as well as its potential distribution. It is important to understand the difference between potential and actual distributions of species, because potential distribution of species assumes that the response of species to environmental gradients is constant, while the actual distribution changes and is dependent of different environmental factors (Jiménez-Valverde et. al., 2008). Models are evaluated by determining their usability and value for reaching the goals of the studies proposed (Guisan & Zimmermann, 2000). The model obtained by this study should enable researches to find new populations of *E. cooki* and provide a wider view of habitat availability for the species that can be applied for its management.

Study Cases

There are well documented cases in which amphibians are affected by habitat loss and fragmentation in Puerto Rico and elsewhere (Cushman, 2006; deMaynadier et al., 1998; Hedges et al., 2004; Houlahan & Findlay, 2003; Marsh & Pearman, 1997; Rothermel & Semlitsch, 2002; Rothermel & Semlitsch, 2006; Ríos-López & Thomas, 2007). Studies in Missouri demonstrated one of the consequences of forest fragmentation for juvenile survival in spotted (*Ambystoma maculatum*) and marbled (*Ambystoma opacum)* salamanders (Rothermel & Semlitsch, 2002), where fragmentation lowered the recruitment rates. Salamanders are a group of amphibians that are not present in Puerto Rico (Joglar, 1998; Rivero, 1998), but in their native countries many are associated with streams and creeks like the Coquí Guajón (Joglar, 1998; Burrowes & Joglar, 1999; Vega-

Castillo, 2000). Crawford and Semlitsch (2007) and Semlitsch (1998) assessed the importance of delineating riparian buffers for the protection of amphibians. This measure if implemented correctly in Puerto Rico, could prevent habitat loss of *Eleutherodactylus cooki* effectively.

In Puerto Rico there are other examples of amphibians with very limited distribution, such as: *Bufo lemur*, *Eleutherodactylus unicolor*, *Eleutherodactylus locustus*, *Eleutherodactylus richmondi* and *Eleutherodactylus juanariveroi.* All of which are in precarious state (Hedges et al., 2004; DNER, 2004; USFWS, 1973; Joglar, 1998; Rivero, 1998; Ríos-López & Thomas, 2007). Most of these species have suffered the ecological consequences of habitat loss because of Puerto Rico's history of land use, in which most lands were used for agriculture before the 1950s. (Grau et al., 2003; Helmer, 2004; Thomlinson et al., 1996). Now new threats emerge, with housing and road developments, which have intensified, thus maintaining fragmentation and habitat loss as a threat for amphibians in Puerto Rico (Joglar, 1998).

Legal framework

The Coquí Guajón was included in the Endagered Species Act (ESA) of 1973 on June 11, 1997 because of its limited distribution and insufficient knowledge of population status. The DNER also enlisted *Eleutherodactylus cooki* as a vulnerable species in 2004 in accordance to the New Wildlife Law of 1999, for the same reasons of the USFWS. Both enlistments regulate any actions concerning this species, with the goal in promoting its conservation. The USFWS recently designated critical habitat areas for the species, protecting 105.6 ha in 2007 (USFWS, 2007), to comply with ESA mandates.

CHAPTER III

METHODS

Introduction

Since *E. cooki* is a habitat specialist, it can be found in a specific type of habitat such as caves formed from large granite boulders or crevices and grottoes in rocky streams with forest cover (Rivero, 1998; Vega-Castillo, 2000). The last known distribution of *Eleutherodactylus cooki* (*E. cooki*) populations at the time that this study began could be found in the United States Fish and Wildlife Service (USFWS) critical habitat designation (USFWS, 2007). The populations from the USFWS document were obtained by expert advice and published literature that consisted of reproduction ecology (Burrowes & Joglar, 1999; Joglar, et al., 1996), population ecology (Joglar et al., 1996, Vega-Castillo, 2000), habitat characterization (Joglar et al., 1996, Vega-Castillo, 2000), population genetics (Burrowes & Joglar, 1999) and predation (Joglar, 1998). These methods were designed for accomplishing the following three objectives:

1. **Expand the present distribution of the Coquí Guajón (*Eleutherodactylus cooki*) using Geographical Information Systems.**
2. **Evaluate current habitat status according to the conservation needs of the species.**
3. **Collect baseline data to provide a snapshot of the population status using individual counts at all localities sampled.**

Study area

We searched for this species in its known distribution in two predominant life zones (Ewel & Whitmore, 1973), which are the subtropical moist and subtropical wet forest within most of the southeast of Puerto Rico and the Sierra Pandura Mountain Range. The elevations where it has been found are limited to intermediate elevations from 91 m up to 400 m above sea level (Burrowes & Joglar, 1999; Rivero, 1998), although for this study we searched beyond these elevations looking for appropriate habitat for the species.

Study period

All locality points were visited during the rainy season from April to October, in order to increase the probability of finding individuals. Searches were conducted between 1400 and 2100 hours to cover daytime and nighttime peaks of vocal activity (Drewry & Rand, 1983; Joglar, 1998).

Methodological design

To determine the potential distribution of *Eleutherodactylus cooki*, locations which were consistent with the known habitat characteristics of the species were searched. The Puerto Rico GAP Analysis Project (Gould et al., 2007) has developed a predicted distribution map for the Coquí Guajón, which provided such information, using the known distribution of the species at the time. The layers they obtained as the possible limiting factors for the distribution of the species were the following: forested boulder strewn streams beds with a buffer of 105 m, in forest adjacent to streams and rivers with steep slopes at elevations between 30 and 375 m. The predicted areas were divided in the same 24 squared-kilometers (km^2) hexagon grids that the GAP project used for its model (Figure 1A). All hexagons where the occurrence was not confirmed and classified as probable was sampled in at least two different localities (Figure 1A). These localities were chosen randomly using the Hawth Analysis Tools extension in ArcGIS (ArcMap

9.2, Environmental System Research Institute, California). Other localities visited, were referred by colleagues and were not found within the GAP model. All localities were found by using Global Positioning System (GPS) (Garmin, 76CSX). When a locality was visited, an area of a radius of 100 m was searched. At each sample site visited, all *Eleutherodactylus cooki* individuals (all age classes considered) heard or seen were counted and the presence was classified between three abundance categories to collect baseline data that provided a snapshot of population status (Appendix B). If other localities were in a 25 m range, samples were taken each with a ten meter radius with the GPS until no individuals were found beyond 25 m of the last sampled point.

