ASSESSMENT OF THE SMALL INDIAN MONGOOSE (HERPESTES AUROPUNCTATUS) IN SUSTAINING CATTLE FEVER TICK POPULATIONS IN PUERTO RICO

by

Madison Torres, B.S.

A thesis submitted to the Graduate Council of
Texas State University in partial fulfillment
of the requirements for the degree of
Master of Science
in Wildlife Ecology
December 2018

Committee Members:

Ivan Castro-Arellano, Chair

Sarah Fritts

Thomas R. Simpson

ACKNOWLEDGMENTS

First and foremost, I would like thank my thesis advisor Dr. Ivan Castro-Arellano for his continual support and guidance. I would also like to thank my committee members Dr. Sarah Fritts and Dr. Thomas R. Simpson for their mentorship. Additionally, I would like to thank Dr. Joseph Veech and Dr. Adalberto Pérez de León for their support in this project.

I also would like to thank my colleagues that assisted me in the field: Candice Rodriguez, Michelle Benavidez, Joey Martinez, Matthew Milholland, Nathan Venezio, Troy Maikis, and Andrea Villamizar.

Finally, I would like to thank my family and friends for their constant love and support.

This project was funded by the United States Department of Agriculture.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The ectoparasite *Rhiphicephalus (Boophilus) microplus*, also referred to as Cattle Fever Tick (CFT), serves as the primary vector for the protozoan pathogen *Babesia* which causes bovine babesiosis in livestock and wildlife hosts. Current management practices in Puerto Rico are failing to control CFT prevalence resulting in major economic losses for the livestock industry on this island. One factor that has not been directly addressed is the pervasiveness of the invasive Small Indian Mongoose (*Herpestes auropunctatus*) in Puerto Rico and its potential to serve as an alternate Cattle Fever Tick host. For this study, radio-telemetry and ectoparasite sampling were conducted on mongooses at five farm sites in Puerto Rico to estimate habitat use and ectoparasite prevalence. I estimated the overlap of mongoose short-term home ranges within cattle pastures and compared utilized and non-utilized habitat types within an estimated area of habitat available to mongooses. Results suggest mongooses nonrandomly select for grasslands and a portion of all mongoose short-term home range estimates overlapped with corresponding farm sites. Cattle Fever Ticks were not found on any of the sampled mongooses, suggesting the mongoose is not serving as a host for CFT populations in Puerto Rico. These results suggest continued research is needed to evaluate other potential CFT hosts to implement improved management practices. This study also provides insight on movement patterns and habitat use for the highly invasive mongoose prevalent throughout many Caribbean islands.

I. INTRODUCTION

Wildlife populations, public health, and economies worldwide are becoming severely impacted by infectious and zoonotic diseases. As globalization and human activity have increased, the occurrence and transmission of infectious diseases has followed. Within the global human population alone, 335 new infectious diseases emerged between 1940 and 2004 (Jones et al 2008).

Babesia species are tick-transmitted intraerythrocytic protozoan parasites within the class Pioplasmasida, subphylum Apicomplexa, order Piroplasmorida, and family Babesiidae (Zintl et al. 2003). There are over 100 identified species worldwide within the genus *Babesia* with documented infections that affect livestock, companion animals, wildlife, and humans. Wildlife species susceptible to infections of *Babesia* include members of canids (Family Canidae), felids (Family Felidae), raccoons (*Procyon lotor*), mongooses (Family Herpestidae), hyenas (*Crocuta crocuta*), lions (*Panthera leo*), mustelids (Family Mustelidae), viverrids, rhinoceroses (*Diceros bicornis*), elephants (*Loxodonta africana*), hyraxes (Order Hyracoidea), cervids (Family Cervidae), and bovids (Family Bovidae) (Penzhorn 2006). *Babesia* species also are known to infect at least 13 avian species worldwide (Pierce 2000). Within the genus *Babesia* there are species with high host specificity owing to distinct morphological differences, i.e. *B. microti* affects rodents and humans, *B. divergens* affects humans and cattle, and *B. major and B. bovis* only affect cattle.

