MONGOOSE IN THE RAINFOREST: ANALYZING POPULATION ESTIMATES AND HABITAT ATTRIBUTES TO SUPPORT MANAGEMENT IN EL YUNQUE NATIONAL FOREST, PUERTO RICO

By

Diana Guzmán-Colón

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

Fisheries and Wildlife - Master of Science

2014

ABSTRACT

MONGOOSE IN THE RAINFOREST: ANALYZING POPULATION ESTIMATES AND HABITAT ATTRIBUTES TO SUPPORT MANAGEMENT IN EL YUNQUE NATIONAL FOREST, PUERTO RICO

By

Diana Guzmán-Colón

The small Indian mongoose, *Herpestes auropunctatus*, was introduced throughout most of the Caribbean and Pacific Islands a century ago. Once established, mongooses can significantly alter food webs, often becoming detrimental to native species. Lack of published information on control techniques makes it difficult for conservation managers to devise effective population control campaigns. In this study, I focus on Puerto Rico (El Yunque National Forest) and the introduced small Indian mongoose. The objectives of my study were to: 1) compare mongoose abundances between YNF and a nearby coastal zone, 2) compare habitat conditions among the dominant forest types found in YNF and the coastal zone, 3) relate the likelihood of capturing mongooses to habitat characteristics at the forest patch scale, and 4.) quantify the influence of localized habitat features on individual trap success. I used mark-recapture for estimating mongoose in YNF and eastern coastal areas in Puerto Rico. I used spatial analysis to model predictors of mongoose capture probability. My results offer insights into the current population status of mongooses in certain areas of eastern Puerto Rico. The ability to predict where to place traps and monitoring trapping outcomes are important for reducing efforts and costs and measuring progress towards the management goal.

ACKNOWLEDGEMENTS

I acknowledge the partnership program between Michigan State University and the University of Puerto Rico. This program made it possible for me to have the privilege of attending graduate school. Dr. William Taylor and Mark Rey were the proponents of this collaboration and I am truly thankful for their support. I greatly appreciate the mentorship from my advisor Dr. Gary Roloff for guiding me through the whole process, and for treating me like a colleague. Thanks to my committee members Dr. Gerald Urquhart and Dr. Scott Winterstein for their guidance. I was able to navigate through the administrative process thanks to Jill Cruth who was always eager to help me with paperwork and deadlines. I want to extend my gratitude to Dr. Robert Montgomery for his statistical help and insight. His work was a significant part of this study.

I am truly grateful for my bosses and collaborators from the United States Department of Agriculture (USDA) Forest Service. Felipe Cano (Wildlife Biologist), Pedro Ríos (Ecosystem Manager), Pablo Cruz (Forest Supervisor), Luis Rivera (Botanist), and the technicians Anastacio Gómez and Benjamín Fuentes. From the USDA Animal and Plant Health Inspection Services (APHIS), Pedro Quiñones and Dr. Kurt VerCauteren. Each of these individuals were essential in planning and executing my fieldwork in one way or another, for providing logistic support and mongoose information, and serving as my mentors in Puerto Rico. My volunteer technicians were instrumental in data collection.

Last but certainly not least I want to thank my family, especially my mom (Nilsa Colón Torres) and dad (Santos Guzmán Santiago) to whom I dedicate this thesis. Their encouragement and support made it easier to cope with the work. To my husband,

Ricardo Rivera, who understands better than anyone else in my life the sacrifices a career as a researcher entails. He took my hand and accepted the challenge ahead of us, he inspires me to be a better professional, a better scientist, a better person.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

The small Indian mongoose, *Herpestes auropunctatus* (hereafter referred to as mongoose; Bennett et al., 2011) has become a serious conservation issue where introduced. Declines in abundance of native birds, reptiles and amphibians have been documented since the introduction of mongooses to islands in the Pacific, Caribbean and South Asia (Seaman and Randall, 1962; Hays and Conant, 2007; Leighton et al., 2008; Watari et al., 2008). In addition, some mongoose populations carry diseases such as rabies and leptospirosis (*Leptospira* sp.), causing managers concern about disease transmission and spread (Tomich, 1979; Nadin-Davis et al., 2008). Mongooses have a complex social structure, diverse feeding habits, and high adaptability, with behavior differing depending on locality (Vilella, 1998). Different management practices to control mongoose populations have been implemented on various islands, but outcomes seem highly dependent on effort and commitment from agencies to the programs. Successful management campaigns for mongooses can be hindered by lack of information on habitat requirements, dispersal capabilities, distribution, and the role of the invasive species in the food web.

To improve the efficiency of trapping, it is important to know the patterns of habitat use that can potentially affect establishment and spread of mongooses. For management strategies involving population control, data on population size and spatial distribution are valuable. The mongoose is commonly associated to habitats that resemble their native range of India and Middle east, thus in the Caribbean, densities tend to be higher in shrubby and dry forests than humid forests (Nellis and Everard, 1983; Barun et al., 2010). Mongooses are usually solitary and their home ranges tend to vary from 2 to 8 hectares and can overlap (Vilella, 1998; Hays, 1999; Quinn and Whisson, 2005). There is no information on localized habitat associations for this species and how this information can be used to improve trapping success. El Yunque National Forest (YNF) in Luquillo, Puerto Rico, is a subtropical rainforest that is occupied by mongooses. Establishment and persistence of mongoose throughout YNF likely depends on their adaptability to new environments, ability to exploit human-dominated areas, and potentially the proximity of YNF to higher quality, source habitats along the Puerto Rican coast.

My goal was to estimate mongoose abundance in YNF and describe how trapping success might be influenced by localized habitat features. This information is valuable to inform control programs and is an initial step in understanding the current status of the mongoose population in selected areas of YNF. My first chapter is dedicated to estimating mongoose abundance in YNF and the coastal forest of the Northeastern Ecological Corridor, describing the general vegetation conditions at trapping sites, and relating these habitat conditions to the frequency of mongoose captures. I used data from a capture-recapture experiment completed during summer 2012. Analyses of these data were used to estimate the population size and identify potentially important environmental correlates of trapping success by forest type.

In Chapter 2, I selected vegetation and spatial variables thought to influence mongoose behavior at localized scales ($79m^2$). These variables were thought to potentially influence localized trapping success. I used logistic regression to estimate the likelihood of capturing a mongoose at a trap location using 9 potential environmental covariates (3 vegetation-based, 5 spatial, and 1 elevation). Significance of candidate models was evaluated using likelihood ratio tests, which provides a chi-square statistic that compares covariate models to a null. Our results provide initial insights into the factors potentially influencing trapping success of mongooses at localized scales that warrant further investigation. Findings from this study are relevant because current mongoose control efforts administered by YNF are not based on spatially explicit recommendations for trap placement.

REFERENCES

REFERENCES

Barun, A., C. C. Hanson, K. J. Campbell, and D. Simberloff. 2010. A review of small Indian mongoose management and eradications on islands. In: C. R. Veitch, M. N. Clout and D. R. Towns (eds.) International Conference on Island Invasives: Eradication and Management. p 17-25. IUCN, Auckland, New Zealand.

Bennett, C. E., B. S. Wilson, and R. DeSalle. 2011. DNA barcoding of an invasive mammal species, the small Indian mongoose (*Herpestes javanicus*; E. Geoffroy Saint-Hillaire 1818) in the Caribbean and Hawaiian Islands. *Mitochondrial DNA* 22: 12-18.

Hays, W. S. T. 1999. Annual dispersal cycle of the small Indian mongoose (*Herpestes auropunctatus*) (Carnivora: Herpestidae) in Hawai'i. *Pacific Science* 53: 252-252.

Hays, W. S. T., and S. Conant. 2007. Biology and impacts of Pacific Island invasive species. 1. A worldwide review of effects of the small Indian mongoose, *Herpestes javanicus* (Carnivora : Herpestidae). *Pacific Science* 61: 3-16.

Leighton, P. A., J. A. Horrocks, B. H. Krueger, J. A. Beggs, and D. L. Kramer. 2008. Predicting species interactions from edge responses: mongoose predation on hawksbill sea turtle nests in fragmented beach habitat. *Proceedings of the Royal Society Biological Sciences* 275: 2465-2472.

Nadin-Davis, S. A., J. Velez, C. Malaga, and A. I. Wandeler. 2008. A molecular epidemiological study of rabies in Puerto Rico. *Virus Research* 131: 8-15.

Nellis, D. W., and C. O. R. Everard. 1983. The biology of the mongoose in the Caribbean. *Studies of the fauna of Curacae and other Caribbean islands*, 195: 1-162.

Quinn, J. H., and D. A. Whisson. 2005. The effects of anthropogenic food on the spatial behaviour of small Indian mongooses (*Herpestes javanicus*) in a subtropical rainforest. *Journal of Zoology* 267: 339-350.

Seaman, G. A., and J. E. Randall. 1962. The mongoose as a predator in the Virgin Islands. *Journal of Mammalogy* 43: 544-546.

Tomich, P. Q. 1979. Studies of *Leptospirosis* in natural host populations I. Small mammals of Waipio Valley, Island of Hawaii. *Pacific Science* 33: 257-279.

Vilella, F. J. 1998. Biology of the mongoose (*Herpestes javanicus*) in a rain forest of Puerto Rico. *Biotropica* 30: 120-125.

Watari, Y., S. Takatsuki, and T. Miyashita. 2008. Effects of exotic mongoose (*Herpestes javanicus*) on the native fauna of Amami-Oshima Island, southern Japan, estimated by distribution patterns along the historical gradient of mongoose invasion. *Biological Invasions* 10: 7-17

CHAPTER 1. MONGOOSE [*HERPESTES AUROPUNCTATUS* (HERPESTIDAE)] POPULATION ECOLOGY IN EL YUNQUE NATIONAL FOREST, PUERTO RICO

Abstract

The small Indian mongoose, *Herpestes auropunctatus*, was introduced throughout most of the Caribbean and Pacific Islands around 100 years ago. Once established, mongooses significantly alter food webs, often becoming detrimental to natives species. Additionally, mongooses are recognized as a primary vector for the rabies virus. In El Yunque National Forest (YNF) in Puerto Rico, management plans to control mongoose populations include the removal of individuals seasonally, but populations remain stable. The objectives of my study were to: 1) compare mongoose abundances between YNF and a nearby coastal zone, 2) compare habitat conditions among the dominant forest types found in YNF and the coastal zone, and 3) relate the likelihood of capturing mongooses to habitat characteristics at the forest patch scale. I used mark-recapture in 5 different forest types in YNF. Each forest type was trapped for 5 days with a 25 trap grid (25m spacing) during the summer of 2012. Estimated population size from a null model (M_0) was 32.3 (SE = 15.3) for the combined forest types in YNF and 62.3 (SE = 31.3) for the coastal site, suggesting that coastal habitats support considerably larger mongoose populations in eastern Puerto Rico. Among the forest types of YNF, I captured the most unmarked mongooses at the site dominated by Sierra Palm *(Prestoea montana*). I found no relationship between capture frequencies and coarse habitat characteristics at the forest patch level, indicating that the likelihood of capturing mongoose in a forest patch was likely influenced by factors other than coarse vegetation. My results offer insights into the current population status of

mongooses in certain areas of eastern Puerto Rico and suggest that coastal forest has the potential to serve as a source habitat for YNF. I recommend integrating different methods for mongoose detection and removal, and establishing population targets that prompt control activities. Also, I recommend focusing trapping of mongoose in forest of YNF where mongooses are most abundant (Palo Colorado and Sierra Palm). My results suggest that mongoose population control likely extends beyond YNF boundaries, thus requiring collaboration among multiple resource management agencies.

Introduction

The small Indian mongoose, *Herpestes auropunctatus* (Bennett et al., 2011; hereafter referred to as mongoose), is an opportunistic omnivore in the order Carnivora. Mongooses were introduced to sugar cane plantations throughout most of the Caribbean and Pacific Islands during the late 1800's to control rats (*Rattus* sp.; Espeut, 1882; Everard and Everard, 1992). Mongooses failed to suppress rat populations and have become detrimental to native species. Along with other introduced mammalian predators like feral cats (*Felis catus*) and dogs (*Canis lupus familiaris*), mongooses have likely contributed to declines in endangered wildlife populations in Hawaii and Puerto Rico (Hays, 1999; Engeman et al., 2006). Additionally, mongooses are recognized as a reservoir and vector for rabies, causing managers concern about disease transmission and spread (Pimentel, 1955; Nadin-Davis et al., 2008). Different management practices to control mongoose populations have been implemented but populations remain stable range-wide (Quinn and Whisson, 2005).

Mongooses have a complex social structure, diverse feeding habits, and high adaptability, with behavior differing depending on locality (Vilella, 1998). These characteristics likely make effective management strategies location-specific. For management strategies involving population control, data on population size and spatial distribution are valuable. Information on migration, fecundity, and dispersal rates provides managers insight into: 1) the amounts, types, and costs of control activities, 2) where these activities should be emphasized, and 3) whether progress towards management objectives is occurring.