Analysis

After collecting the baseline data, it was used to generate an actual distribution map and a new predicted habitat model to evaluate and compare the accuracy of both GAP and new models. The new predicted habitat model used the same layers, but readjusted to include more details (i.e. elevation set at between 20 and 450 m above sea level) and a geology layer was also added. The complete list of layers considered for this model is enumerated in Appendix C. We intended to add layers in an effort to provide an accurate model that contained within its potential distribution, the recently discovered populations obtained from the USFWS critical habitat designation (Appendix A), and the localities found with the GAP model and information received by colleagues. For evaluating the habitat status of the lands where the species was found, a land stewardship layer was used, provided by GAP Project. The number of proposed developments per municipality obtained by the Puerto Rico Planning Board website (http://gis.jp.gobierno.pr/pr/) also helped us determine if the land management was compatible with the conservation needs of the species.

Several data analysis techniques were used to analyze the spatial distribution of the new predicted habitat model. By using simple descriptive statistics we were able to obtain the percentage of available habitat of *E. cooki* for comparing both habitat and individuals abundance. The percent of error in commissions (predicted to occur but did not occur) and omissions (not predicted to occur but did occur) was calculated to evaluate the accuracy of the new and GAP model, and a Chi-square was done to determine if there was a significant difference between the percent of errors obtained by both models.

CHAPTER IV

RESULTS AND DISCUSSION

This study produced new insights about this species that can be useful for its conservation. New populations were found, and its distribution was expanded to new localities and elevations. Another very important aspect that was included in this study was the current habitat status of the species. This information can be useful for the management of this species. The following are the results obtained from reaching each objective of the study:

Collect baseline data to provide a snapshot of the population status using individual counts at all localities sampled

The methods used to find populations of *E. cooki* proved to be effective. A total of 169 localities were sampled in which the species was present in 108 (64.0%) (Figure 2) sites. The Coquí Guajón was very abundant only in 11/108 (10.1%) of the sample sites, abundant in 25/108 (23.1%) and not abundant in 72/108 (66.6%) sites (Table 1). These results should alarm the scientific community and agencies responsible for the species populations, specially where isolated populations with low abundance were found, due to the high risk of them disappearing. The municipality of Yabucoa contained most of the localities where the species was very abundant with 7/11 (63.3%). Taking into consideration the sum of all categories established, San Lorenzo had the most localities where the species was present, with 41/108 (37.9%) sampled localities (Figure 3).

Expand the present distribution of the Coquí Guajón (*E. cooki*) using Geographical Information Systems (GIS).

The majority of the localities were obtained using the Geographical Approach to Planning (GAP) Analysis Model (Figure 4A). A total of 101 localities where within the predicted habitat of the GAP model, and we were able to locate *E. cooki* in 66 (65.3%) of them. These results demonstrated that the GAP model can be a useful tool for finding new populations of this species (Table 2). The efficiency of the GAP model was tested by determining the percent of error in commissions and omissions to evaluate if it predicted accurately the absence and presence of individuals at each site sampled. Surprisingly, although it proved to be a useful tool, it had a low percent in commission errors with 35% (35/101), but a high percent of error in omissions with 62% (42/68). The remaining 42 points where the species was present were located using information acquired from colleagues and by chance while moving from one point to the next. The major finding of this study was that of the 108 sampled localities, only five were found within 100 m of the USFWS critical habitat areas, meaning that 103 (95.4%) of the sampled points are new records for this species.

New valuable information was obtained about the distribution of the species. The past elevation range was considered to be from 36 m up to 400 m above sea level (Burrowes & Joglar, 1999; Burrowes et al., 2004; Rivero, 1998; USFWS, 2007). This study revealed that populations of the Coquí Guajón could be found at elevations ranging from 26 m up to 421 m above sea level (Appendix B). This new range has two management issues that should be considered. The first is that the range expands to even lower elevations where there are more human populated areas. Secondly, that the expansion to higher elevations increases the risk of finding populations of *E. cooki* infected or interacting with species that have the pathogenic fungus *Bd*. In a recent publication it was found that the range of the presence of *Bd* in Puerto Rico begins at an elevation of 500 m where the diversity of infected species was higher (Burrowes, et al., 2008). We also found the population of *E. cooki* that extends the farthest to the west of Puerto Rico in the municipality of Patillas (Figure 5).

When the new habitat model was generated, other layers were re-examined, such as the elevation range layer, which was modified after studying the presence data. These layers refined the GAP model and increased our knowledge of the species distribution. For example, after overlaying the localities where *E. cooki* was present on the land cover layer (PRGAP, 2006), we were able to ascertain the land cover suitable for the species. *Eleutherodactylus cooki* was mainly found in young and mature secondary forests, followed by shrubs and finally to a less extent in abandoned plantations (Figure 6). We also observed that the hydrology and geology are two very important factors for determining habitat suitability for the species. Hydrology was considered for generating the GAP model, but the layer used only considered rivers and streams, and it did not contain smaller hydrological systems like small creeks and ephemeral streams (Gould et al., 2007). The geology layer was never considered for generating the GAP model. The geology and hydrology are two well-known factors for *E. cooki* habitat suitability (Joglar et al., 1996, Vega-Castillo, 2000). When all these new and redefined layers were applied to the new model, including a modified landform layer similar to the one used in the GAP model, our model (Figure 4B) predicted 11472.2 ha of new suitable habitat for *E. cooki* that was not considered in the GAP model (Table 2). A total of 158 localities were within the predicted habitat of the new model, and 105 (66.5%) of them had *E. cooki* present.