Babesia species are having worldwide impacts as they are the causal agents of babesiosis, a tick-borne infectious disease that can cause severe morbidity and mortality to infected individuals. After *Babesia* parasites infect and destroy red blood cells, the specific host begins to show clinical signs of the disease. In the case of Bovine babesiosis, also known as piroplasmosis, Texas Fever, redwater, or tick fever, cattle may suffer from diarrhea, anemia, abortion, and death after infection (Zintl et al. 2003).

Vector species for *Babesia* are hard-ticks within the family Ixodidae. *Rhipicephalus* (*Boophilus*) *microplus*, also referred to as a cattle fever tick (CFT), has a one-host life cycle and transmits *B. bovis* to livestock (*Bos taurus*), the main host, and other wildlife hosts, including buffalo (*Bison bison*), horse (*Equus caballus*), dog (*Canis lupus*), donkey (*Equus asinus*), sheep (*Ovis aries*), goat (*Capra aegagrus hircus*), swine (*Sus domesticus*), and several species of deer (Family Cervidae). (Pérez de León 2012). The native range for *R. microplus* includes tropical climates within the Indian subcontinent, but the current global range includes tropical and subtropical countries in Africa, Central and South America, and Australia (Estrada-Peña 2001, Pérez de León 2012). In the early to mid 1900s, the U.S. experienced an outbreak of bovine babesiosis by way of the tick vector *Ixodes scapularis*. With collaborative efforts from the U.S. Cattle Fever Tick Eradication Program (CFTEP), established in 1906, government agencies, and livestock owners, the US was declared CFT free in 1943 and the last outbreak of bovine babesiosis was in 1949 (Pérez de León 2012). Successful management strategies for CFT and bovine babesiosis required an integrated approach that includes pasture vacation, acaracide dips, and systemic acaracides (Pérez de León 2012). Some of the challenges CFTEP faced included acaracide residue in dairy products, acaricide resistance, and the incomplete knowledge of the ecology of the vector and hosts (Rodríguez-Vivas et al. 2014).

Despite successful CFT eradication programs in mainland USA, babesiosis is still prevalent throughout several countries including many Caribbean islands. Puerto Rico, a U.S. territory, is one of the islands where CFT management is ongoing. The economic losses attributed to the tick, *R. microplus*, on Puerto Rico has been estimated at more than $20 million dollars per year (Geri et al. 1989). As a result, there is a need to understand potential modes of babesiosis transmission on the island.

Puerto Rico has no extant native terrestrial mammal species that could serve as alternative CFT hosts. Several species of mammals have been introduced to this island; namely, black rats (*Rattus rattus*), Norway rats (*Rattus norvegicus*), house mice (*Mus musculus*), dogs (*Canis lupus familiaris*), cats (*Felis catus*), donkeys, pigs (*Sus domesticus*), horses, and goats. However, these hosts are unlikely to have a strong role maintaining CFT infestations because they are under human control or their spatiotemporal overlap with cattle can be managed. Rhesus (*Macaca mulatta*) and patas (*Erythrocebus patas*) monkeys are other species that have been introduced to the island, but they occurin low numbers and are unlikely to inhabit cattle pastures as they currently have a restricted range within the island (Gonzalez-Martinez 2004).

In contrast, the invasive small Indian mongoose (SIM, *Herpestes auropunctatus*) is a small carnivore with a ubiquitous presence throughout the island and thus has the potential to help sustain and spread CFTs. Little ecological research has been conducted on the SIM (Family Herpestidae, Suborder Feliformia, Order Carnivora) in its native range, which extends throughout southern Asia. Ecological studies of SIM have been primarily done on islands where the species has been introduced as a biological control agent (Hoagland et al. 1989). The SIM is an omnivorous species with a diet consisting of rodents, reptiles, amphibians, birds, insects, and crustaceans. They were first introduced to the West Indies on Trinidad in 1870 in attempt to control the rodent populations in sugar cane fields. Mongooses have since been introduced to Jamaica, Cuba, Puerto Rico, Greneda, Barbados, St. Croix, Hawaii, Fiji, and other islands in the Caribbean for the same purpose (Hoagland et al. 1989).