El Yunque National Forest (YNF) in Luquillo, Puerto Rico, is a subtropical rainforest that is occupied by mongoose. Along with habitat loss due to anthropogenic activities, mongoose occurrence on subtropical islands has exerted a strong pressure on already threatened species (Gorman, 1975; Nellis and Everard, 1983; Nellis and Small, 1983; Watari et al., 2008). For example, mongooses occupy areas where the Puerto Rican parrot (*Amazonia vittata;* IUCN red list: Critically Endangered) has been reintroduced (Vilella, 1998). Since 2000, 6 wild parrots have fallen prey to mongooses; each individual parrot loss represents 3% of the wild population (Engeman et al., 2006). Based on analysis of stomach contents, mongoose are also known to prey on small reptiles and amphibians (Pimentel, 1955; Gorman, 1975; Nellis and Everard, 1983; Vilella, 1998), potentially aiding the extinction of some amphibian and reptile species (Seaman and Randall, 1962; Philibosian and Ruibal, 1971; Watari et al., 2008). Although mongooses are not the only threat to parrots and other native species in YNF, a plan to simultaneously integrate mongoose control into existing predator management programs (i.e., rat control) could prove effective at reducing threats to native species.

In addition to becoming the top predator in the faunal community structure of YNF, mongooses have also become a public health concern. Before the introduction of mongooses during the 1890's, Puerto Rico was likely rabies-free. Several cases of rabies in dogs and cats were documented in 1933 and subsequent studies found that mongooses were the disease vector and reservoir on the island (Pimentel, 1955; Everard and Everard, 1992).The YNF is a popular recreation destination for humans, with approximately one million visitors per year (Pedro Ríos, Ecosystem Manager, US Forest Service, *pers.comm.).* Mongoose occurrence and abundance in YNF is likely related to the frequent use of picnic areas by humans, who leave food items that attract mongoose prey (Quinn and Whisson, 2005). Hence, mongoose eradication efforts by governmental authorities have concentrated around the main picnic areas.

In Puerto Rico and other areas of the Caribbean and Pacific islands, mongooses prefer dry forests, scrub areas, and pasturelands (Pimentel, 1955; Vilella and Zwank, 1993; Vilella, 1998).Prevalence of mongoose throughout YNF likely depends on their adaptability to new environments, ability to exploit human-dominated areas, and potentially the proximity of YNF to higher quality, source habitats along the Puerto Rican coast. Current management plans for YNF include the removal of 10 to 20 mongooses from places of high human usage (U.S. Forest Service, 1997); this strategy will be more effective if informed by data on the demographics and spatial structure of the mongoose population. To establish a low cost and effective population management plan for mongoose in YNF, such information is essential to correctly identify source populations and identify colonization pathways for this species.

The objectives of this project were to: 1) compare mongoose abundance between YNF and a nearby coastal zone that potentially serves as a source population, 2) compare habitat conditions among the dominant forest types found in YNF and the coastal zone, and 3) relate the likelihood of capturing a mongoose to habitat conditions in the dominant forest types and the coastal zone. The results from my project contribute to a better understanding of mongoose distribution and ecology in eastern Puerto Rico. Ultimately this type of information can be used to implement more effective population control techniques.

Methods

Study site

El Yunque National Forest is part of the Luquillo Sierra Mountains located in northeast Puerto Rico (Figure 1.1). Elevations of YNF range from 600 to 1080m with 5,000mm of annual rainfall (Murphy and Stallard, 2012). The YNF consists of 4 forest types that are generally delineated by elevation and coarse vegetation structure (Table 1.1). Tabonuco (*Dacryodes excelsa*) forest occurred on mountain foothills with an elevation >600m; Palo Colorado (*Cyrilla racemiflora)* and Sierra Palm (*Prestoea montana*) forests occur between 600m and 850m; and the Dwarf forest (or Elfin woodlands) occurs >850m. The dry season in YNF occurs from May to October; the wet season from November to April. Mongooses disperse and breed during the dry season and females give birth during the wet season (Coblentz and Coblentz, 1985; Hays, 1999).

Rivers and associated riparian zones from YNF flow north into the Northeastern Ecological Corridor (NEC; Figure 1). The NEC encompasses 1,202ha of undeveloped land and includes 10.5 km of coastline. The NEC is composed of secondary forest and scattered wetlands, and receives an average of 1,500mm of rain annually (Murphy and Stallard, 2012). Coastal forests tend to be drier and dominated by shrub vegetation; conditions well suited for mongoose (Vilella, 1998). In addition to trapping in YNF, I also trapped the coastal forest of the NEC to compare trapping efficiency in high quality habitat.

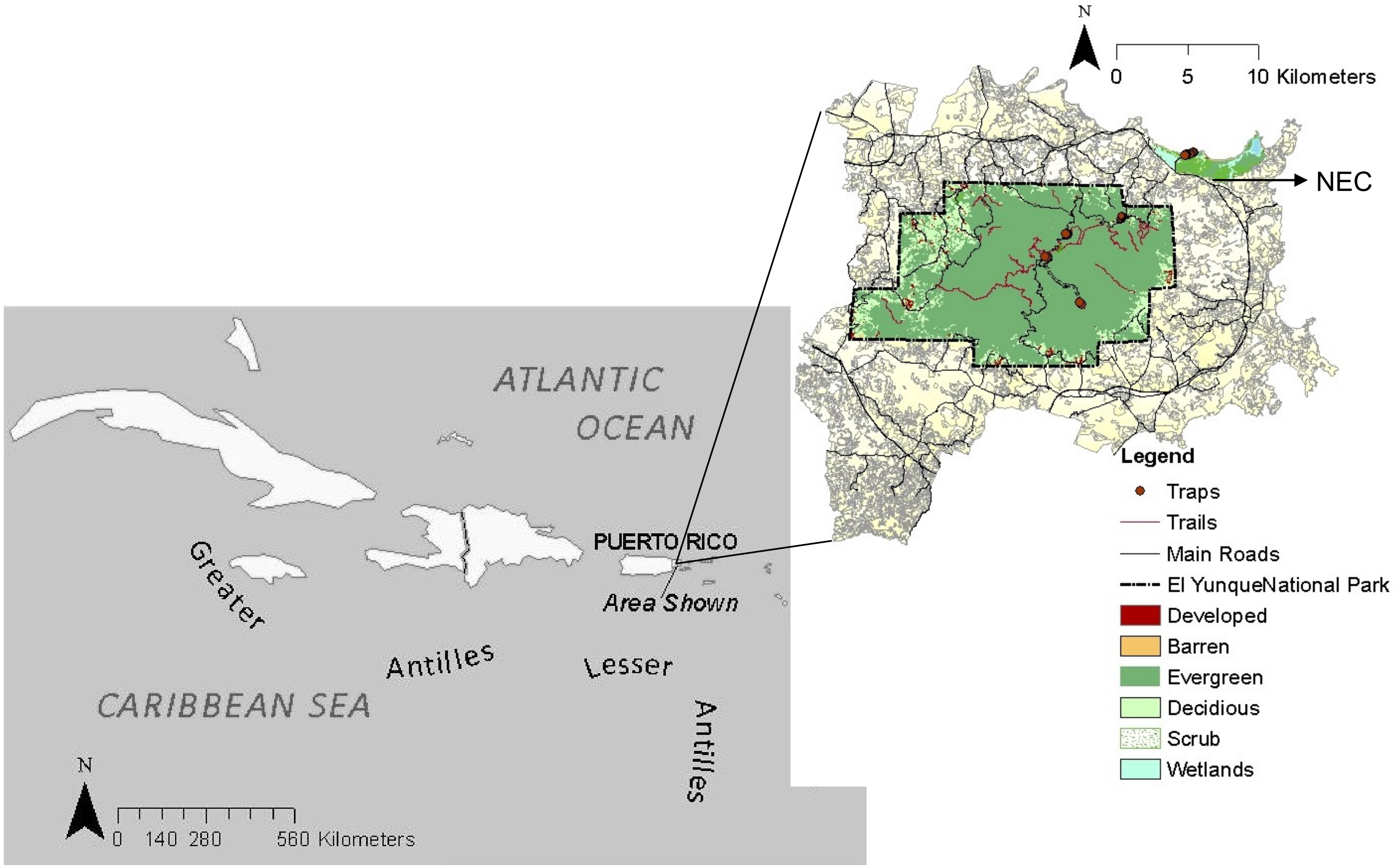

Figure 1.1. Puerto Rican archipelago and location of El Yunque National Forest (YNF) and the Northeast Ecological Corridor (NEC), eastern Puerto Rico. For interpretation of the references to color in this and all other figures, the reader is referred to the electronic version of this thesis.

Table 1.1. Forest types, coarse vegetation structure, and dominant plant species in El Yunque National Forest (YNF), Puerto Rico (Quinn and Whisson, 2005; Weaver, 2008)

Forest Type	Dominant Species	Understory (dominant)
Tabonuco	*Dacryodes excelsa*	Diverse understory that varies with location: High slopes *Cecropia schreberiana* (Pumpwood) *Sloanea berteriana* (Bullwood) *Prestoea montana* (Sierra Palm) Ridges *Cyrilla racemiflora* (Swamp titi), *Schefflera morototoni* (Morototo)
Palo Colorado	*Cyrilla racemiflora* *Prestoea montana*	Dense patches of ornamental plants: *Sanchezia speciosa* (Firecracker) *Hamelia patens* (Coral), *Bambusa vulgaris* (Bamboo) *Impatiens* sp. (Impatients)
Sierra Palm	*Prestoea montana*	Structure is similar to Palo Colorado forest. Sierra Palm can be intertwined with Tabonuco and Dwarf Forests.
Dwarf Forest	*Ocotea spathulata* *Tabebuia rigida* *Calyptranthes krugii* *Eugenia borinquensis* *Calycogonium squamulosum*	Epiphytes, Bromeliad and Fern species (*Cyathea bryophylla* and *C. arborea*). There is not a distinction between understory and canopy vegetation in this forest type. *P. montana* is also found.

Mongoose Capture and Handling

I trapped each forest type in YNF (n=4) and the coastal forest in the NEC from May to July, 2012. Site locations for trapping were based on the occurrence of representative vegetation structure of each forest type and proximity to the road or trail network to facilitate site access. At each trapping site, I deployed 25 traps at 25m spacing (125x125m) and monitored the trapping grid for 5 days. Trap locations were recorded with a handheld Garmin (Garmin International, Inc., Olathe, Kansas) global positioning system (GPS) receiver.

I used a wire Tomahawk live trap (66cm L x 22cm W x 22cm H), with easy release door baited with canned tuna to catch mongoose. Traps were opened and baited every morning before 9 am and checked and closed in the late afternoon, corresponding to the diurnal activity patterns of mongoose. Captured individuals were injected with an intramuscular solution of xylazine. The solution was prepared by combining 0.5ml of xylazine with 5ml of distilled water in a sterilized blood collection tube. Mongooses were injected with 1cc from this solution to immobilize the animal (Vilella, 1998). Each mongoose was ear-tagged with a unique numbered metal tag, sexed, and weighed (Table A1). I also recorded the condition of the fur, tooth wear, and measured body length (nose to base of tail) for each captured individual (Table A1). After mongooses recovered from the anesthesia they were released at the capture site. Forest Service personnel trapped and handled all mongooses and hence the project was deemed exempt from the Institutional Animal Use and Care Committee requirements at Michigan State University.

Habitat characteristics

I collected habitat data at each individual trap location on the day that the trap grid was established (n=25 plots per trap grid). These data included ocular estimates of understory cover (%), overstory canopy cover (%), and woody debris (%) within a 5m radius plot centered on the trap. Cover estimates were grouped into 4 categories (0%; 1-30%; 31-60%; 61-100%) and I tabulated the number of plots in each category as a measure of patch-level cover. I considered trees <60cm in height part of the understory. Woody debris ≥4cm in diameter was included in downed wood estimates. The number of cover classes used in each analysis differed because of low cell counts for some categories. In these instances, cover classes were merged.

I used Fisher's exact test (two-sided) to compare 3 classes of overstory canopy cover (0-30%, 31-60%, and 61-100%) among the 5 forest types (Agresti, 2002). I also used Fisher's exact test to compare the 4 cover categories for downed wood among the 5 forest types. Fisher's exact test provides a more robust chi-squared approximation with small expected cell counts than the chi-squared test (Agresti, 2002). I used a chi-squared test to compare 3 classes of understory cover (0%, 1-60%, and 61-100%) among the 5 forest types (Agresti, 2007).