These results demonstrate that the new model obtained a slightly higher percentage than the GAP model (Table 2). The efficiency of the new model was also tested by determining the percent of error in commissions and omissions, to evaluate if it predicted accurately the absence and presence of individuals at each site sampled. It also had a low percent in commission errors with 34% (53/158), but our model had a percent of error in omissions of only 27% (3/11). The percent of error in omissions of the models differed significantly ($p=0.048$), the PRGAP model had a 62% of error compared to the 27% of the new model. The localities that we were referred to by colleagues and the USFWS critical habitats were also within the new model. These results proved that the new model produced with the data obtained from this study was a more accurate and efficient model than the GAP model. This result was expected due to the limited available occurrence data available when the GAP model was generated in comparison to the occurrence data generated by this study and the USFWS critical habitat designation (Figure 1B).

Evaluate current habitat status according to the conservation needs of the species.

Habitat status is a very important issue for this species because the Coquí Guajón is a highly specialized species, with a very limited distribution in Puerto Rico (Burrowes & Joglar, 1999; Joglar, 1998; Rivero, 1998; USFWS, 2007; Vega-Castillo, 2000). Our findings were of great relevance to this species, and should be taken into account when making management decisions for its conservation. Since land use management is primarily taken care of by each individual municipality, and regulated by government agencies, we decided to analyze our habitat status data by municipalities in which the presence of *E. cooki* had been confirmed. The municipalities which are stakeholders, starting with the ones that have the largest area to the smallest are the following:

Yabucoa, San Lorenzo, Patillas, Humacao, Las Piedras, Juncos and Maunabo (Table 3). We knew that each of these municipalities possessed one or more critical habitats for *E. cooki*, as declared by the USFWS (Table 3 and Figure 5). We knew Yabucoa was the municipality with the most critical habitat areas. Thus, we suspected that it was the municipality where individuals were most abundant, however, this did not necessarily had to be the case. What the predicted habitat model told us was that the municipality of Maunabo, being the one with the smallest total area, has the most suitable habitat available for *E. cooki*. Although Yabucoa does have more suitable habitat than Maunabo with 4099.2 ha vs. 2414.0 ha, when you examine the total available area relative to the size of each municipality, Maunabo has 44.3% of its total area suitable for *E. cooki* vs. Yabucoa with 28.7% (Table 3 and Figure 7). Knowing the percent of available habitat can be very important for the management of this species, because it seems to be an efficient tool to make decisions on how we can manage the lands where this species is or can be present. For example, with the results of this study, we now know that if there is a proposed development in the municipality of Maunabo, there is a probability of 44.3% that it is in *E. cooki's* habitat and individuals maybe present. This may be overlooked frequently because development and human populations in the southeast region of Puerto Rico are generally considered as sparse and of low density (Martinuzzi et al. 2007; Gould et al., 2008a, 2008b). When we examined the land stewardship of the localities where the species is present, and its predicted habitat, we realized that the majority of the lands were not owned by a conservation agency or group.

The critical habitat areas between Maunabo and Yabucoa were the only exception, since they are owned by the Conservation Trust of Puerto Rico. A very small area of the

Department of Natural and Environmental Resources (DNER) in the Carite State Forest also fell within the predicted area (Figures 5 and Figure 7). This drove us to determine if development was causing a threat to *E. cooki* populations. We found that municipalities with higher quantities of development cases had lower habitat availability. This occurs probably because of the difficulty of developing in areas where there is a high percentage of potential habitat for the species, and municipalities with less available habitat have lands easier to develop, like grasslands for example. This seems to be good news at first, because there is a lager development tendency occurring where there is a lower possibility of encountering *E. cooki* populations, but it is also alarming, because populations that have little potential habitat are more at risk because of the high tendency of urban expansion. This is an aspect that government agencies should take into account when approving developments in these municipalities, and they ought to be more vigilant when reviewing flora and fauna studies made by developers in these areas.

CHAPTER V

CONCLUSIONS AND RECOMENDATIONS

The current distribution of the Coquí Guajón *(Eleutherodactylus cooki)* is broader than what was known at the time this study began (USFWS, 2007). The species was discovered more to the west, reaching new elevations, and new populations with high abundance were also discovered. The GAP Analysis model proved to be a useful tool for locating new populations of *E. cooki*. Due to the data collected using the GAP model, our new habitat model of *E. cooki* acquired more accuracy for predicting the presence of this species in Puerto Rico. This new model is a management tool that can be used to meet the conservation needs of this species. The new model can be employed the same way the GAP model was utilized in this research to find other populations, and for evaluating the land management threats that the species is facing. The new model can also be refined even more with future research to increase its accuracy by using a procedure similar to the one used herein to refine the GAP model. This was not done because of time constraints, but we recommend and invite other researchers to do so.