The small Indian mongoose can thrive in diverse habitat types from natural forests to agricultural fields to urban areas. Mongooses often select grasslands (Nellis 1989, Viella 1998). These are ecosystems commonly used for cattle pastures (Burridge 2011) thus pointing out to a potential high spatial overlap with cattle. Additionally, mongooses and related taxa within Feliformia (i.e. civets, genets, hyaenas) have been documented to serve as hosts for several *Babesia* species (Penzhorn 2006). An ectoparasite study completed on the U.S. Virgin Islands documented 351 *H. auropunctatus* hosting 1,566 ectoparasites that included *R. microplus* individuals (Corn et al. 2009). In the Caribbean, densities of the invasive mongoose can range from 1 to 10 per ha and have a home range of 2.2 to 4.2 ha (Nellis 1989). Clearly this species is capable of attaining high densities and can move between different habitat types on these islands. Further, the mongoose is also the primary rabies reservoir in Puerto Rico and accounts for up to 74% of reported cases (Krebs et al. 2002). In spite of its importance as an invasive species, little is known about the ecology of the SIM in Puerto Rico since it only has been studied in the northwestern part of the island in the tropical forest of the Sierra de Luquillo (Quinn and Whisson 2005).

Given the combination of biological characteristics of *R. microplus* and *H. auropuncatus*, this carnivore species is potentially having a strong, and previously unrecognized, role for the maintenance of CFT infestations in Puerto Rico. Quantitatively ascertaining the contribution of Small Indian Mongoose to these infestations should be part of an integral strategy for CFT eradication and management strategies.

This study aims to assess the potential role of *H. auropunctatus* hosting CFT in Puerto Rico cattle farms using a spatially explicit approach. An overarching objective is to assess habitat use by SIM using radio-telemetry and to examine if CFTs are present in their tick loads using ectoparasite sampling. Specifically, I aim to estimate overlap of mongoose home ranges within cattle pastures, compare utilized and non-utilized habitat types within an estimated area of habitat available to mongooses, and estimate ectoparasite prevalence on mongooses sampled at five locations in Puerto Rico.

II. METHODS

Study Sites

A research collaboration involving the livestock industry in Puerto Rico, the Puerto Rico Department of Agriculture (PR-DA), and the United States Department of Agriculture (USDA) was established to develop an integrated CFT control program. (Miller et al. 2014) Five property owners volunteered to participate in the program because adult CFTs were detected on their farms. These five farms served as my study sites. My sites consisted of four dairy farms in the Puerto Rican municipalities of Lajas (18.0011890, 67.042908), Isabela (18.46116, -67.05652), San Sebastian (18.378265, 67.022423), Naguabo (18.238525, 65.719208), and one beef farm in Sabana Grande (18.036125, 66.931173) (Figure 1). The farm in Lajas was divided between two disjunct, non-adjacent cattle pastures.

Isabela and San Sebastián are located on the northwestern side of the island that borders the Atlantic Ocean. Lajas and Sabana Grande are located on the southwestern side of the island that borders the Caribbean Sea. Naguabo is located on the eastern side within mountainous terrain near El Yunque National Forest (Figure 1). Environmental factors and climate vary among the sites.

Puerto Rico is classified into 6 ecological life zones: Subtropical Dry Forest, Subtropical Moist Forest, Subtropical Wet Forest, Subtropical Rain Forest, Lower Montane Wet Forest, and Lower Montane Rain Forest; creating variation in resource availability throughout the island (Ewel and Whitmore 1973). Lajas and Sabana Grande are in the subtropical dry forest zone and have a tropical savanna climate. Isabela, San Sebastián, and Naguabo are in the subtropical moist forest and have a tropical rainforest climate with high precipitation, 1000-2200 mm of rainfall annually. Isabela is the closest to the coast and receives high winds. Naguabo has a mountainous topography and is in close proximity to El Yunque National Rainforest.