Mark-recapture

Mongoose home ranges vary between 2 to 8 hectares, and individual home ranges likely overlap (Hays, 1999). Hence, I assumed that multiple mongoose home ranges overlapped my trapping grids. I also assumed that the mongoose population during my 5-day sampling event was closed, i.e., there were no births, deaths, immigration, or emigration. Low sample sizes and recapture rates precluded the use of sophisticated population models that account for individual and temporal heterogeneity in recapture rates. Thus, I used the bias corrected constant capture probability model (hereafter denoted as M_0; Otis et al., 1978; Rivest and Lévesque, 2001). The population model was implemented using the RCapture package for R (R Development Core Team, 2010). A characteristic of the closure assumption is that survival rates are assumed equal to one, thus the primary utility of the M_0 model is to estimate abundance (Otis et al. 1978). I estimated mongoose abundance for the tropical rainforests of YNF collectively and separately for the coastal habitat of the NEC.

Capture Frequency and Habitat

To relate the likelihood of capturing a mongoose to measured habitat characteristics, I calculated average daily capture frequencies (based on a possible 125 traps per day) for each forest type. Traps that contained non-target species or that were sprung were censored from the daily calculations. I also converted my cover estimates for overstory canopy cover, understory cover and woody debris to binary data (present or absent) at each trap location. Subsequently, the number of plots with cover present in a forest type can be viewed as a patch-level cover estimate.

Results

Habitat Characteristics

Tabonuco forest consistently had the highest overstory canopy cover (61-100% on 88% of the vegetation plots) among the 5 forest types (Figure 1.2), indicating that dense overstory canopy cover was relatively contiguous. Dwarf forest had the lowest overstory canopy cover (0-30% on 80% of the vegetation plots; Figure 1.2). Canopy cover in Palo Colorado and Sierra Palm forests was generally dichotomous, i.e., plot locations either had high or low overstory canopy cover (Figure 1.2), suggesting a patchy distribution. The coastal forest appeared to have the most diverse canopy cover among plots (Figure 1.2). The Fisher's exact test for canopy cover indicated that differences existed among the forest types ($P < 0.001$). The results indicate that I sampled a relatively complete gradient of overstory canopy cover conditions during mongoose trapping.

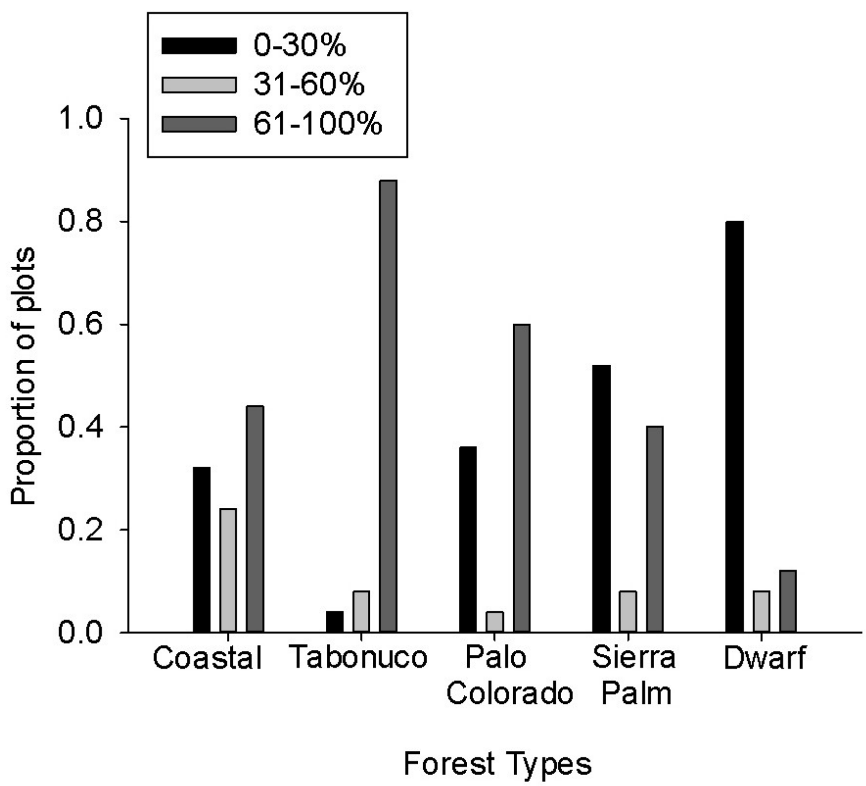

Figure 1.2. Proportion of plots in overstory canopy cover classes by forest type in El Yunque National Forest and Northeastern Ecological Corridor (i.e., Coastal), Puerto Rico, 2012.

Understory cover was highest (61-100% on 76% of the vegetation plots) in Dwarf forest and lowest (0% on 44% of the vegetation plots) in Sierra Palm (Figure 1.3). Understory cover in coastal, Palo Colorado, and Sierra Palm forests was variable among plots, with intermixed patches of 0%, 1-60%, and 61-100% cover (Figure 1.3). The chi-squared test for understory cover indicated differences among forest types (χ^2_8 = 30.57, P< 0.001). These results indicate that all forest types trapped for mongoose contained understory cover and that amount of cover at individual trap locations was highly variable (Figure 1.3).

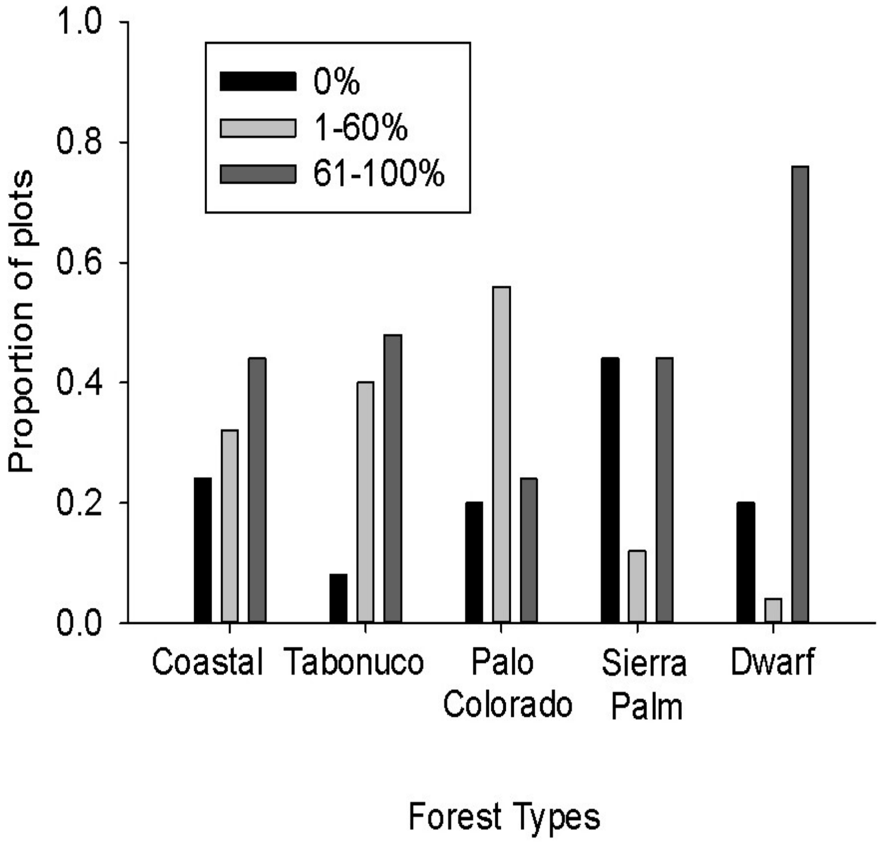

Figure 1.3. Proportion of plots in understory cover classes by forest type in El Yunque National forest and Northeastern Ecological Corridor (i.e., Coastal), Puerto Rico, 2012.

Woody debris cover was generally low among the 5 forest types I sampled, with the majority of plots containing <61-100% cover (Figure 1.4). Palo Colorado and Sierra Palm were the only forest types with some plots having high (61-100%) downed wood cover (Figure 1.4). There were differences in downed wood cover among the 4 forest types (Fisher's Exact Test; $P<0.001$). My results indicate that I trapped at locations with varying amounts of downed wood in the Tabonuco, Palo Colorado, and Sierra Palm forests types, but that downed wood was not an important component of the coastal and Dwarf types (Figure 1.4).

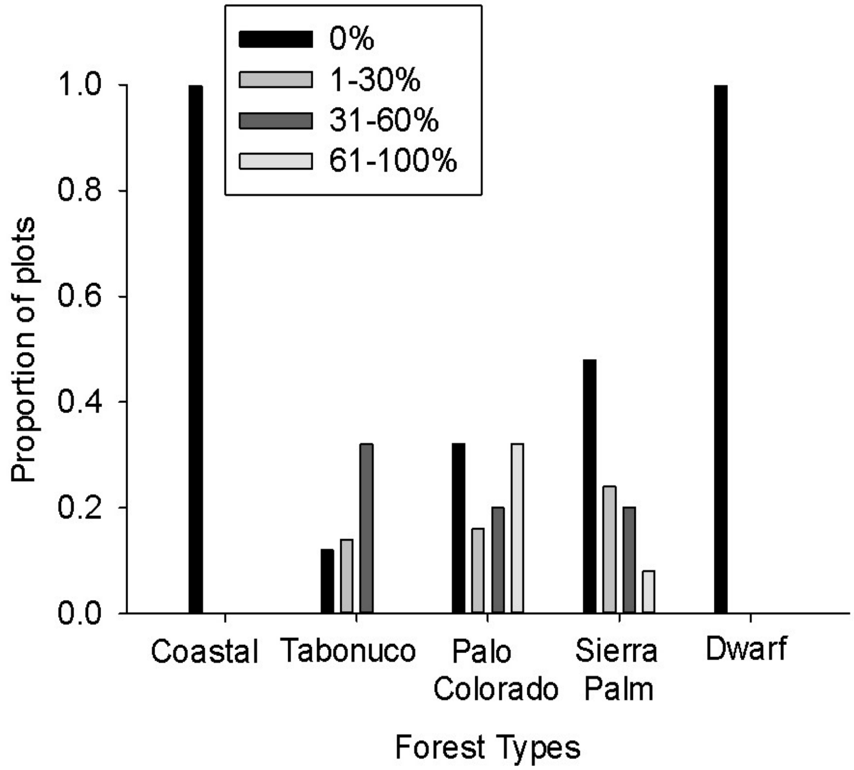

Figure 1.4. Proportion of plots for woody debris cover per forest type in El Yunque National forest and Northeastern Ecological Corridor (i.e., Coastal), Puerto Rico, 2012

Mark-recapture

I trapped 34 mongooses and recaptured 4 marked individuals (Table 1.2). The sex ratio was 1:1 (Table 1.2). On average, males were heavier (mean = 2.60kg, SE = 0.07; t_{30}= -2.708, P= .01) than females (mean = 2.20kg, SE = 0.10), however the sexes did not differ in body length (t_{30} =-0.1666, P= 0.87). Males averaged 296cm (SE =0.36) whereas females averaged 293cm (SE =0. 35). Also, mongoose weight and body size did not vary by forest type ($F_{3,33}$ = 0.75, P = 0.53 and $F_{3,33}$ =1.13, P=0.40, respectively; Table 1.3). Fifteen rats, one feral cat and 4 brown freshwater crabs (*Epilobocera sinuatifrons*) were also trapped during the study. No mongooses were captured in the Tabonuco forest so this site was not used in abundance calculations. Based on the M_0 model, I estimated that 32.3 (SE = 15.3) and 62.3 (SE = 31.3) mongoose home ranges overlapped my trapping grids in YNF and the coastal forest, respectively. Relative densities were 2.4 mongooses/ha for the four forest types in YNF and 12.2 mongooses/ha in the coastal forest of the NEC.

Capture Frequency and Habitat

The highest mongoose capture frequency (0.17 captures/day) was observed in coastal forest; lowest capture frequency (0.00 captures/day) in Tabonuco (Table 1.4). No consistent patterns in daily capture frequency of mongoose and coarse measures of vegetation were identified, suggesting that patch-level overstory canopy cover, understory vegetation, or downed wood were not correlated with trapping success. For example, overstory canopy cover was highest in coastal and Tabonuco forest types but the extremes of mongoose capture frequency were observed in these forest types (Table 1.4). Likewise, downed wood was absent from coastal and Dwarf forests, but capture frequencies were >8 times higher in coastal forest. The presence of understory cover was generally consistent among forest types (ranging from 56% to 88% of the plots) yet capture frequencies of mongoose varied considerably (Table 1.4). In my study, patch-level vegetation structure did not consistently relate to mongoose capture frequency. These results suggest that factors other than coarse vegetation are influencing mongoose catchability.

Table 1.2. Mongoose trapping results by forest type in El Yunque National Forest (i.e., Palo Colorado, Sierra Palm, and Dwarf) and coastal type in the Northeast Ecological Corridor, Puerto Rico, 2012.

	Females		Males		
Forest Type	N	Recaptures	N	Recaptures	Total
Palo Colorado	3	1	2	1	5
Sierra Palm	5	0	2	0	7
Dwarf	1	0	2	0	3
Coastal	8	0	11	2	19

Table 1.3. Average mongoose weight (SE) and body size (SE) by forest type in El Yunque National Forest (i.e., Palo Colorado, Sierra Palm, and Dwarf) and coastal type in the Northeast Ecological Corridor, Puerto Rico, 2012.