The new areas where the presence of *E. cooki* was confirmed should be declared critical habitat by the USFWS, due to the limited distribution of the species and the high degree of specialization of the species (Burrowes & Joglar, 1999; Joglar, 1998; Rivero, 1998; USFWS, 2007; Vega-Castillo, 2000). Lands already declared as critical habitats, should be the first priorities for acquisition, followed by the localities with highest abundance located in this study (Appendix B). The habitat of this species can also be conserved using other conservation measures that can ensure its proper management, for example federal, local or NGO land stewardship agreements with landowners who do not want to sell their lands. The Coquí Guajón habitat is restricted to caves and boulders, but we concluded that it has an important association with hydrological systems (e.g. perennial and ephemeral streams, creeks and runoffs) were of equal importance to the species. Our success in locating new populations was dependent upon the presence of these two factors. They provided a suitable habitat for the species to find shelter, forage, reproduce and maintain gene flow, by using the hydrological systems as biological corridors (Burrowes & Joglar, 1999; Burrowes, 2000; Joglar et al., 1996; Joglar, 1998; Vega-Castillo, 2000). Further GIS analysis should be done to evaluate possible connectivity between populations thru hydrological systems, and the opportunity to establish these biological corridors should also be considered as a priority for conservation. We stress the importance of conserving these corridors not only because its utility for the species, but also because of the potential damage that can occur if the hydrology (ephemeral or perennial) of the area is changed adversely, to a point that can convert a suitable habitat into a non-suitable one. This can be caused by erosion and sediments, contaminants and provoked droughts that can alter temperature and relative humidity of the hydrologic systems within *E. cooki's* habitat that must be maintained constant (Rogowitz et al., 1999; Rogowitz et al., 2001). Some of these altering effects were witnessed during this study within *E. cooki's* habitat and it could have drastically altered normal conditions of some areas (Appendix D). We do not concur with the opinion of the USFWS that these features in unoccupied habitats cannot be determined as essential for the conservation of the species. The USFWS should include unoccupied habitats that are suitable for the species and its surroundings to insure that the hydrology of the area is conserved. To determine which are these hydrological important areas, hydrological/hydraulic (H/H) studies must be done, not only in forest areas, but also in urban areas to assess all threats. This is another reason why the USFWS should also extend the buffer zones for the species, depending upon the results of the H/H studies. It is also well known from other studies that narrow buffer zones in riparian habitats are not as effective as wide zones because of this factor (Houlahan & Findlay, 2003; Semlitsch & Bodie, 2003).

The connections between what little available habitats remaining in some municipalities are extremely important to maintain, and this study has demonstrated that these areas are currently under most threat. Information on the percent of available habitat should be kept track of, in case of the need to create a captive breading program with possibilities of releasing individuals is necessary for conserving the species, as in the case of the Puerto Rican Parrot (*Amazona vittata*; Morell, 2008). It is very important for the conservation of the Coquí Guajón, that a well planned land acquisition process should commence before the species reaches a threshold were it can not recover, leading to its ultimate extinction. It is extremely alarming to know that most of the populations and available habitat of this species are in privately owned lands, which potentially do not take into consideration the best interests of this species. Situations like this have been witnessed before with *Eleutherodactylus jasperi*, and this species has already been lost (Joglar, 1998). In present time another species facing similar threats is *Eleutherodactylus juanariveroi,* which is also limited to privately owned lands. However, there is still hope for these two species, the most important thing is to learn from similar past events and ensure that the same errors are not committed once more. The USFWS and DNER should create educational programs to enhance public awareness. The regional endemism of this species should be exploited, to help residents of the southeast region of Puerto Rico feel ownership for this species.

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TABLES

Table 1. *Relative abundance of* Eleutherodactylus cooki *at localities where it was present (n = 108).*

Relative abundance	Qty. of individuals	Occurrence (%)
Very abundant	9 +	11/108 (10.1%)
Abundant	5-8	25/108 (23.1%)
Not abundant	1-4	72/108 (66.6%)

Table 2. *Comparison between* Eleutherodactylus cooki *predicted habitat models.*

Model	**Area (ha)**	**Accuracy**	**Presence of *E. cooki***	**Predicted *E. cooki* presence**
New Model	15336.6	66.5%	105	158
GAP	3864.4	65.3%	66	101

Table 3. *Relationships between area, predicted* Eleutherodactylus cooki *habitat distribution, and development cases among municipalities in southeast Puerto Rico.*

Municipality	**Area (ha)**	***E. cooki Predicted* Habitat (ha)**	**Habitat Available (%)**	**Development Cases**	**USFWS Critical Habitat Areas**
Humacao	11628.5	950.4	8.2	398	1
Juncos	6892.5	476.8	6.9	307	1
Las Piedras	8790.1	1175.1	13.4	293	2
Maunabo	5452.1	2414.0	44.3	81	3
Patillas	12235.9	3598.1	29.4	148	1
San Lorenzo	13774.2	2468.9	17.9	325	2
Yabucoa	14304.6	4099.2	28.7	234	9