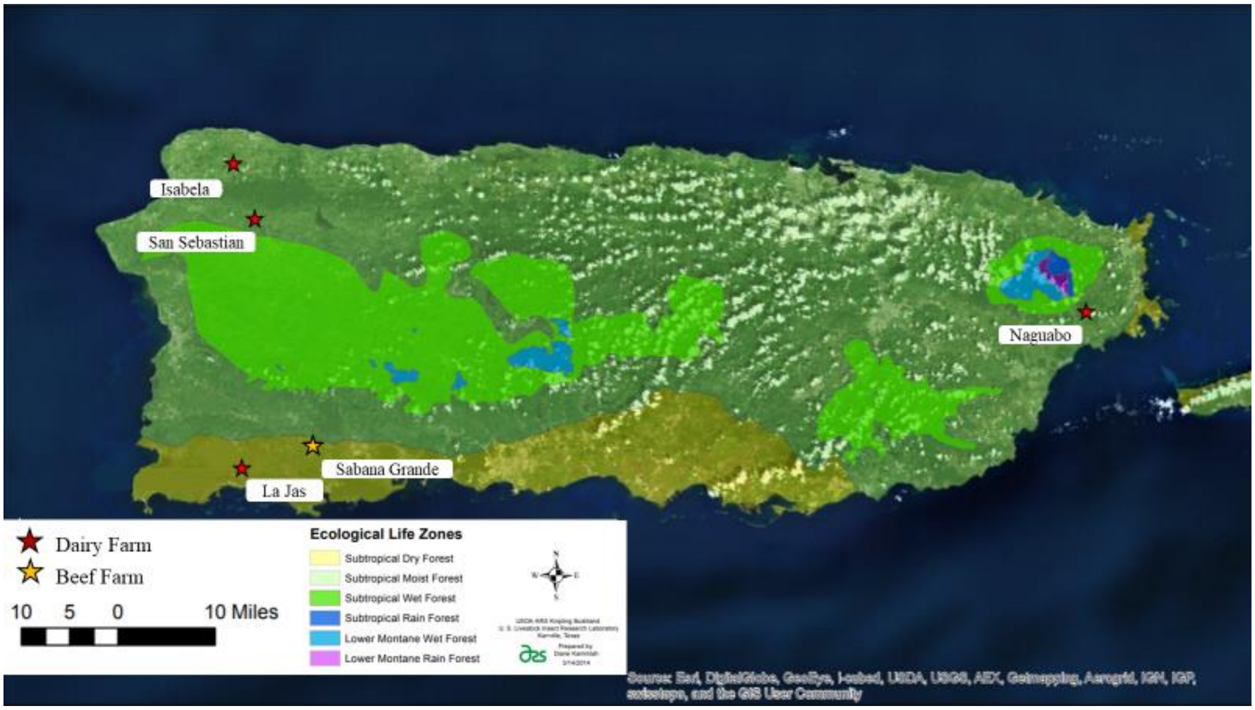


Figure 1. Ecological life zones of Puerto Rico and the locations of the five farm sites participating in the CFT control program.

Radio- Telemetry and Ectoparasite Sampling

I conducted fieldwork in three-month intervals during two summer seasons (May-August 2014 and 2015) in conjunction with other research personnel divided into two teams to allow for concurrent telemetry and ectoparasite sampling. During Season 2014, I focused on radio-telemetry at the four dairy farms with a three-week trapping effort at the end of the season for ectoparasite sampling. During Season 2015, the research team focused on ectoparasite sampling at all five farms and I conducted concurrent radio-telemetry at the Lajas site. Trapping of individuals was with medium (20"x7"x7") Tomahawk Live Traps© (Tomahawk Live Traps, Hazelhurst, WI, USA) that were set in line transects within site perimeters and baited with tuna canned in oil. Transect lines varied between 10-50 traps per line depending on the ecotone being sampled, i.e. grassland, forest edge, or riparian zones. Mongooses captured for ectoparasite sampling were euthanized with approved procedures for animal use through the Institutional Animal Care and Use Committee (IACUC) of Texas State University (Protocol #0514_0303_07) and following the American Society of Mammalogists (ASM) guidelines for working with wild mammals (Sikes et al. 2011). Euthanasia for each mongoose consisted of an initial isoflurane sedation followed by cervical dislocation. Each mongoose was thoroughly visually inspected for ectoparasites. Collected ectoparasites were sent to the National Veterinary Services Laboratories (NVSL), USDA-APHIS for identification.