Habitat Type	Weight(kg)	Body Length(cm)
Palo Colorado	2.22 (0.07)	270 (23.4)
Sierra Palm	2.51 (0.20)	279 (20.9)
Dwarf	2.22 (0.12)	270 (46.7)
Coastal	2.45 (0.10)	308 (9.9)

Table 1.4. Average daily captures (SE) and percentage of overstory canopy cover, understory cover and downed wood by forest type in El Yunque National Forest (i.e., Palo Colorado, Sierra Palm, and Dwarf) and coastal type in the Northeast Ecological Corridor, Puerto Rico, 2012.

		Percent of coverage for all plots		
Forest	Mean daily captures (SE)	Canopy cover	Understory cover	Downed wood
Coastal	0.17(0.02)	72	76	0
Tabonuco	0.00 (0.00)	100	88	88
Palo Colorado	0.07(0.02)	68	80	68
Sierra Palm	0.06(0.02)	56	56	52
Dwarf Forest	0.02(0.00)	44	80	0

Discussion

I found that the coastal forest of eastern Puerto Rico supported a greater abundance of mongoose than the 4 forest types of YNF combined. Among the 4 tropical forest types sampled in YNF, mongooses were most frequently captured in the mid-elevation Palo Colorado and Sierra Palm types, suggesting that control activities should target these areas. My data also suggest that coarse vegetation structures associated with forest types on YNF are not related to mongoose catchability and hence, factors other than forest type and coarse vegetation must be considered. I caution that my observations of mongoose abundance and catchability may not represent broad-scale patterns across YNF because my study was spatially (5 sites) and temporally (1 summer) restricted. I recommend a more spatially and temporally extensive trapping effort to further clarify these relationships.

Mongoose population estimates in tropical forests of the Caribbean tend to be low when compared to other habitats (Pimentel, 1955; Vilella, 1998; Hays and Conant, 2007). In Puerto Rico high quality mongoose habitats tend to occur in dry and scrub areas (Pimentel, 1955; Vilella and Zwank, 1993). My findings were consistent with these studies; tropical forests of YNF supported fewer mongooses than the drier, scrubbier coastal habitat of eastern Puerto Rico. Other studies have also found that mongooses have a general tendency to avoid rainy areas in the islands of St. Croix, Trinidad (Nellis and Everard, 1983) and St. John's (Coblentz and Coblentz, 1985). The mechanism causing this pattern is not clear. Pimentel (1955) suggested that mongooses occur at lower abundances in forested areas because prey and shelter are less available however this assertion was not directly studied.

When higher quality habitats like coastal scrub are interspersed with presumably lower quality habitats like tropical forest, mongoose populations may resemble a metapopulation, with the higher quality areas serving as sources (Dias, 1996; Peles et al., 1999; Keymer et al., 2000). Although I did not document marked mongooses moving among trapping grids in my study, coastal habitats in Puerto Rico are structurally connected to YNF and hence it is conceivable that the mongoose populations in YNF and the coastal zones have intermixed. Hence, mongoose population control for YNF may need to extend beyond the national forest boundaries.

Researchers and managers often utilize forest habitat characteristics to predict occupancy of an area by a certain organism to improve trapping success or increase sightings (Baldwin and Bender, 2008; Hoffman, 2010; Erwin, 2011; Wiebe et al., 2013). In this study, mongoose capture frequency was not related to the habitat elements that I thought would correlate with mongoose habitat selection (i.e., overstory canopy cover, understory cover and woody debris). I hypothesized that these characteristics provided shelter from the heavy and frequent rains of YNF and also resulted in greater prey abundance. In YNF, I believe that mongoose abundance is more closely associated with human activity (e.g., around trails and trash) as opposed to vegetation structure. The Sierra Palm and Palo Colorado sites were closer to recreational areas and these forest types had the highest mongoose capture frequencies in YNF.

It has been proposed that mongooses use recreation areas when human activity within YNF increases, potentially exploiting food made available by poor sanitation practices (Quinn et al., 2006). Improvements in trash management have resulted in fewer mongoose sightings in YNF parks (Luis Rivera, Plant Biologist, USFS, *pers.*

comm). Mongooses do not necessarily come into direct contact with humans in these areas, but rather use recreational sites when human activity is low. Indeed, Quinn et al. (2006) and Leighton et al. (2008) found that mongooses tended to avoid direct human contact unless infected with the rabies virus. Consistent with these observations from Puerto Rico, Hussain et al. (2011) found that mongoose populations in Pakistan were higher in areas located close to villages compared to wild areas and croplands. Hussain et al. (2011) inferred that mongooses occurred in proximity to villages because of high rodent populations in the area. It is plausible that mongooses in YNF may also be attracted to recreation areas because prey may occur at higher densities in areas frequented by humans. To further understand the relationship between mongooses and recreationists on YNF, future research should explore how foods left behind by visitors are influencing mongoose prey (insects, rats and other vertebrates) and thus potentially augmenting localized mongoose populations.

I recognize several limitations to my study. The study occurred over a single season (summer 2012) therefore mongoose population estimates do not reflect fluctuations related to rainy and dry seasons. A low number of recaptures precluded the use of more sophisticated population estimation approaches and hence, I was unable to include the effects of individual animal covariates such as age, reproductive status, or sex on capture success. Nevertheless, this assessment provides the first published study using marked and released mongoose on YNF and thus offers a baseline for subsequent capture-recapture studies. Additionally, I only surveyed areas of YNF that were accessible via trails and thus my sample did not include a random sample of habitats. Hence, mongoose population status in less visited areas of the park, such as release sites for the Puerto Rican parrot, remains unknown.

Management implications

Species invasions in ecosystems have ecological, social and economic implications (Esler et al., 2010). Therefore, resource managers are expected to employ monitoring and control techniques for invasive species that are scientifically sound, consistent with the goals of the agency, and effective. The impacts of invasive mongooses on ecological, social, and economic factors has been well-documented (Nellis and Small, 1983; Coblentz and Coblentz, 1985; Watari et al., 2008; Barun et al., 2010; Fukasawa et al., 2013). For YNF, the primary management goal for mongooses is to reduce threats to humans and animals by avoiding further rabies transmission and predation on parrots. The U.S. Forest Service in Puerto Rico currently spends $10,000 a year for population control, with only two personnel trapping seasonally around recreation areas (Barun et al., 2010). Effectiveness of this control program on the larger mongoose population is difficult to quantify. Based on recommendations from different tropical islands combined with the results from my local study, I suggest several ways in which mongoose monitoring and trapping can be improved in YNF.

Mongoose population management is location- and time-specific therefore it is important to consider forest types, proximity to human disturbance, season, and mongoose breeding patterns during control programs. Hays and Conant (2007) found that mongoose trapping success declined during rainy days. Trap success may also decline when females are nursing because they use smaller home ranges (Barun et al., 2010). Trap success will likely be highest during the end of the dry season, when mongoose populations are highest and known to be dispersing for breeding (Hays, 1999). Integrating different methods for detection and removal, coupled with population targets that trigger concern, can prove effective for decreasing mongoose abundance, as demonstrated with feral cat eradications (Nogales et al., 2004).

Mongooses quickly learn to associate bait with trapping (Pimentel, 1955; Coblentz and Coblentz, 1985). Coblentz and Coblentz (1985) demonstrated that 5 days of intensive trapping reduced mongoose populations by 80% on the island of St. John. Based on my findings and if the patterns from St. John hold true for YNF, I recommend trapping in the forest types where mongoose populations were most abundant (i.e., Palo Colorado and Sierra Palm). However, as Quinn et al. (2006) noted, I caution against placing traps close to picnic cabanas when human usage is high, as mongooses tend to avoid human encounters. Also, Forest Service personnel have indicated that documenting mongooses crossing trails and subsequently trapping that location increases the chances of capture (Anastacio Gómez and Benjamín Fuentes, U.S. Forest Service Biological Technicians, *pers. comm.*), presumably because mongooses use consistent travel routes (Quinn and Whisson, 2005).

Inter-agency collaboration for long-term success in eradicating mongooses in YNF is critical. As my study suggests, effective mongoose management likely extends beyond the YNF boundary where the Forest Service does not have jurisdiction. A coordinated effort among the Puerto Rico Department of Natural Resources and USDA-Wildlife Services is needed for efficient use of resources and to accomplish population control over large areas. All of these agencies share similar goals for invasive species management, i.e., to control the introduction and spread of invasive species and where feasible, eradicate the species from the ecosystem.

APPENDIX

Table A1. Condition of mongooses (weight, length, teeth and fur) caught during May-July 2012, eastern Puerto Rico.

Forest	TagID	Weight(kg)	Length(mm)	Teeth	Fur	Sex
Palo Colorado	923	2.40	280	Good	Good	F
Palo Colorado	924	2.14	350	Good	Good	F
Palo Colorado	922	2.32	270	Good	Good	F
Palo Colorado	911	1.99	210	Good	Good	M
Palo Colorado	921	2.26	240	Worn/Missing	Thinned	M
Sierra Palm	2000	2.83	280	Worn/Missing	Good	M
Sierra Palm	1949	2.84	280	Good/Missing	Good	M
Sierra Palm	1948	3.34	340	Good	Good	F
Sierra Palm	1901	2.27	280	Good	Good	F
Dwarf	1999	2.21	350	Good	Good	M
Dwarf	1974	2.01	350	Good	Good	F
Dwarf	1926	2.44	210	Good	Good	M
NEC	1998	1.90	350	Worn	Good	F
NEC	1913	2.04	280	Good	Good	F
NEC	1980	2.69	280	Good	Good	M
NEC	1904	2.49	350	Good	Good	M
NEC	1907	2.30	270	Good	Good	F
NEC	1971	3.05	350	Good	Good	M
NEC	1918	3.04	280	Good	Good	M
NEC	1919	2.32	280	Good	Good	M
NEC	1978	1.84	280	Good	Good	F
NEC	1928	2.68	350	Worn	Good	M
NEC	1942	2.80	280	Worn	Good	M
NEC	1920	2.59	350	Good	Good	M
NEC	1972	2.44	280	Good	Good	M
NEC	1997	1.46	350	Good/Missing	Good	F

REFERENCES

REFERENCES

Agresti, A. 2002. Categorical Data Analysis. Wiley, New York.

Agresti, A. 2007. An introduction to categorical data analysis. Second ed. Wiley, New York.

Baldwin, R. A., and L. C. Bender. 2008. Distribution, occupancy, and habitat correlates of American martens (*Martes americana*) in Rocky Mountain National Park, Colorado. *Journal of Mammalogy* 89: 419-427.

Barun, A., C. C. Hanson, K. J. Campbell, and D. Simberloff. 2010. A review of small Indian mongoose management and eradications on islands. In: C. R. Veitch, M. N. Clout and D. R. Towns (eds.) International Conference on Island Invasives: Eradication and Management. p 17-25. IUCN, Auckland, New Zealand.

Bennett, C. E., B. S. Wilson, and R. DeSalle. 2011. DNA barcoding of an invasive mammal species, the small Indian mongoose (*Herpestes javanicus*; E. Geoffroy Saint-Hillaire 1818) in the Caribbean and Hawaiian Islands. Mitochondrial DNA 22: 12-18.

Coblentz, B. E., and B. A. Coblentz. 1985. Control of the Indian mongoose *Herpestes auropunctatus* on St-John, United States Virgin Islands. *Biological Conservation 33: 281-288.*

Dias, P. C. 1996. Sources and sinks in population biology. Trends in Ecology & Evolution 11: 326-330.

Engeman, R., D. Whisson, J. Quinn, F. Cano, P. Quinones, and T. H. White. 2006. Monitoring invasive mammalian predator populations sharing habitat with the critically endangered Puerto Rican parrot *Amazona vittata*. *Oryx* 40: 95-102.

Erwin, M. D. 2011. Population characteristics and habitat selection of muskrats (*Ondatra zibethicus*) in response to water level management at the Summerberry Marsh Complex, The Pas, Manitoba, Canada, Iowa State University, Ames, Iowa.

Esler, K. J., H. Prozesky, G. P. Sharma, and M. McGeoch. 2010. How wide is the "knowing-doing" gap in invasion biology? *Biological Invasions* 12: 4065-4075.

Espeut, W. B. 1882. On the acclimatization of the Indian mongoose in Jamaica. *Proceedings of the Zoological Society of London*: 712-714.

Everard, C. O. R., and J. D. Everard. 1992. Mongoose rabies in the Caribbean. *Annals of the New York Academy of Sciences* 653: 356-366.

Fukasawa, K., T. Hashimoto, M. Tatara, and S. Abe. 2013. Reconstruction and prediction of invasive mongoose population dynamics from history of introduction and management: a Bayesian state-space modelling approach. *Journal of Applied Ecology* 50: 469-478.

Gorman, M. L. 1975. The diet of feral *Herpestes auropunctatus* (Carnivora: Viverridae) in the Fijian Islands. *Journal of Zoology* 175: 273-278.