FIGURES

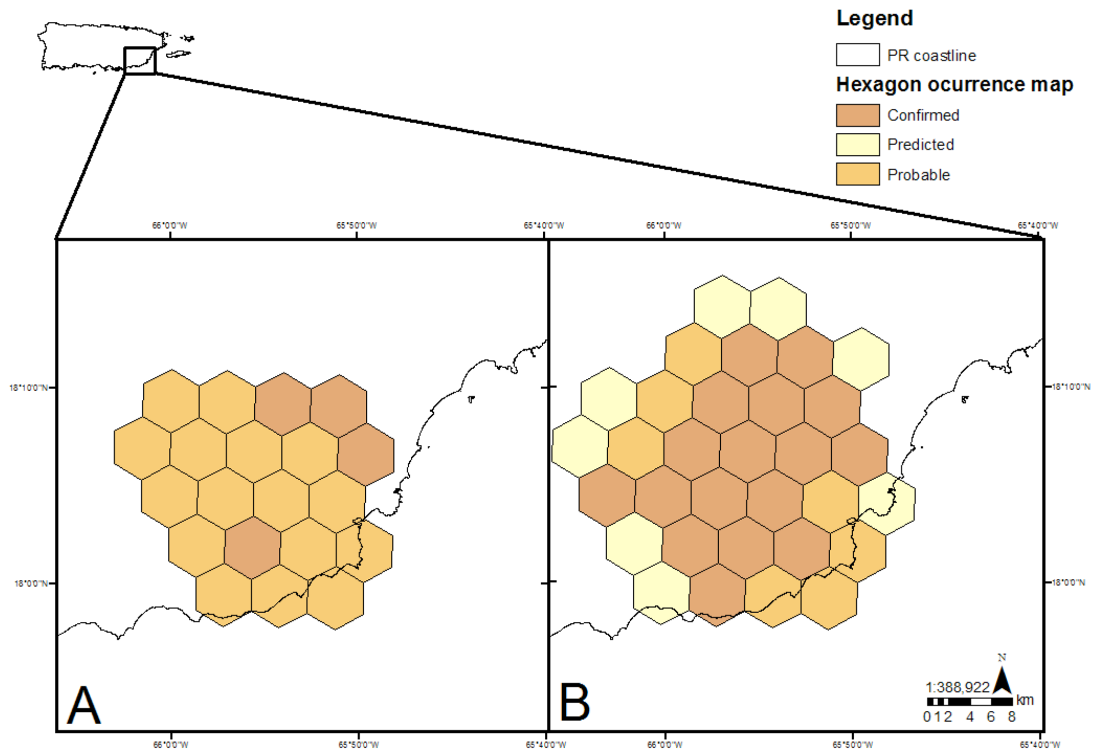


Figure 1. Map of *Eleutherodactylus cooki* hexagon-based occurrence in (A) PRGAP and (B) New model.

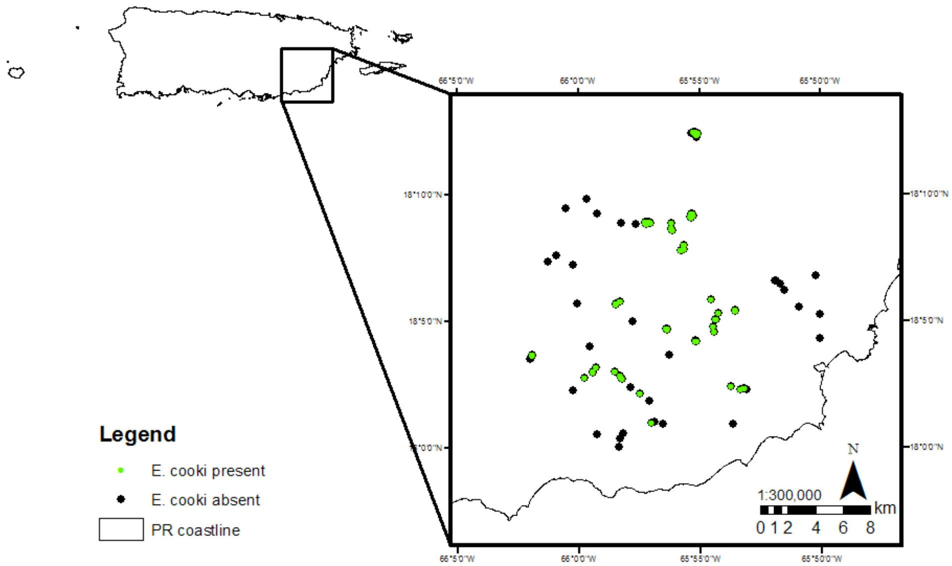


Figure 2. Localities sampled throughout the study in southeast Puerto Rico. Green dots represent localities where *E. cooki* was present (n = 108), and black dots represent localities were *E. cooki* was not found (n = 61).

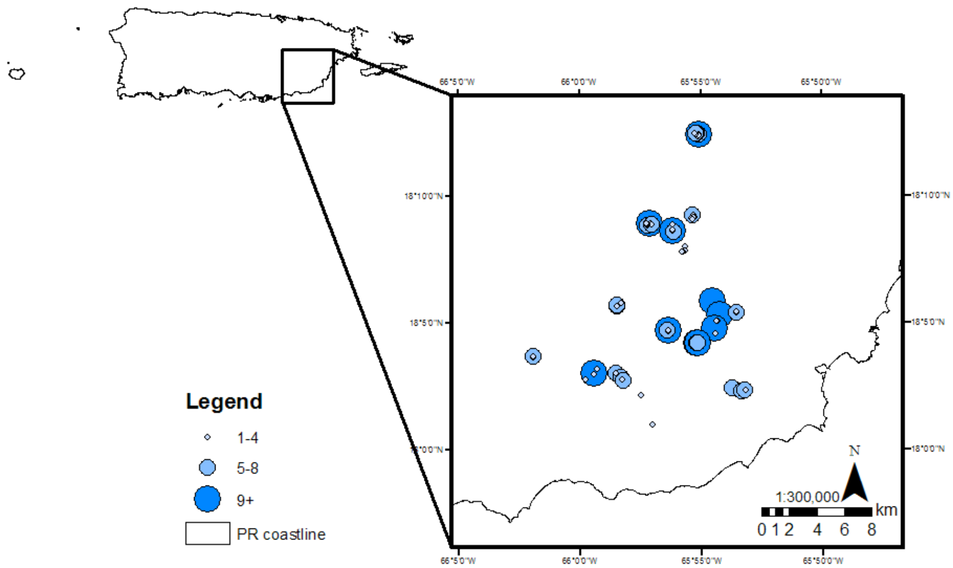


Figure 3. Relative abundance of *Eleutherodactylus cooki* at each locality where it was present (n = 108). Circle size is proportional to the numbers of individuals observed.