Mongooses captured for radio-telemetry were sedated by an intramuscular injection (approzimately10 mg/kg) of ketamine (Ketalar, Parke-Davis & Company LLC, Morris Plains, NJ, USA) administered on-site by a licensed veterinary technician. Each mongoose was fitted with a radio collar (Model M1545, Advanced Telemetry Systems Inc., Isanti, MN, USA) weighing 16g (less than 5% of animal weight in all cases) and released at the individual's capture location. After 25 mongooses were collared among all the sites, we returned to each site for approximately two weeks to track the individuals on foot using triangulation procedures.

Capture locations and telemetry reference points were collected with a GPS unit (Garmin Montana 650, Garmin Corp., Kansas City, KS, USA) and a telemetry receiver with GPS capabilities (Model R4500S, Advanced Telemetry Systems Inc., Isanti, MN, USA), and a 3 Element Folding Yagi Antenna. GPS points were converted to decimal degrees (WGS84) for spatial analysis using the software programs Location Of A Signal (LOAS) (Biotas™ (2004). Ecological Software Solutions LLC. Hegymagas, Hungary), Google Earth Pro (Google LLC, Mountain View, CA, USA), and ArcGIS (Environmental Systems Research Institute (ESRI), Redlands, CA, USA).

The telemetry team comprised of two researchers simultaneously tracking collared individuals. The team collected triangulation points three times a day: morning, afternoon, and evening. Since mongooses are diurnal, we did not sample before sunrise or after sunset. The goal of each telemetry effort was to collect three GPS reference points with corresponding bearings towards the transmitter signal at a 90-degree angle. If triangulation was not possible due to weather or lost signal, biangulation was done using two reference points and bearings. My objective was to collect 30 sets of triangulation points per individual, which would yield 30 estimated locations (fixes) of an individual at a given time (i.e. fixes). Collared individuals with less than 20 location fixes were excluded from spatial analyses.

Spatial and Statistical Analyses

I used LOAS to derive the estimated location fix from the triangulation points using the Maximum Likelihood Estimator. If the Maximum Likelihood Estimator method failed, then the best biangulation method was implemented which calculates all intrabearing angles and select the bearings whose angle is nearest to 90 degrees defined here as the "best" angle. Outliers in the location data were removed in Google Earth by comparing the length of core activity to fix distances from activity core. If a fix was greater than half the distance of the activity core, it was considered an outlier and removed from further analyses.

In ArcGIS, I used Minimum Bounding Geometry (Type: Convex Hull) on each set of location fixes to create a Minimum Convex Polygon (MCP) short-term home range for each mongoose. A buffer zone was created around each farm site for habitat use analyses. The buffer area of 1.7 km was selected to account for the greatest maximum distance recorded between location points among all tracked mongoose individuals. I used Calculate Geometry function in ArcGIS was used to measure the area of each buffer zone, MCP, and farm site. (APPENDIX: Table 2, Figures 2-5)

The United States Geological Survey Puerto Rico National Land Cover Database (NLCD) (2001) was used for habitat classification. The 70 detailed land cover categories in the NLCD were combined into five main categories: Grasslands and Pastures (G), Shrubland and Woodland (SW), Forest (F) Urban Development (UD), and Wetlands and Freshwater (WF). The Zonal Statistics as Table tool from ArcGIS was used to calculate percent of habitat type within each buffer zone and polygon. Extract by Mask (Spatial Analyst) was used to extract habitat categories within farm buffer zones. Reclassify (Spatial Analyst) was used to obtain % suitable habitat (land covers types found in mongoose MCPs) within the farm buffer zone.

Compositional Data Analysis (CoDA) was used to compare utilized habitat (MCP) to available habitat (Farm Area). Compositional analyses accounts for dependence within percentile by using log ratios of proportions of habitat use and encompasses all MANOVA/MANCOVA – type linear models (Aebischer et al. 1993).

III. RESULTS

Twenty-nine mongooses were fitted with radio-telemetry collars. During Season I, twenty-five mongooses were collared among four farm sites: Naguabo (n = 4), San Sebastian (n = 7), Isabela (n = 5), and Lajas (n = 9). Three recaptures occurred in the first season, one at San Sebastian and two at Isabela, and eighteen collars were left on mongooses in the field. During Season II, four mongooses were collared at the site in Lajas using recovered collars from Season 2014. No recaptures occurred in the second season and all four collars were left on mongooses in the field. Approximately 1,290 triangulation points were recorded and 435 individual fix locations estimated throughout both field seasons.