Hays, W. S. T. 1999. Annual dispersal cycle of the small Indian mongoose (*Herpestes auropunctatus*) (Carnivora: Herpestidae) in Hawai'i. *Pacific Science* 53: 252-252.

Hays, W. S. T., and S. Conant. 2007. Biology and impacts of Pacific Island invasive species. 1. A worldwide review of effects of the small Indian mongoose, *Herpestes javanicus* (Carnivora : Herpestidae). *Pacific Science* 61: 3-16.

Hoffman, J. N. 2010. Habitat characteristics affecting Allegheny woodrat (*Neotoma magister*) populations on the Chestnut Ridge in Southwestern Pennsylvania Thesis, Indiana University of Pennsylvania, Indiana, PA

Hussain, I., T. Mahmood, and M. S. Nadeem. 2011. Population estimates, habitat preference and the diet of small Indian mongoose (*Herpestes javanicus*) in Potohar Plateau, Pakistan. *Pakistan Journal of Zoology* 43.

Keymer, J. E., P. A. Marquet, J. X. Velasco ‐ Hernández, and A. L. Simon. 2000. Extinction thresholds and metapopulation persistence in dynamic landscapes. *The American Naturalist* 156: 478-494.

Leighton, P. A., J. A. Horrocks, B. H. Krueger, J. A. Beggs, and D. L. Kramer. 2008. Predicting species interactions from edge responses: mongoose predation on hawksbill sea turtle nests in fragmented beach habitat. *Proceedings of the Royal Society Biological Sciences* 275: 2465-2472.

Murphy, S. F., and R. F. Stallard. 2012. Water quality and landscape processes of four watersheds in eastern Puerto Rico. In: U. S. G. Survey (ed.) No. 1789. p 292, Professional Paper.

Nadin-Davis, S. A., J. Velez, C. Malaga, and A. I. Wandeler. 2008. A molecular epidemiological study of rabies in Puerto Rico. *Virus Research* 131: 8-15.

Nellis, D. W., and C. O. R. Everard. 1983. The biology of the mongoose in the Caribbean. *Studies of the fauna of Curacae and other Caribbean islands*, 195: 1-162.

Nellis, D. W., and V. Small. 1983. Mongoose predation on sea turtle eggs and nests. *Biotropica* 15: 159-160.

Nogales, M., A. Martín, B. R. Tershy, C. Donlan, D. Veitch, N. Puerta, B. Wood, and J. Alonso. 2004. A review of feral cat eradication on islands. *Conservation Biology* 18: 310-319.

Otis, D. L., K. P. Burnham, G. C. White, and D. R. Anderson. 1978. Statistical-Inference from capture data on closed animal populations. *Wildlife Monograms*: 7-135.

Peles, J. D., D. R. Bowne, and G. W. Barrett. 1999. Influence of landscape structure on movement patterns of small mammals. In: G. W. Barrett and J. D. Peles (eds.) Landscape ecology of small mammals. Springer, New York, NY.

Philibosian, R., and R. Ruibal. 1971. Conservation of the lizard *Ameiva polops* in the Virgin Islands. *Herpetologica* 27: 450-454.

Pimentel, D. 1955. Biology of the Indian mongoose in Puerto Rico. *Journal of Mammalogy* 36: 62-68.

Quinn, J. H., and D. A. Whisson. 2005. The effects of anthropogenic food on the spatial behaviour of small Indian mongooses (*Herpestes javanicus*) in a subtropical rainforest. *Journal of Zoology* 267: 339-350.

Quinn, J. H., D. A. Whisson, and F. Cano. 2006. Managing the Small Indian Mongoose (Herpestes javanicus) in the Midst of Human Recreation: What is the Optimal Approach? In: R. M. Timm and J. M. O'Brien (eds.) Proc. 22nd Vertebrate Pest Conference. p 393-398. University of California, Davis.

R Development Core Team. 2010. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Rivest, L.-P., and T. Lévesque. 2001. Improved log-linear model estimators of abundance in capture-recapture experiments. *Canadian Journal of Statistics* 29: 555-572.

Seaman, G. A., and J. E. Randall. 1962. The mongoose as a predator in the Virgin Islands. *Journal of Mammalogy* 43: 544-546.

U.S. Forest Service. 1997. Revised land resource management plan, Caribbean National Forest Luquillo Experimental Forest, Puerto Rico. Management bulletin R8-MB80G (USFS).

Vilella, F. J. 1998. Biology of the mongoose (*Herpestes javanicus*) in a rain forest of Puerto Rico. *Biotropica* 30: 120-125.

Vilella, F. J., and P. J. Zwank. 1993. Ecology of the small Indian mongoose in a coastal dry forest of Puerto Rico where sympatric with the Puerto Rican nightjar. *Caribbean Journal of Science* 29: 24-29.

Watari, Y., S. Takatsuki, and T. Miyashita. 2008. Effects of exotic mongoose (*Herpestes javanicus*) on the native fauna of Amami-Oshima Island, southern Japan, estimated by distribution patterns along the historical gradient of mongoose invasion. *Biological Invasions* 10: 7-17.

Weaver, P. R. L. 2008. Dwarf forest recovery after disturbances in the Luquillo mountains of Puerto Rico. *Caribbean Journal of Science* 44: 150-163.

Wiebe, P. A., J. M. Fryxell, I. D. Thompson, L. Borger, and J. A. Baker. 2013. Do trappers understand marten habitat? *Journal of Wildlife Management* 77: 379-391.

CHAPTER 2. THE INFLUENCE OF LOCALIZED HABITAT FEATURES ON MONGOOSE TRAPPING SUCCESS IN EL YUNQUE NATIONAL FOREST AND NORTHEASTERN ECOLOGICAL CORRIDOR, PUERTO RICO

Abstract

Small mammals are considered one of the most detrimental biological invaders in island ecosystems. Conservation organizations and government agencies allocate a substantial amount of resources to manage these invasive species. However, lack of published information on the effectiveness of trapping and control techniques makes it difficult for conservation managers to devise effective eradication campaigns. Trapping effectiveness for mammals is highly varied as many factors affect trapping success (e.g. biological, abiotic, and trapping methods). In this study, I focus on Puerto Rico (El Yunque National Forest) and the introduced small Indian mongoose (*Herpestes auropunctatus*). To facilitate the implementation of mongoose trapping programs, I quantified the influence of localized habitat features on individual trap success. I placed trapping grids on 5 forest types that were monitored for 5 days. At each trap I collected vegetation information (i.e., overstory canopy cover, understory cover, woody debris). I calculated distances (m) to: coastal shoreline, trails, roads (paved and unpaved), rivers, recreation areas, and also included elevation (m) for each trap location. I developed a candidate model set (each model contained uncorrelated variables) and estimated the likelihood of capturing a mongoose at a trap location using logistic regression. I included a random effect for each trapping grid to account for spatial autocorrelation among traps within the same grid. Cover estimates differed among locations (understory cover, F_4=8.4, P<0.001; overstory canopy cover, F_4=13.1, P<0.001; and woody debris, F_4=14.3, P<0.001) but that within a grid variability was low (SE<10%). On

average, traps were located closer to roads, recreational areas, coastal shorelines, and trails when compared to the broader landscape, but farther from rivers however these measurements for any given covariate were highly variable. We trapped 34 mongooses and recaptured 4 marked individuals. I found 4 competing models for describing the likelihood of capturing a mongoose at a trap location that included positive relationships to distances from rivers and recreational areas and canopy cover but negative relationships for distances to trails and coastal shoreline. The top-ranking model (27% AIC_{wt}) included proximity to rivers and this parameter was significant (P=0.003). Models revealed that vegetation features in the vicinity of traps had no influence on the likelihood of catching a mongoose. Rather, I found significant support that distance metrics were the best predictors of mongoose capture probability within a trap grid. The ability to predict where to place traps and monitoring trapping outcomes are important for reducing efforts and costs and measuring progress towards the management goal.

Introduction

The introduction and establishment of exotic invasive species is often related to loss of biodiversity and ecosystem function. The negative impacts of exotic invasive species on biodiversity varies across biomes, but over the last 20 years these species have been the primary cause of native species extinctions on islands (Millenium Ecosystem Assessment, 2005). Small mammals are considered one of the most detrimental biological invaders, especially on islands (Courchamp et al., 2003). Islands are particularly vulnerable because they often lack natural competitors and contain resources that are readily exploited (MacArthur and Wilson, 1967). Management of invasive species is often hindered by lack of information on habitat requirements, dispersal capabilities, distribution, and the role of the invasive species in the food web.

Conservation organizations and government agencies dedicate a substantial amount of resources to managing invasive species, with the majority of successful population control occurring on uninhabited and smaller islands (Oppel et al., 2011; Fukasawa et al., 2013). For example, the eradication of 43 exotic species in the Galápagos Islands resulted in the conservation of at least 198 endemic vertebrate and plant species (Donlan et al., 2003). Removal of exotic Artic foxes (*Alopex lagopus*) and red foxes (*Vulpes vulpes*) by the US Fish and Wildlife Service from the Aleutian Islands protected important seabird nesting areas in the northern hemisphere (Ebbert and Byrd, 2002). On the Amami island of Japan, several capture techniques proved effective in reducing small Indian mongoose (*Herpestes auropunctatus*) populations from 5,000-10,000 individuals in 1999 to 1,000-2,000 individuals in 2003 (Watari et al., 2008; Fukasawa et al., 2013). On bigger islands such as Hawaii, New Zealand and the

Greater Antilles, it is more difficult to exclude, control, and eradicate invasive species (Bomford and O'Brien, 1995; Courchamp et al., 2003).

Trapping effectiveness for mammals is highly varied. Many factors affect trapping success including biological (i.e., population density, age), abiotic (i.e., seasonality, weather change), and trapping protocol (i.e., bait used, layout, methods; Wiener and Smith, 1972), thus effective approaches for invasive species control is highly localized. For invasive small mammals, live trapping and poisoning are the most common methods for population management (Courchamp et al., 2003; Clout and Russell, 2006). Successful control programs for different small mammal species (e.g., mustelids (*Mustela* sp.), rats (*Rattus* sp.), house mice (*Mus musculus*), and feral cats (*Felis catus*)) have occurred on the islands of New Zealand, West Australia, Hawaii, and South Africa, among other island ecosystems (Morris, 2001; Courchamp et al., 2003; Nogales et al., 2004; Oppel et al., 2011). Few noteworthy control or eradication programs exist in the published literature for islands of the Caribbean (Table 2.1), where rats, feral cats and dogs (*Canis lupus familiaris*), house mice and small Indian mongooses (*Herpestes auropunctatus*) have been linked to native species declines.

Here, I focus on the smallest of the Greater Antilles islands in the Caribbean, Puerto Rico, and the introduced invasive species small Indian mongoose (hereafter referred to as mongoose). The mongoose is native to the Middle East and southern Asia and was first introduced to Jamaica near the end of the 19th century (Pimentel, 1955). Mongooses were subsequently transferred to other Caribbean islands to control rat populations in sugar cane plantations (Pimentel, 1955). Mongooses quickly established in these novel systems where native species were not previously threatened by a mammalian predator (Hays and Conant, 2007; Watari et al., 2008). Mongooses have been implicated with the decline and extinction of several species of reptiles, amphibians and birds in island ecosystems (Pimentel, 1955; Seaman and Randall, 1962; Nellis and Everard, 1983; Nellis and Small, 1983; Coblentz and Coblentz, 1985; Hays and Conant, 2007) and are recognized as a primary rabies vector (Pimentel, 1955). Currently, mongooses are a threat to endangered species on numerous islands (Nellis and Small, 1983; Vilella and Zwank, 1993; Engeman et al., 2006; Watari et al., 2008; Borroto-Páez, 2009), but data are lacking on the effectiveness of past or current management programs. Lack of published information on the effectiveness of control techniques makes it difficult for conservation managers to devise effective eradication campaigns (Barun et al., 2010).

In Puerto Rico, the US Forest Service and US Department of Agriculture-Wildlife Services have been the agencies overseeing mongoose control. Control efforts are concentrated in insular areas such as El Yunque National Forest (YNF). The primary concerns in YNF are protection of the Puerto Rican parrot (*Amazonia vittata;* IUCN red list: Critically Endangered; Vilella, 1998) from mongoose predation and removal of mongooses from high human use areas to avoid rabies transmission. However, no published information exists on mongoose population status or trapping efficiency in YNF. To facilitate the implementation of mongoose trapping programs I quantified the influence of localized habitat features on individual trap success.

Table 2.1. Mongoose trapping methods, duration, and results on islands of the Caribbean (Everard and Everard, 1992; Pascal et al., 1996; Barun et al., 2010).