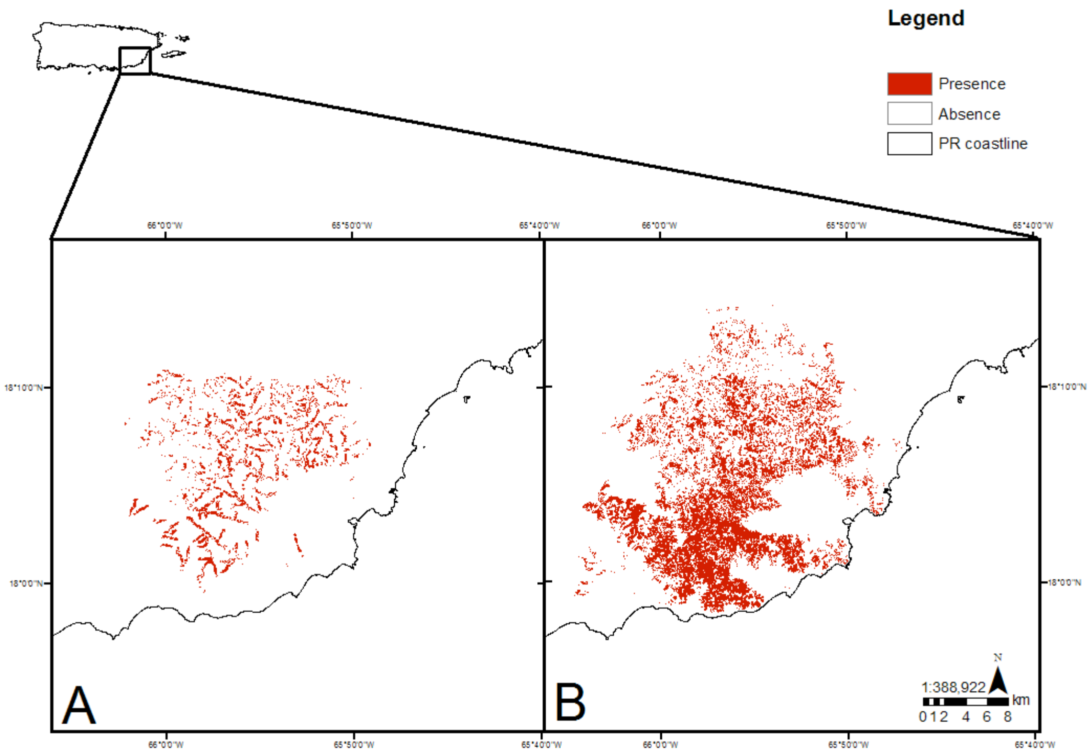


Figure 4. Comparison between both *Eleutherodactylus cooki* habitat prediction models (A) PRGAP (3864.4 ha) and (B) New model (15336.6 ha).

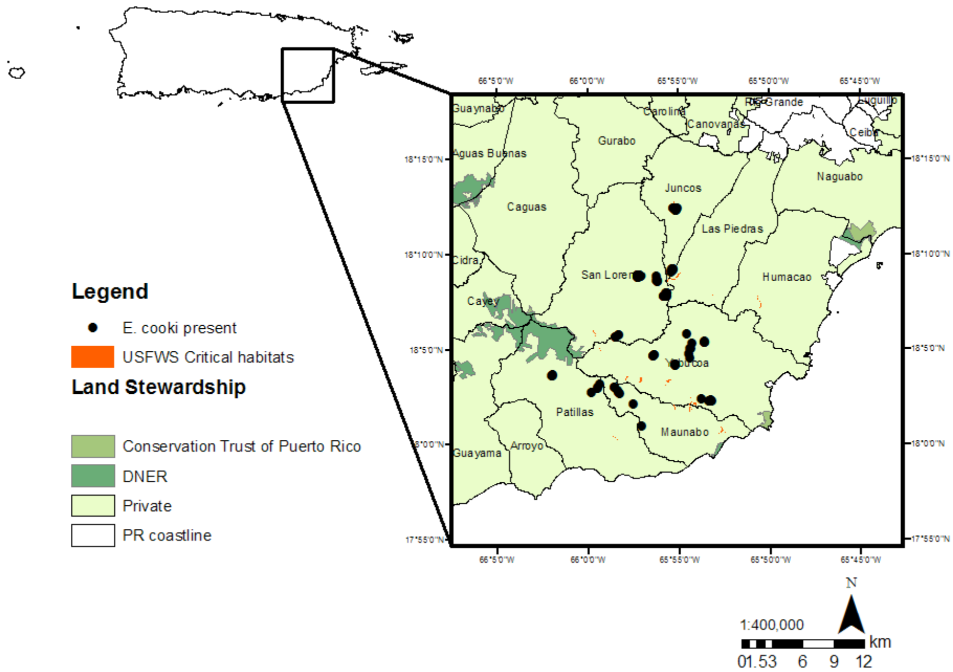


Figure 5. Map of the land stewardship at the localities where *Eleutherodactylus cooki* is present, including areas sampled in this study and US Fish and Wildlife Service Critical habitats.

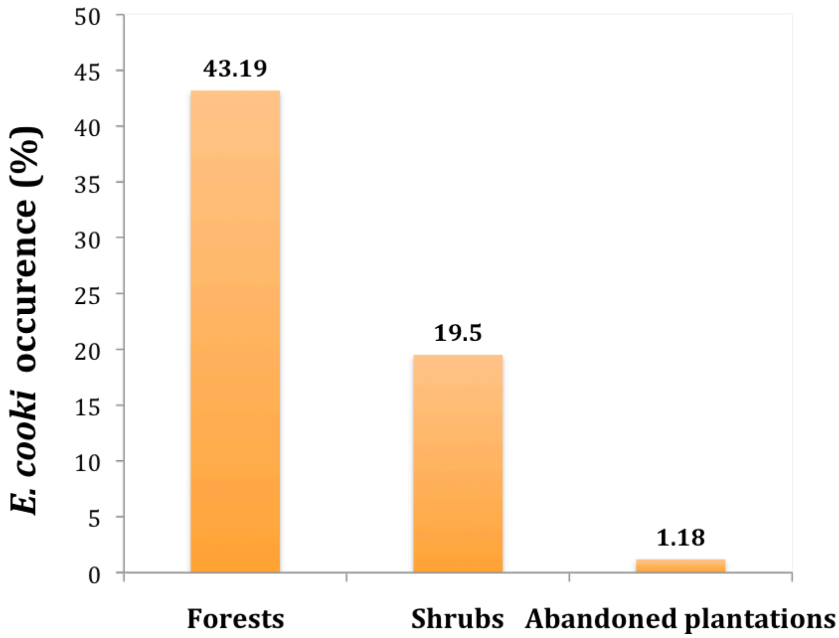


Figure 6. *Eleutherodactylus cooki* landcover suitability at all localities sampled (*n* = 169).