Data from fourteen collared mongooses were used in the spatial analysis: five from Isabela, five from Lajas, and four from San Sebastian. Fifteen collared mongooses were excluded from the analysis, because the number of fixes was less than 20 due to loss of signal, terrain and time restraints at a site, or mortality (APPENDIX: Table 1). The Naguabo site was excluded from telemetry analysis based on geographical features as the farm was entirely surrounded by steep terrain that impeded feasible accuracy of radio-telemetry, even after numerous attempts from field crew.

Spatial Analysis

Mongoose short-term home range estimates (MCPs) varied between 7 - 89.8 ha. A portion, or all, of the fourteen MCPs overlapped with their corresponding farm sites and varied between 2% to 100% of the farm or pasture area (Table 1 and Appendix: Figure 1). Habitat composition of the five habitat types for each study site was predominantly grasslands and pastures (G) with subsequent percentages, in descending order, of shrubland and woodland (SW), forest (F), wetlands and freshwater (WF), and urban development (UD) (Table 2). Farms were on average 70% grasslands and pastures. Percent habitat composition within the fourteen mongoose MCPs was predominantly grasslands and pastures with subsequent high to low composition consisting of shrubland and woodland, forest, urban development, and wetlands and freshwater (Table 3). Four MCPs had 100% habitat composition of grassland and pastures. Figures 3-6 illustrate the habitat composition of each farm site with the corresponding composition of habitat for each mongoose MCPs.

Table 1: Minimum Convex Polygon (MCP) home range estimates for the 14 collared mongooses used for spatial analysis and the overlap area of MCP within corresponding farm sites.

Farm	Mongoose ID	Minimum Convex Polygon Area (ha)	Area of MCP overlap within farm site (ha)	% MCP overlap with farm site
San Sebastian	M044	89.8	10.0	11.1
	M184	55.5	1.1	2.0
	M243	15.3	11.6	75.8
	M284	7.0	7.0	100
Isabela	M372	6.6	6.6	100
	M383	32.0	11.3	35.3
	M394	33.9	11.2	33.0
	M423	27.5	27.5	100
	M433	34.9	14.0	40.1
Lajas P1	M324	33.7	10.2	30.3
	M463	25.4	4.6	18.1
	M273_SII	14.2	6.5	45.8
	M353_SII	43.5	35.4	81.4
Lajas P2	M223	8.5	6.4	75.3

Table 2. Total area and percent habitat composition within each farm site. (G = Grasslands and Pastures, SW = Shrubland and Woodland, F = Forest, UD = Urban Development, WF = Wetlands and Freshwater)

		Habitat Type				
Farm	**Area (ha)**	**G**	**SW**	**F**	**UD**	**WF**
San Sebastian	87.62	95.34	1.43	2.00	1.23	0.00
Isabela	105.83	98.15	0.45	0.34	1.06	0.00
Lajas P1	107.85	84.79	0.80	0.11	1.45	12.90
Lajas P2	13.98	6.29	64.52	29.03	0.00	0.16

Table 3. Percent habitat composition within the 14 mongoose minimum convex polygon (MCP) home range estimates. (G = Grasslands and Pastures, SW = Shrubland and Woodland, F = Forest, UD = Urban Development, WF = Wetlands and Freshwater)

		% MCP home range				
Farm	**Mongoose**	**G**	**SW**	**F**	**UD**	**WF**
San Sebastian	M044	77.35	2.88	10.99	8.78	0.00
	M184	75.91	20.27	1.73	2.09	0.00
	M243	82.89	2.63	8.48	5.99	0.00
	M284	100.00	0.00	0.00	0.00	0.00
Isabela	M372	100.00	0.00	0.00	0.00	0.00
	M383	82.85	12.92	3.73	0.51	0.00
	M394	74.58	18.48	6.94	0.00	0.00
	M423	100.00	0.00	0.00	0.00	0.00
	M433	81.40	14.66	3.62	0.32	0.00
Lajas P1	M324	92.57	1.47	0.40	0.00	5.56
	M463	98.34	0.00	0.00	0.00	1.69
	M273_SII	100.00	0.00	0.00	0.00	0.00
	M353_SII	99.28	0.46	0.15	0.00	0.10
Lajas P2	M223	6.87	69.47	22.39	0.00	1.27