Island	Agency	Trapping Method	Duration	Results
Josh VanDyl	JVD Preservation Society	Occasional live-trapping	Since 1970	Unknown
Jamaica	Jamaican Iguana Recovery Group	Live-trapping everyday	Since 1997	>1000[a]
St. Croix	US Wildlife Service	Live-trapping seasonal	>5yrs	Unknown
St. John	VI National Parks	Live-trapping seasonal	>5yrs	Unknown
St. Lucia	Durell Wildlife Conservatio Trust and St. Lucia Forestr Department	Live-trapping removal experiment	Unknown	Unknown
Trinidad	Agricultural Society	Bounty system	1902-1930	>150,000[a]
Guadeloupe	Public Health Agency	Unknown	One year 1977	15,787 [a]
Cuba	Nationwide	Eggs with strychnine sulfate	1981-1985	Unknown
Grenada	Unknown	Sodium fluoroacetate in cowhide	1970	Population recovered[b]

[a]Number of mongooses trapped to date since program establishment.

[b]Average mongoose densities were reduced but the population recovered six months later (Everard and Everard, 1992)

Methods

Study Site

Our study was conducted in four forest types of YNF, which is part of the Luquillo Sierra Mountains in northeast Puerto Rico (Figure 2.1). Elevations of YNF range from 600 to 1,080m with 5,000mm of annual rainfall (Murphy and Stallard, 2012). The forest types in YNF are generally based on elevation and coarse vegetation structure (Guzmán-Colón 2013:Chapter 1). Tabonuco (*Dacryodes excelsa*) forest is found at an elevation >600m; Palo Colorado (*Cyrilla racemiflora)* and Sierra Palm (*Prestoea montana*) occur between 600m and 850m; and the Dwarf forest (or Elfin woodlands) occurs >850m. There are two seasons in YNF: the dry season occurs from May to October and the wet season from November until April, although intermittent rain is common during the dry season. Tabonuco and Dwarf forests in YNF were rarely visited by tourists or US Forest Service personnel during our study, whereas Palo Colorado and Sierra Palm forests were commonly visited.

Rivers and associated riparian zones from YNF flow north into the Northeastern Ecological Corridor (NEC; Figure 2.1). The NEC is a protected area under jurisdiction of the Department of Natural Resources of Puerto Rico. The NEC is 1,202 ha of secondary forest and scattered wetlands. The climate in this coastal forest is warmer than YNF (highs in the lower 30s°C and lows in the 20s°C), averaging 10°C higher than YNF (Departamento de Recursos Naturales y Ambientales (DNRA), 2008). Mean annual rainfall in eastern Puerto Rico increases with elevation from about 1,400 millimeters (mm) in coastal forests to 5,000 mm per year at the highest locations in YNF

(Gould et al., 2006). The NEC consists of a mosaic of shrubby vegetation but is dominated (>40% of the sampled plots) by dense (61-100%) understory cover (Guzmán-Colón 2013: Chapter 1).

Mongoose Capture

In each trapping grid, I placed 25 Tomahawk live traps (Tomahawk Live Trap, Hazelhurst, WI) at 25m spacing (125x125m) and monitored the grid for 5 days. Locations for trapping grids were based on the occurrence of representative vegetation structure of each forest type and proximity to the road or trail network to facilitate site access (Figure 2.1). Trap locations within a grid were recorded with a handheld Garmin (Garmin International, Inc., Olathe, Kansas) global positioning system (GPS) receiver, and uploaded into ArcMap 10.1 (Environmental Systems Resource Institute, Redlands, California). Traps were baited with tuna every morning before 9 am, checked in the late afternoon and closed, and subsequently re-opened the following morning to coincide with the diurnal activity patterns of mongoose. For each trap location (n=25 per grid) I recorded whether a mongoose was captured or not during the 5-day trapping period.

Vegetation Structure Variables

Habitat data were collected at each individual trap on the day that trap grids were established. These data included ocular estimates (to the nearest 5%) of understory cover (%), canopy cover (%), and woody debris (%) within a 5m-radius plot centered on the trap (Table 2.2). Trees <60cm in height were considered part of the understory. Woody debris ≥4cm in diameter was included in downed wood estimates. I tested for differences in vegetation conditions among the grid locations using Analysis of Variance with Tukey pairwise multiple comparison procedures (Ott and Longnecker, 2010).

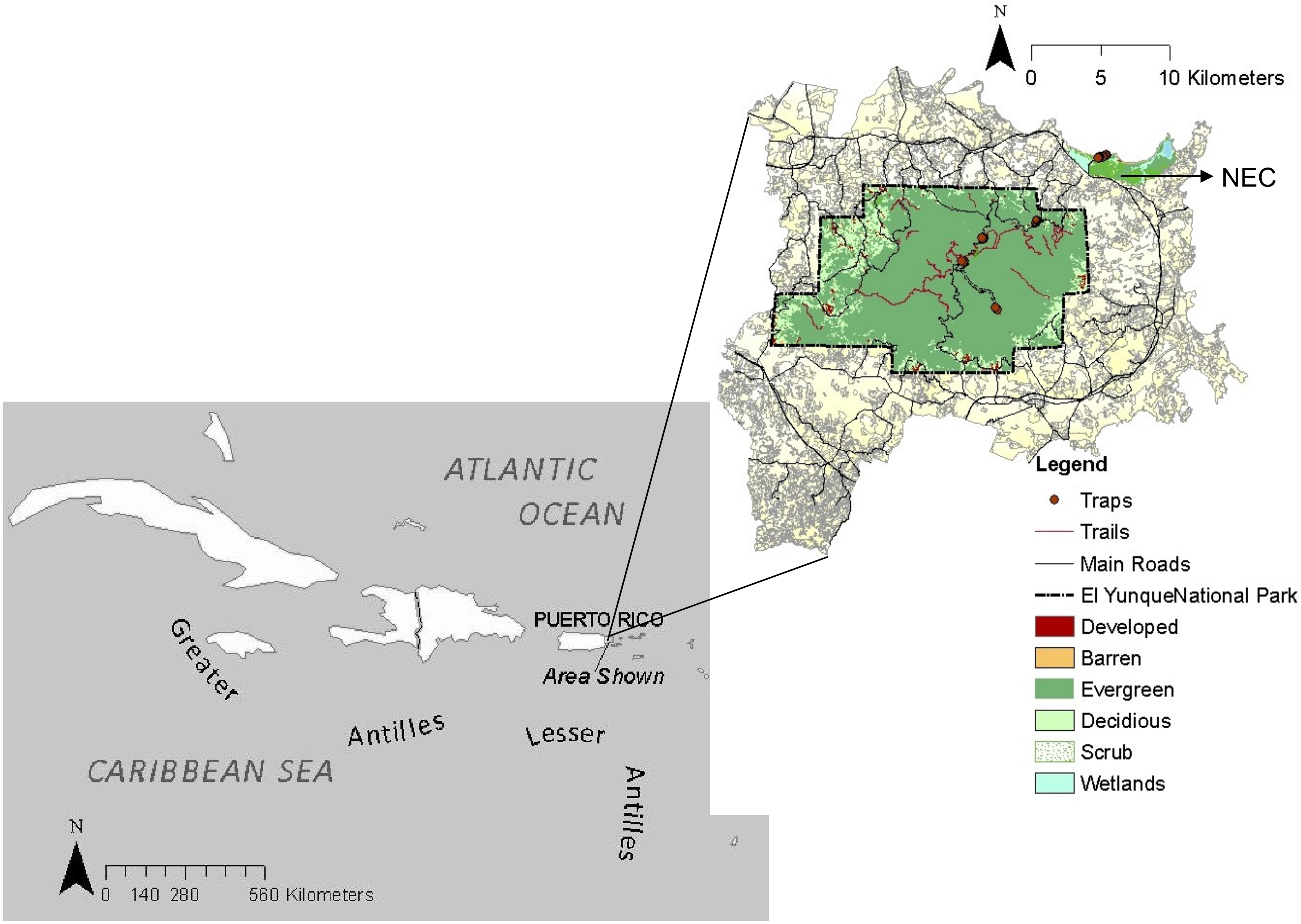

Figure 2.1. Puerto Rican archipelago and location of El Yunque National Forest (YNF) and the Northeast Ecological Corridor (NEC), eastern Puerto Rico.

Spatial Variables

I used spatial data for YNF and the NEC that were available from the US Department of Agriculture-Forest Service's International Institute for Tropical Forestry and Remote Sensing Lab. I selected spatial variables based on our knowledge of mongoose behavior and the factors that likely affect trapping success. I calculated distances (m) from each trap location to nearest: coastal shoreline, trail, road (paved and unpaved), river, and recreation area (Table 2.3). I also included elevation (m) as a potential explanatory variable.

Data Analysis

I used 9 environmental covariates (3 vegetation-based, 5 spatial, and 1 elevation) to develop a candidate model set (n=22; Table 2.4) and estimated the likelihood of capturing a mongoose at a trap location using logistic regression. Pearson's correlation was used to identify collinear covariates and only uncorrelated variables (i.e., $P>0.05$) were used in the same candidate model. Covariates were standardized using the scale function in program R (R Development Core Team, 2010). I allowed the model intercept to vary by trapping grid (n=5) to account for location-specific dependencies in the data. I used Akaike information criterion with correction for small sample size (AIC_c) to rank the candidate models and denoted parameters significant if the 95% confidence intervals did not overlap 0. I evaluated significance of models using likelihood ratio tests. The likelihood ratio test results in a chi-square statistic that compares a model with covariates to a null model. A significant result indicates that the covariate model fits the data better than the null model (Yu et al., 2011).

Results

Our vegetation sample consisted of 125 plots equally divided among 5 locations, where each location corresponded to a different vegetation type (Table 2.2). Average understory cover at trap locations ranged from 50% to 96% among the locations, with the densest understory in Sierra Palm and Dwarf forests (Table 2.2). Within a location, understory cover at individual traps ranged from low (≤30%) to high (100%; Table 2.2), however variability among traps was generally low (i.e., all SE<10%; Table 2.2) suggesting that the majority of traps were located in average understory cover conditions. I found that average understory cover differed among locations (F_4=8.4, P<0.001), with traps in Dwarf forests consistently occurring in denser understory cover (P<0.001) than in any of the other locations, with the exception of Sierra Palm (P=0.28). I also found that understory cover at individual traps was denser in Sierra Palm than in Palo Colorado forests (P=0.04). Our results indicate that understory cover differed among trapping grids but that within a grid variability was generally low (SE<10%). Low variability of understory cover within a trap grid likely explains its absence from top-ranking models for predicting mongoose capture probability at individual traps (Table 2.4).

Average overstory canopy cover ranged from 24% to 87% among locations with cover at individual traps within a location ranging from ≤30% to 100% (Table 2.2). Within a location variability was low (i.e., <9%) indicating that overstory canopy cover at most of the individual traps tended to occur around average conditions. Average overstory canopy cover differed among locations (F_4=13.1, P<0.001). Compared to Dwarf forest, all other locations had denser overstory cover (P<0.002; Table 2.2). Additionally, traps at the Tabonuco site had denser overstory canopy than the NEC (P=0.04). Our results indicate that overstory canopy cover among trapping grids differed but that low variation occurred within a trapping grid, consistent with our results for understory cover. Although overstory canopy cover appeared in a top-ranking model (Table 2.4), low variability among individual traps within a site likely precluded its significance as a predictor of mongoose trapping success at individual trap locations.

I found that coverage of woody debris was <41% for all trapping locations (Table 2.2). Downed wood around traps at the Dwarf forest and NEC locations was absent, while the average cover among the other locations ranged from 21% to 41% (Table 2.2). Woody debris cover at individual traps exhibited a wide range (low 0% to high 100) within a location, but variability among traps within a location was generally low (i.e., all SE<9%; Table 2.2). Observed differences in woody debris cover differed among trap locations (F_4=14.3, P<0.001) with cover consistently lower in Dwarf and Coastal forests than any other location on YNF (Table 2.2). I also found that cover of woody debris was higher in the Palo Colorado forest (P<0.001) than in other locations, except for Sierra Palm (P=0.11). Although woody debris cover differed among trapping grids, low variability (SE<9%) within a trap grid and the absence of woody debris on two sites (one of which (NEC) had high mongoose abundance; Guzmán-Colón 2013:Chapter 1) likely explains why woody debris cover was absent from our top-ranking models (Table 2.4).

Individual traps in our sample tended to occur farther from rivers than locations generally available in the broader landscape (Table 2.3).Conversely, occupied traps were relatively closer to roads, recreational areas, coastal shoreline, and trails than average locations in the broader landscape (Table 2.3). Trails, rivers, and roads were correlated ($P<0.01$) and hence our bias towards locating trap grids close to trails likely resulted in trapping locations that differed from those generally available in the broader landscape.

I trapped 34 mongooses and recaptured 4 marked individuals. More mongooses were caught on the NEC grid compared to all other locations combined (Guzmán-Colón 2013:Chapter 1). Mongoose capture frequency at individual traps ranged from 75% to 0%. Thirteen of 25 traps in the NEC successfully captured a mongoose during the 5-day trapping period; 2 traps had a capture frequency of 75% and 2 of 50%, while the other 9 traps had a single capture (25%). I captured mongoose at 5 traps in Palo Colorado forest, with 2 of those traps having a frequency of 50%. In the Sierra Palm and Dwarf forest grids, I trapped mongooses at 5 and 3 traps, respectively, with a single capture per trap. No mongooses were captured in the Tabonuco forest.