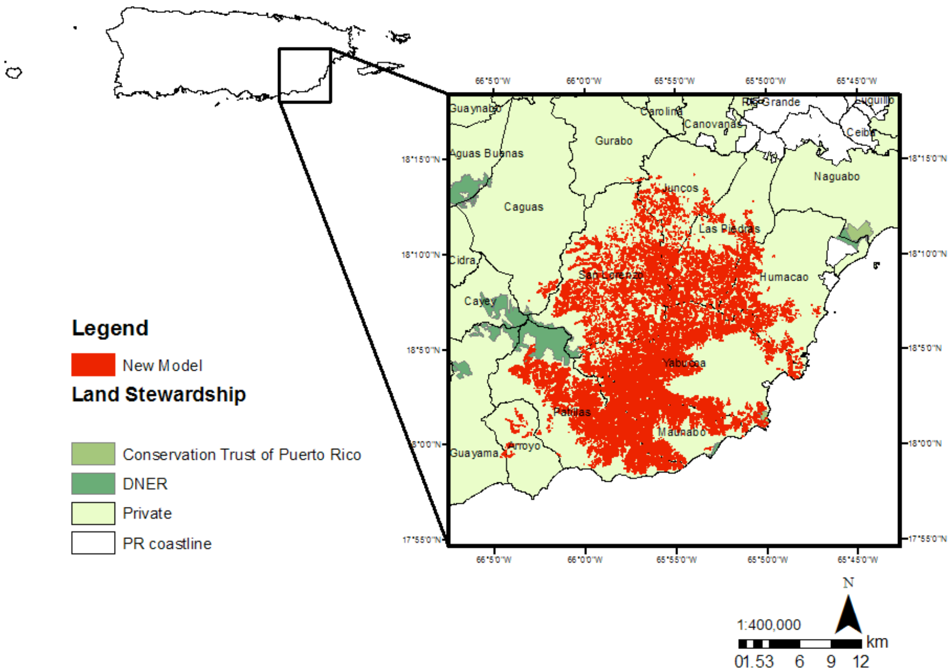
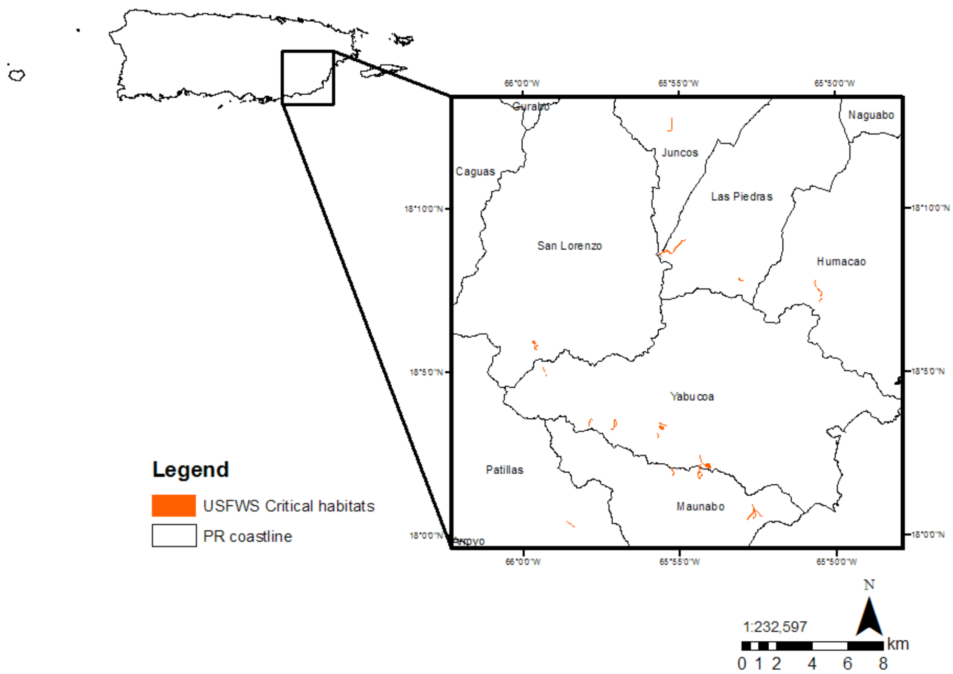


Figure 7. Map of land stewardship in areas of predicted occurrence *of Eleutherodactylus cooki* by the New model.

APPENDIXES

APPENDIX A. US FISH AND WILDLIFE SERVICE *ELEUTHERODACTYLUS COOKI* CRITICAL HABITAT AREAS.


Legend
USFWS Critical habitats
PR coastline
Gurabo
Naguabo
Juncos
Caguas
Las Piedras
San Lorenzo
Humacao
Yabucoa
Patillas
Maunabo
66°0'0"W
65°55'0"W
65°50'0"W
18°10'0"N
18°5'0"N
18°0'0"N
1:232,597
N
km
0 1 2 4 6 8

APPENDIX B. LOCALITIES VISITED THROUGHOUT THE STUDY WHERE *ELEUTHERODACTYLUS COOKI* WAS PRESENT (1) OR ABSENT (0). ABUNDANCE OF *E. COOKI* WAS DETERMINED FROM THE QUANTITY HEARD OR OBSERVED (1 = NOT ABUNDANT (1-4 INDIVIDUALS), 2 = ABUNDANT (5-8 INDIVIDUALS), 3 = VERY ABUNDANT (9+ INDIVIDUALS).