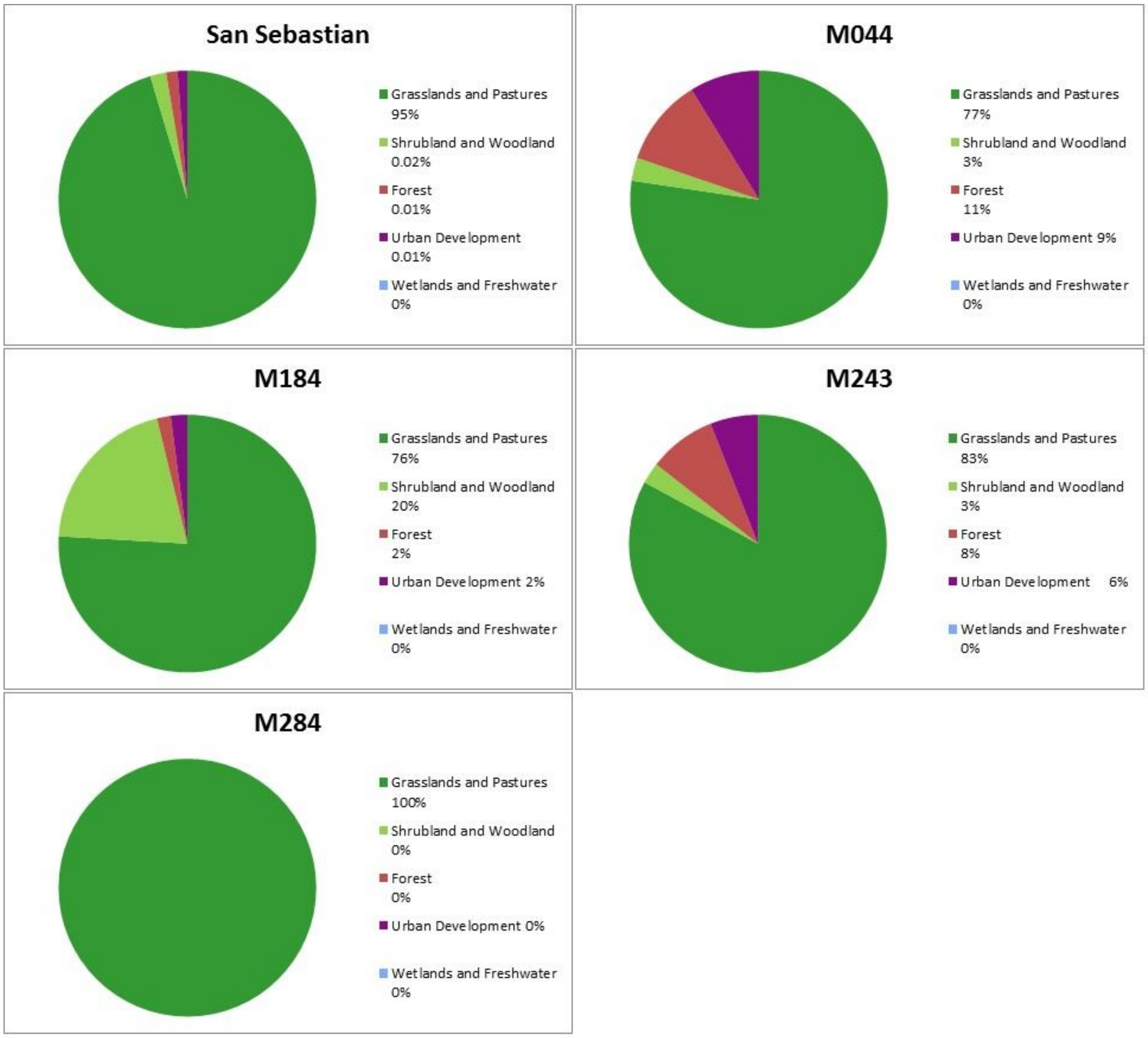


Figure 2. Habitat composition within the San Sebastián farm site (Upper left insert) and the minimum convex polygon (MCP) home ranges of the four radio-collared mongooses (individuals M044, M184, M243, and M284) from this site used in spatial analyses.