I identified 4 competing (i.e., $\Delta AIC<2$) models for predicting the likelihood of a trap capturing a mongoose (Table 2.4). Collectively, the competing models accounted for 58% of the evidence weight (Table 2.4). Likelihood ratio tests indicated that all models performed better than a null model ($P<0.02$). The top-ranking model (27% AIC_{wt}) was based on distance to rivers (Table 2.4); as distance to rivers increased within a trap grid, the likelihood of capturing mongoose significantly increased ($P=0.003$; Table 2.5). One competing model included the distance to rivers parameter (i.e., Overstory

Canopy Cover + Rivers) but overstory canopy cover alone did not significantly contribute to the model (P=0.50). Other competing models included: 1) distance to trails and recreation areas, and 2) distance to coastal shoreline. Parameters for the trails + recreation model were not strong predictors (i.e., P>0.06; Table 2.5), and this model accounted for only 10% of the AIC weight (Table 2.4). The coastal shoreline model (10% AIC_{wt}; Table 2.4) indicated that as distance to the shoreline increased, the likelihood of capturing a mongoose decreased (P=0.01; Table 2.5). This model likely reflects higher mongoose abundance associated with coastal forests of the NEC (Guzmán-Colón 2013: Chapter 1).

Table 2.2. Average vegetation structure in 5m radius plots centered on mongoose trap locations in El Yunque National Forest (YNF; 4 forest types) and the Northeastern Ecological Corridor (NEC), Puerto Rico, summer 2012.

	Understory Cover[a] (%)		Overstory Canopy Cover (%)		Woody Debris Cover[b] (%)	
Location	Mean (SE)	Range	Mean (SE)	Range	Mean (SE)	Range
Tabonuco forest (YNF)	54 (7)	0-100	87 (4)	30-100	21 (4)	0-60
Palo Colorado forest (YNF)	50 (7)	0-100	72 (8)	0-100	41 (8)	0-100
Sierra Palm forest (YNF)	77 (6)	30-100	75 (7)	30-100	25 (6)	0-85
Dwarf forest (YNF)	96 (4)	15-100	24 (7)	0-100	0 (0)	0
Coastal forest (NEC)	56 (9)	0-100	60 (7)	0-100	0 (0)	0

[a]Includes woody vegetation <60cm in height

[b]Includes woody debris ≥4 cm diameter

Table 2.3. Average distances for spatial covariates in El Yunque National Forest (YNF) and Northeastern Ecological Corridor (NEC), eastern Puerto Rico. The distances from traps were used in regression models. Landscape distances represent the average distances from every location throughout our assessment area.

	Distance from trap (m)		Landscape Distances (m)	
Covariate	Mean (SD)	Range	Mean (SD)	Range
Roads	815 (948)	4-2,610	936(801)	0-4,608
Elevation	434 (350)	2-1,008	404 (243)	0-1,059
Recreational Areas	3,772 (3,813)	0-10,783	5,979 (3,172)	0-15,542
Rivers	350 (365)	2-1,214	242 (179)	0-1,270
Shore	6,656 (3,681)	14-10,320	9,881 (3,969)	0-19,775
Trails	803 (1,023)	0-2,879	1,465 (1,189)	0-5,899

Table 2.4. Models for predicting the likelihood of capturing a mongoose at a trap location in eastern Puerto Rico, summer 2012. Aikake's Information Criterion adjusted for small sample size (AIC_C), difference from top-ranked model (ΔAIC_C), model weights (AICcWt), and model cumulative weights (Cum.Wt).

Covariates[a]	K	AICc	ΔAICc	AICcWt	Cum.Wt
Rivers	2	98.1629	0	0.2677	0.2677
Canopy + Rivers	3	99.8023	1.6394	0.1179	0.3857
Trails + Recareas	3	100.1596	1.9966	0.0987	0.4843
Shore	2	100.1614	1.9985	0.0986	0.5829
Under + Rivers	3	100.1885	2.0256	0.0972	0.6801
Recareas	2	101.5759	3.4129	0.0486	0.7287
Trails	2	101.7468	3.5838	0.0446	0.7733
Under + Canopy + Rivers	4	101.8684	3.7055	0.042	0.8153
Roads + Shore	3	101.9446	3.7817	0.0404	0.8557
Under + Shore	3	102.1185	3.9556	0.037	0.8927
Canopy + Recareas	3	103.5121	5.3492	0.0185	0.9112
Under + Recareas	3	103.654	5.4911	0.0172	0.9284
Wood + Elevation	3	104.3116	6.1487	0.0124	0.9408
Elevation	2	104.3511	6.1882	0.0121	0.9529
Wood	2	104.3547	6.1918	0.0121	0.965
Roads	2	105.5944	7.4314	0.0065	0.9715
Under + Canopy + Recareas	4	105.6283	7.4654	0.0064	0.9779
Under + Elevation + Wood	4	106.2514	8.0885	0.0047	0.9826
Under + Elevation	3	106.3399	8.1769	0.0045	0.9871
Wood + Under	3	106.3867	8.2238	0.0044	0.9915
Canopy	2	106.4012	8.2382	0.0044	0.9958
Under	2	106.4887	8.3258	0.0042	1

[a] Canopy = overstory canopy cover, Under = Understory cover, Wood = Cover of downed wood; Distance variables (measured as distance to nearest in m): Rivers = river, Trails = trail, Recareas = recreation area, Shore = coastal shoreline; Elevation = elevation.

Table 2.5. Top-ranking and competing (<2m ΔAICc) model parameter estimates for predicting the likelihood of capturing a mongoose at a trap location in eastern Puerto Rico, summer 2012.

Parameter	Estimate (SE)	z value	P value
Rivers	0.67(.29)	2.91	0.003
Canopy+Rivers	0.19(0.28)	0.67	0.501
	0.69(0.23)	2.97	0.003
Trails+Recareas	-0.63(0.39)	-1.61	0.107
	0.43(0.23)	1.90	0.058
Shore	-0.61(0.24)	-2.52	0.011

[a] Canopy = overstory canopy cover, Distance variables (measured as distance to nearest in m): Rivers = river, Trails = trail, Recareas = recreation area, Shore = coastal shoreline.

Discussion

I explored how localized (i.e., within a 1.6ha trapping grid) habitat features can potentially affect trapping success for mongooses. Our findings are relevant because current mongoose control efforts administered by YNF are not based on spatially explicit recommendations for trap placement. The USDA-Wildlife Services also traps mongooses in YNF and they often position traps along trails to increase capture probability, but a formal assessment of capture probability is lacking (K. VerCauteren, Research Scientist, USDA-Wildlife Services, National Wildlife Research Center, *pers. comm.*). Our candidate set of habitat features were presumably linked to how mongooses use tropical island landscapes for shelter, dispersal or food. Our models revealed that biotic features (i.e., overstory canopy cover, understory cover and amount of woody debris) in the immediate vicinity of individual traps had no influence on the likelihood of catching a mongoose. Rather, I found that distance metrics were the best predictors of mongoose capture probability within a trap grid. Mongooses were more readily caught in traps farther from rivers, closer to trails, farther from recreation areas, and closer to coastal shoreline. Our sample represented a broad range of habitat conditions in vegetation types commonly found in eastern Puerto Rico and thus our results may be broadly applicable to other areas, but I caution that our analyses were spatially restricted to the 1.6ha trapping grid.

Proximity to rivers was the most influential variable on mongoose trapping success. Nellis and Everard (1983) also observed lower population densities of mongooses near water, such as rivers, when compared to dry, tropical forests. In our study, the location of rivers was correlated with factors in other top-ranking models (e.g., distances to trails, recreation areas, and coastal shoreline) so the river effect on mongoose is likely confounded by these other factors. The mechanism associated with traps farther from rivers catching more mongoose is not clear, but literature suggests that mongooses prefer the arid habitat characteristics of their native range (Nellis and Everard, 1983; Barun et al., 2010). In tropical forests, more arid conditions are likely found away from rivers, near upper-slopes and ridge-tops. A dense river network like that in eastern Puerto Rico (Figure 2.2), may result in less habitat suitable for mongoose and therefore partially explain why mongoose abundance is generally lower in tropical forests compared to more arid coastal areas on Caribbean islands (Guzmán-Colón 2013: Chapter 1).

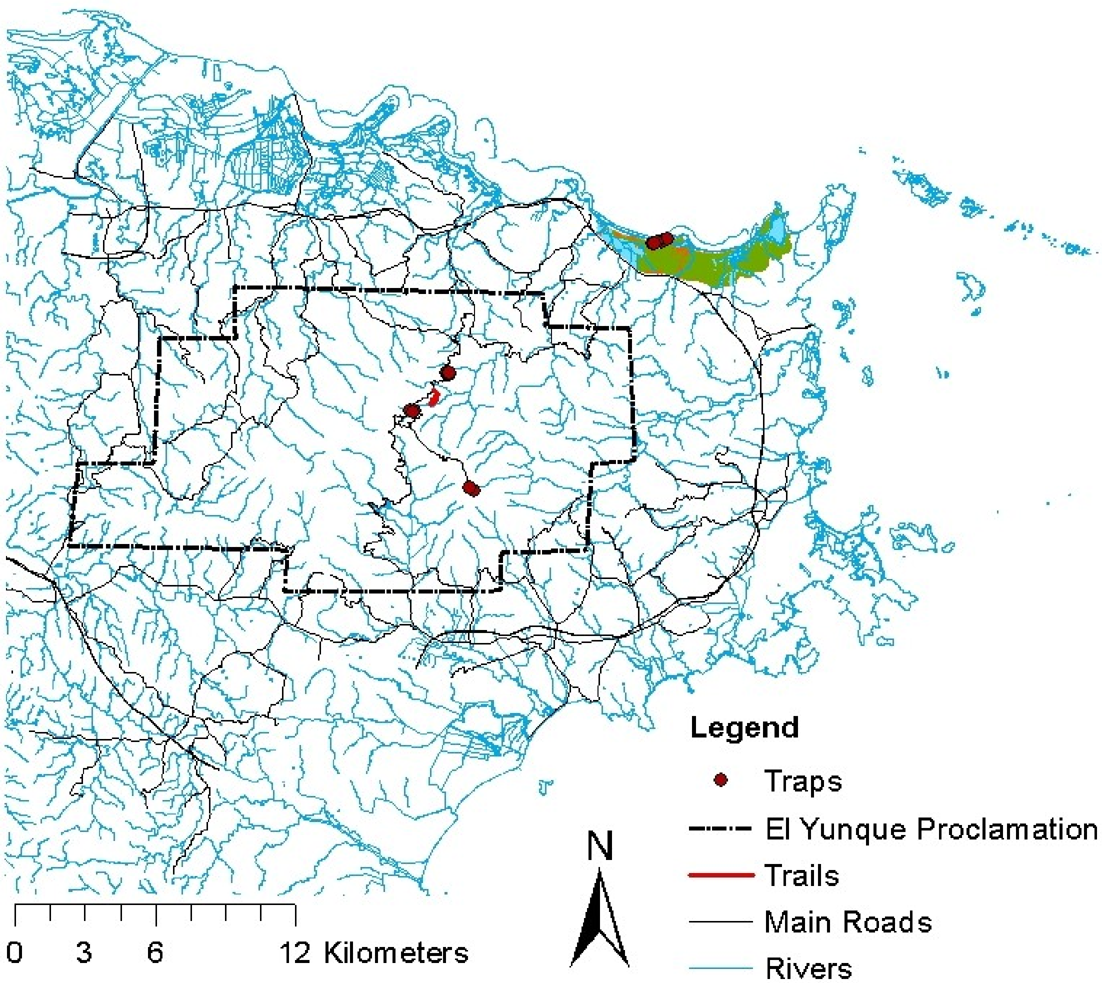

Figure 2.2.River systems of eastern Puerto Rico.

Another somewhat unexpected result was the weak correlation between proximity to trails and mongoose capture probability; however I caution that our trap grids were not randomly dispersed relative to trail locations. Rather, trap grids were purposefully placed in proximity to trails to facilitate access into remote portions of YNF. Within a trap grid that was associated with a trail, our results weakly indicate that those traps closer to the trail were more likely to capture mongooses. This finding is consistent with the approach of USDA-Wildlife Services for trapping mongoose in YNF, i.e., distribute traps along the trail network to improve capture rates.