Location*	Elevation (m)	Abundance
1	19.00	0
2	20.00	0
3	26.00	1
4	30.00	2
5	30.00	0
6	33.00	1
7	33.00	1
8	35.00	2
9	35.00	1
10	38.00	2
11	39.00	0
12	47.00	3
13	61.00	3
14	63.00	0
15	80.00	0
16	85.00	0
17	86.00	0
18	86.00	0
19	94.00	0
20	96.00	1
21	96.00	1
22	98.00	0
23	99.00	2
24	99.00	0
25	103.00	1
26	103.00	1
27	103.00	0
28	103.00	0
29	104.00	0
30	105.00	0
31	106.00	1
32	107.00	0
33	108.00	1
34	108.00	0
35	109.00	0
36	109.00	0
37	110.00	1
38	110.00	1
39	112.00	1
40	112.00	2
41	113.00	1

Location*	Elevation (m)	Abundance
42	115.00	1
43	116.00	0
44	118.00	2
45	121.00	0
46	122.00	1
47	127.00	2
48	130.00	3
49	130.00	1
50	131.00	2
51	140.00	2
52	140.00	0
53	143.00	0
54	152.00	0
55	162.00	3
56	164.00	0
57	165.00	2
58	165.00	2
59	165.00	0
60	170.00	3
61	176.00	2
62	177.00	1
63	179.00	1
64	179.00	2
65	179.00	0
66	183.00	3
67	184.00	1
68	186.00	0
69	191.00	2
70	198.00	0
71	201.00	1
72	212.00	3
73	214.00	0
74	215.00	1
75	218.00	0
76	219.00	2
77	219.00	1
78	219.00	0
79	221.00	2
80	222.00	0
81	226.00	0
82	226.00	0

Location*	Elevation (m)	Abundance
83	227.00	3
84	228.00	2
85	228.00	1
86	233.00	1
87	234.00	1
88	237.00	1
89	237.00	2
90	237.00	0
91	239.00	3
92	242.00	1
93	256.00	2
94	269.00	0
95	276.00	0
96	279.00	2
97	282.00	1
98	287.00	0
99	296.00	1
100	296.00	1
101	297.00	1
102	300.00	1
103	301.00	1
104	301.00	1
105	301.00	0
106	302.00	2
107	302.00	1
108	302.00	2
109	302.00	1
110	304.00	1
111	304.00	2
112	304.00	1
113	305.00	1
114	305.00	1
115	306.00	1
116	307.00	1
117	308.00	1
118	308.00	1
119	308.00	0
120	310.00	1
121	311.00	1
122	313.00	1
123	314.00	1

Location*	Elevation (m)	Abundance
124	316.00	1
125	326.00	1
126	328.00	1
127	328.00	1
128	330.00	0
129	345.00	0
130	353.00	1
131	362.00	3
132	370.00	0
133	421.00	1
134	603.00	0
135	642.00	0
136	NA	2
137	NA	1
138	NA	1
139	NA	1
140	NA	1
141	NA	1
142	NA	1
143	NA	3
144	NA	1
145	NA	1
146	NA	1
147	NA	2
148	NA	1
149	NA	1
150	NA	1
151	NA	1
152	NA	1
153	NA	1
154	NA	1
155	NA	1
156	NA	0
157	NA	0
158	NA	0
159	NA	0
160	NA	0
161	NA	0
162	NA	0
163	NA	0
164	NA	0

Location*	Elevation (m)	Abundance
165	NA	0
166	NA	0
167	NA	0
168	NA	0
169	NA	0

***Exact locations can be requested at USFWS or DNER**

APPENDIX C. GIS LAYERS USED FOR GENERATING THE NEW MODEL

Hydrology

Reference:

Puerto Rico Center for Municipal Revenues (Centro de Recaudación de Ingresos Municipales CRIM) PR Office of Management and Budget, 2006

Layer of the Hydrography Revision, 2001-04 from CRIM Basemap, scale 1:5000, PR Quadrangle

- For the Municipalities of the southeast region of Puerto Rico.

Landcover

Reference:

Puerto Rico GAP Analysis Project (PRGAP), 2006, PRGAP Landcover: USDA Forest Service, International Institute of Tropical Forestry, Río Piedras, Puerto Rico.

Landcover layers

Forested area layers

- Mature secondary lowland moist noncalcareous evergreen forest
- Mature secondary montane wet noncalcareous evergreen forest
- Mature secondary montane wet alluvial evergreen forest
- Young secondary lowland moist noncalcareous evergreen forest
- Young secondary lowland moist alluvial evergreen forest
- Young secondary montane wet noncalcareous evergreen forest

Shrubland layers

- Lowland moist noncalcareous shrubland and woodlands
- Montane wet noncalcareous evergreen shrubland and woodland

Abandoned Plantation layers

- Lowland moist abandoned and active coffee plantations

Elevation

Reference:

U.S Geological Survey (USGS), ERDOS Data Center, Sioux Falls, SD, 1999

Layer of National Elevation Data Set, modified to 5 m intervals

- Between 20 and 450 meters

Geology

Reference:

Bawiec, W.J. 2001. Geology, Geochemistry, Geophysics, Mineral occurrences, and Mineral Resources Assessment for the Commonwealth of Puerto Rico. USGS Open file report 98-38.

Geology layers

- Granodiorite-quartz diorite of San Lorenzo
- Metavolcanic rocks
- Quartz-diorite plutonic complex

Topography

Reference:

Landforms: Gould, W.A; Martinuzzi, S.; Jimenez, M.E.; Edwards, B.R.; Ramos-González, O.M. 2008. Topographic units of Puerto Rico. Scale 1: 260,000. IITF-RMAP-04. Río Piedras, P.R: US Department of Agriculture Forest Service, International Institute of Tropical Forestry.

Landforms layers

- Slope bottom
- Low slope
- Side slope
- Upper slope
- Moderately steep slope
- Steep slope
- Slope crest

APPENDIX D. THREATS TO *ELEUTHERODACTYLUS COOKI'S* HABITAT OBSERVED DURING THIS STUDY.

Runoff water entering *Eleutherodactylus cooki* habitat through street drainages.

Sediments entering into the hydrologic system of *Eleutherodactylus cooki* by landslides caused by habitat alterations.

Roads collapsed in a locality where *Eleutherodactylus cooki* was present.