I also found that capture probability was weakly correlated with distance to recreation areas in YNF; as proximity to recreation area increased the likelihood of a trap catching a mongoose also increased. This result was again somewhat unexpected as mongooses have been closely associated with human activities (Quinn and Whisson, 2005; Hussain et al., 2011). In fact, current mongoose control programs administered by YNF are often centered on recreation areas (Felipe Cano, USFS Biologist, *pers comm*). I believe that our observed results for both trails and recreation areas may vary depending on season. Quinn et al. (2006) found that mongoose behavior changed when tourists were abundant in the park; mongooses adopted smaller home ranges and foraged for less time to avoid direct human encounters. Our study was conducted during the summer months (May-July) when tourism in YNF is high. I posit that mongoose use habitats closer to recreation areas during the non-tourism season to exploit prey that are attracted to these areas (Quinn et al., 2006; Hussain et al., 2011) but this warrants formal investigation.

Managers responsible for invasive species control are required to maximize the benefits of limited resources with a task that likely seems impossible. Hence, information on ways to improve the efficiency of control techniques is often desired. Although our research represents limited temporal (single season) and spatial (5 locations, 1.6ha trapping grid) scopes, our findings may enhance trapping programs for mongoose on other Caribbean islands. Fine-scale vegetative conditions surrounding trap locations apparently have minimal effect on mongoose capture frequency. Rather, traps should be on the mid- and upper-slopes away from rivers and, where feasible, along trails. I also found that distance to the coast was potentially an important trapping consideration that reinforces the finding that mongoose abundance varies by forest type and hence control programs should focus on high population areas (Guzmán-Colón 2013: Chapter 1). Finally, although our research represents only one season, it is a step towards closing the gap for much needed information about localized habitat features and trapping success. It is important to keep testing assumptions about mongoose behavior and their response to habitat features, and update models and management designs. Being able to predict where to place traps and monitoring the outcomes are important to reduce efforts and costs and measure progress towards the management goal.

REFERENCES

REFERENCES

Barun, A., C. C. Hanson, K. J. Campbell, and D. Simberloff. 2010. A review of small Indian mongoose management and eradications on islands. In: C. R. Veitch, M. N. Clout and D. R. Towns (eds.) International Conference on Island Invasives: Eradication and Management. p 17-25. IUCN, Auckland, New Zealand.

Bomford, M., and P. O'Brien. 1995. Eradication or Control for Vertebrate Pests? *Wildlife Society Bulletin* 23: 249-255.

Borroto-Páez, R. 2009. Invasive mammals in Cuba: an overview. *Bioogical Invasions* 11: 2279-2290.

Clout, M. N., and J. C. Russell. 2006. The eradication of mammals from New Zealand islands. In: F. Koike, M. N. Clout, M. Kawamichi, M. De Poorter and K. Iwatsuki (eds.) Assessment and Control of Biological Invasion Risks. p 127-141. IUCN, Gland, and Cambridge, and Shoukadoh Book Sellers, Kyoto, Japan.

Coblentz, B. E., and B. A. Coblentz. 1985. Control of the Indian mongoose *Herpestes auropunctatus* on St-John, United States Virgin Islands. *Biological Conservation* 33: 281-288.

Courchamp, F., J.-L. Chapuis, and M. Pascal. 2003. Mammal invaders on islands: impact, control and control impact. *Biological Reviews* 78: 347-383.

Departamento de Recursos Naturales y Ambientales (DNRA). 2008. Plan Integral de Usos de Terrenos y Manejo de la Reserva Natural Corredor Ecológico del Noreste. p 29-79. Departamento de Recursos Naturales y Ambientales, Junta de Planificación, Puerto Rico.

Donlan, C. J., B. R. Tershy, K. Campbell, and F. Cruz. 2003. Research for requiems: the need for more collaborative action in eradication of invasive species. *Conservation Biology* 17: 1850-1851.

Ebbert, S. E., and G. V. Byrd. 2002. Eradication of invasive species to restore natural biological diversity on Alaska Maritime National Wildlife Refuge. Occasional Papers of the IUCN Species Survival Commission 27: 102-109.

Engeman, R., D. Whisson, J. Quinn, F. Cano, P. Quinones, and T. H. White. 2006. Monitoring invasive mammalian predator populations sharing habitat with the critically endangered Puerto Rican parrot *Amazona vittata*. *Oryx* 40: 95-102.

Everard, C. O. R., and J. D. Everard. 1992. Mongoose rabies in the Caribbean. *Annals of the New York Academy of Sciences* 653: 356-366.

Fukasawa, K., T. Hashimoto, M. Tatara, and S. Abe. 2013. Reconstruction and prediction of invasive mongoose population dynamics from history of introduction and management: a Bayesian state-space modelling approach. *Journal of Applied Ecol*ogy 50: 469-478.

Gould, W. A., G. González, and G. Carrero Rivera. 2006. Structure and composition of vegetation along an elevational gradient in Puerto Rico. *Journal of Vegetation Science* 17: 653-664.

Guzmán-Colón, D. 2013. Mongoose in the rainforest: Analyzing population estimates and habitat attributes to support management in El Yunque National Forest, Puerto Rico. Thesis, Michigan State University, East Lansing, MI.

Hays, W. S. T., and S. Conant. 2007. Biology and impacts of Pacific Island invasive species. 1. A worldwide review of effects of the small Indian mongoose, *Herpestes javanicus* (Carnivora : Herpestidae). *Pacific Science* 61: 3-16.

Hussain, I., T. Mahmood, and M. S. Nadeem. 2011. Population estimates, habitat preference and the diet of small Indian mongoose (*Herpestes javanicus*) in Potohar Plateau, Pakistan. *Pakistan Journal of Zoology* 43.

MacArthur, R. H., and E. O. Wilson. 1967. The Theory of Island Biogeography. Princeton University Press.

Millenium Ecosystem Assessment. 2005. Ecosystems and Human Well-being: Biodiversity Synthesis, World Resources Institute, Washington, DC.

Morris, K. D. 2001. The control of the introduced black rat on Barrow and adjacent islands off the north west coast of Western Australia. In: C. R. Veitch and M. Clout (eds.) Turning the Tide : the Eradication of Invasive Species. p 26. Invasive Species Specialist Group of the World Conservation Union (IUCN), University of Auckland, New Zealand.

Murphy, S. F., and R. F. Stallard. 2012. Water quality and landscape processes of four watersheds in eastern Puerto Rico. In: U. S. G. Survey (ed.) No. 1789. p 292, Professional Paper.

Nellis, D. W., and C. O. R. Everard. 1983. The biology of the mongoose in the Caribbean. *Studies of the fauna of Curacae and other Caribbean islands*, 195: 1-162.

Nellis, D. W., and V. Small. 1983. Mongoose predation on sea turtle eggs and nests. *Biotropica* 15: 159-160.

Nogales, M., A. Martín, B. R. Tershy, C. Donlan, D. Veitch, N. Puerta, B. Wood, and J. Alonso. 2004. A review of feral cat eradication on islands. *Conservation Biology* 18: 310-319.

Oppel, S., B. M. Beaven, M. Bolton, J. Vickery, and T. W. Bodey. 2011. Eradication of Invasive Mammals on Islands Inhabited by Humans and Domestic Animals. *Conservation Biology* 25: 232-240.

Ott, R. L., and M. Longnecker. 2010. Multiple Comparisons: Tukey's W Procedure. In: M. Taylor (ed.) An Introduction to Statistical Methods and Data Analysis. Brooks/Cole, Cengage Learning.

Pascal, M., J. F. Cosson, F. Bioret, P. Yesou, and F. Siorat. 1996. Alien species eradication and the general topic of island biodiversity restoration: The special case of Brittany island mammals. *Vie Milieu* 46: 345-354.

Pimentel, D. 1955. Biology of the Indian mongoose in Puerto Rico. *Journal of Mammalogy* 36: 62-68.

Quinn, J. H., and D. A. Whisson. 2005. The effects of anthropogenic food on the spatial behaviour of small Indian mongooses (*Herpestes javanicus*) in a subtropical rainforest. *Journal of Zoology* 267: 339-350.

Quinn, J. H., D. A. Whisson, and F. Cano. 2006. Managing the Small Indian Mongoose (Herpestes javanicus) in the Midst of Human Recreation: What is the Optimal Approach? In: R. M. Timm and J. M. O'Brien (eds.) Proc. 22nd Vertebrate Pest Conference. p 393-398. University of California, Davis.

R Development Core Team. 2010. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Seaman, G. A., and J. E. Randall. 1962. The mongoose as a predator in the Virgin Islands. *Journal of Mammalogy* 43: 544-546.

Vilella, F. J. 1998. Biology of the mongoose (*Herpestes javanicus*) in a rain forest of Puerto Rico. *Biotropica* 30: 120-125.

Vilella, F. J., and P. J. Zwank. 1993. Ecology of the small Indian mongoose in a coastal dry forest of Puerto Rico where sympatric with the Puerto Rican nightjar. *Caribbean Journal of Science* 29: 24-29.

Watari, Y., S. Takatsuki, and T. Miyashita. 2008. Effects of exotic mongoose (*Herpestes javanicus*) on the native fauna of Amami-Oshima Island, southern Japan, estimated by distribution patterns along the historical gradient of mongoose invasion. *Biological Invasions* 10: 7-17.

Wiener, J. G., and M. H. Smith. 1972. Relative efficiencies of four small mammal traps. *Journal of Mammalogy* 53: 868-873.

Yu, W., H. El Barmi, and Z. Ying. 2011. Restricted one way analysis of variance using the empirical likelihood ratio test. *Journal of Multivariate Analysis* 102: 629-640.

CONCLUSIONS

The work for this thesis involved estimating the population of mongooses in some areas of YNF and analyzing relevant habitat features related to mongoose behavior for management information purposes. Information on mongoose captures was used for exploring how localized habitat features can affect trapping success. It is important to be able to determine which features of the habitat are important for invasive species in order to start efficient population control campaigns. A strength of my research is that this assessment provides the first published study using marked and released mongoose on YNF and thus offers a baseline for subsequent capture-recapture studies, it also provides suggestions on where control activities should be targeted inside the park. However, my observations of mongoose abundance and catchability may not represent broad-scale patterns across YNF because my study was spatially and temporally restricted.

In Chapter 1 I used a set of lo-linear models proposed by Otis et al. (1978) to evaluate closed populations. I captured 34 mongooses and recaptured 4 individuals. Because of the low sample sizes and recapture rates in the study, the use of sophisticated population models that account for individual and temporal heterogeneity in recapture rates were precluded by the null model (M_0) with bias correction(Rivest and Lévesque, 2001). More powerful and informative models can be built if a constant monitoring program throughout various seasons is established. When analyzing the relationship of capture frequencies and vegetation structure, I found that patch-level vegetation structure did not consistently relate to mongoose capture frequency. These results suggested that factors other than coarse vegetation are influencing mongoose catchability, thus in Chapter 2 I explored other spatial characteristics that can potentially affect the likelihood of trapping success.

In Chapter 2 I explored the influence of localized habitat features on individual trap success. We used 9 environmental covariates (3 vegetation-based, 5 spatial, and 1 elevation) to develop a candidate model set (n=22) for estimating the likelihood of capturing a mongoose at a trap location using logistic regression. This candidate set of habitat features were presumably linked to how mongooses use tropical island landscapes for shelter, dispersal or food. From the information gathered in Chapter 1 we were expecting the results that vegetation covariates were unlikely to affect mongoose trapping success. Mongooses were frequently caught in traps farther from rivers, closer to trails, farther from recreation areas, and closer to coastal shoreline. These results provide initial insights into the factors that can be influencing mongoose trapping success, and thus warrant further investigation. Although these results can be broadly applicable to other areas in YNF, I caution that my analyses were based on a small number of locations.

Based on findings from both chapters and past research, more guidance can be provided consistent with the USDA Forest Service and Fisheries and Wildlife Service goals in regards to mongoose management. Knowing the breeding season for local mongooses, bait preference, and mongoose aggregations in the landscape have aided management campaigns in other Caribbean islands. In YNF I suggest integrating different methods for detection and removal, coupled with population targets that trigger concern, also, I recommend trapping in the forest types where mongoose populations were most abundant (e.g., Palo Colorado and Sierra Palm). However, because of the high volume of tourists in YNF, trapping on days were park visits are high might not be advisable (Quinn et al., 2006). Information on ways to improve the efficiency of control techniques is often desired, as resources for managing invasive species need to be maximized. Although our research represents a limited temporal (single season) and spatial (5 locations, 1.6ha trapping grid) scope, our findings may enhance trapping programs for mongoose on other Caribbean islands.

REFERENCES

REFERENCES

Otis, D. L., K. P. Burnham, G. C. White, and D. R. Anderson. 1978. Statistical-Inference from capture data on closed animal populations. Wildl. Monogr.: 7-135.

Quinn, J. H., D. A. Whisson, and F. Cano. 2006. Managing the Small Indian Mongoose (*Herpestes javanicus*) in the Midst of Human Recreation: What is the Optimal Approach? In: R. M. Timm and J. M. O'Brien (eds.) Proc. 22nd Vertebrate Pest Conference. p 393-398. University of California, Davis.

Rivest, L.-P., and T. Lévesque. 2001. Improved log-linear model estimators of abundance in capture-recapture experiments. Canadian Journal of Statistics 29: 555-572.