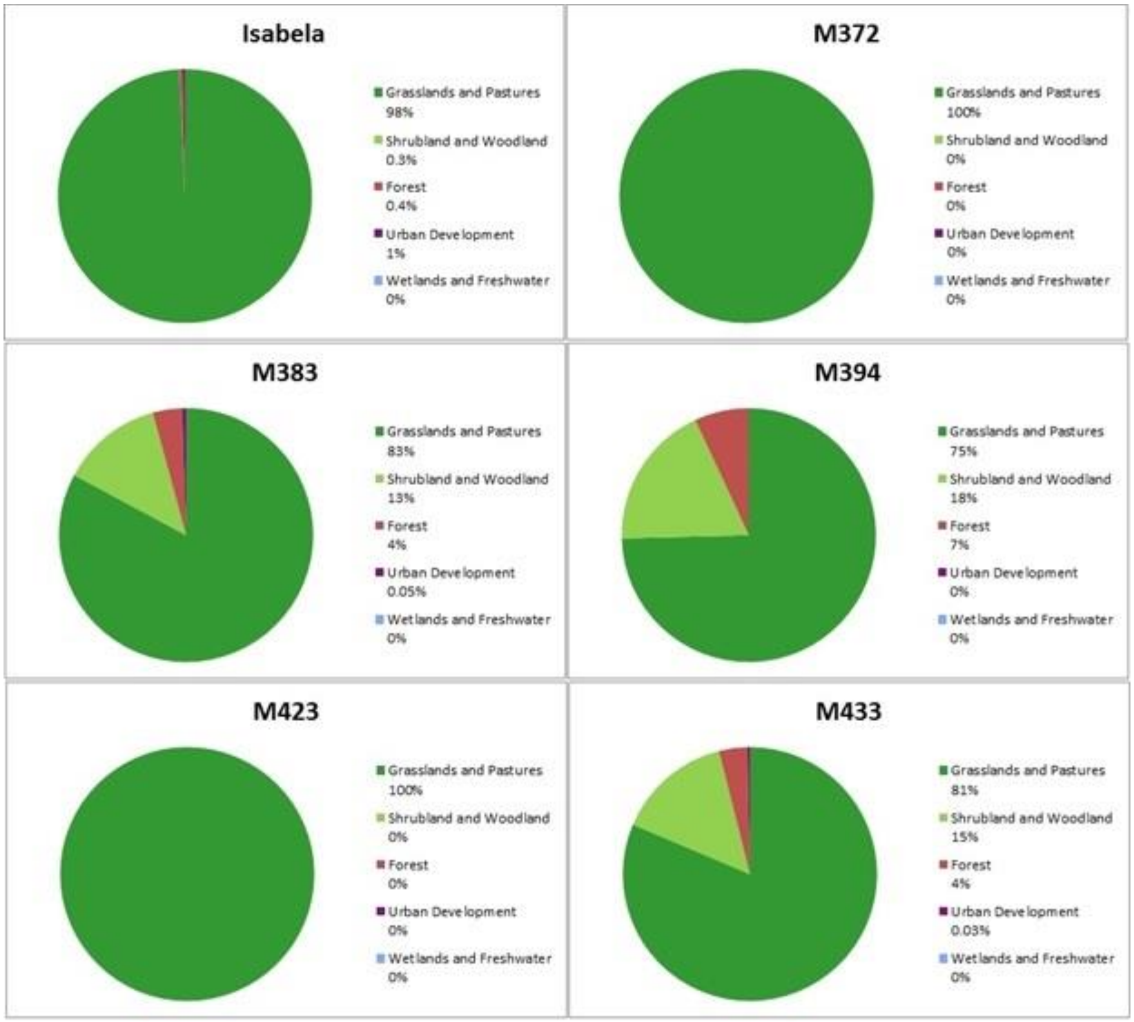


Figure 3. Habitat composition within the Isabela farm site (Upper left insert) and the minimum convex polygon (MCP) home ranges of the five radio-collared mongooses (individuals M372, M383, M394, M423, and M433) from this site used in spatial analysis.

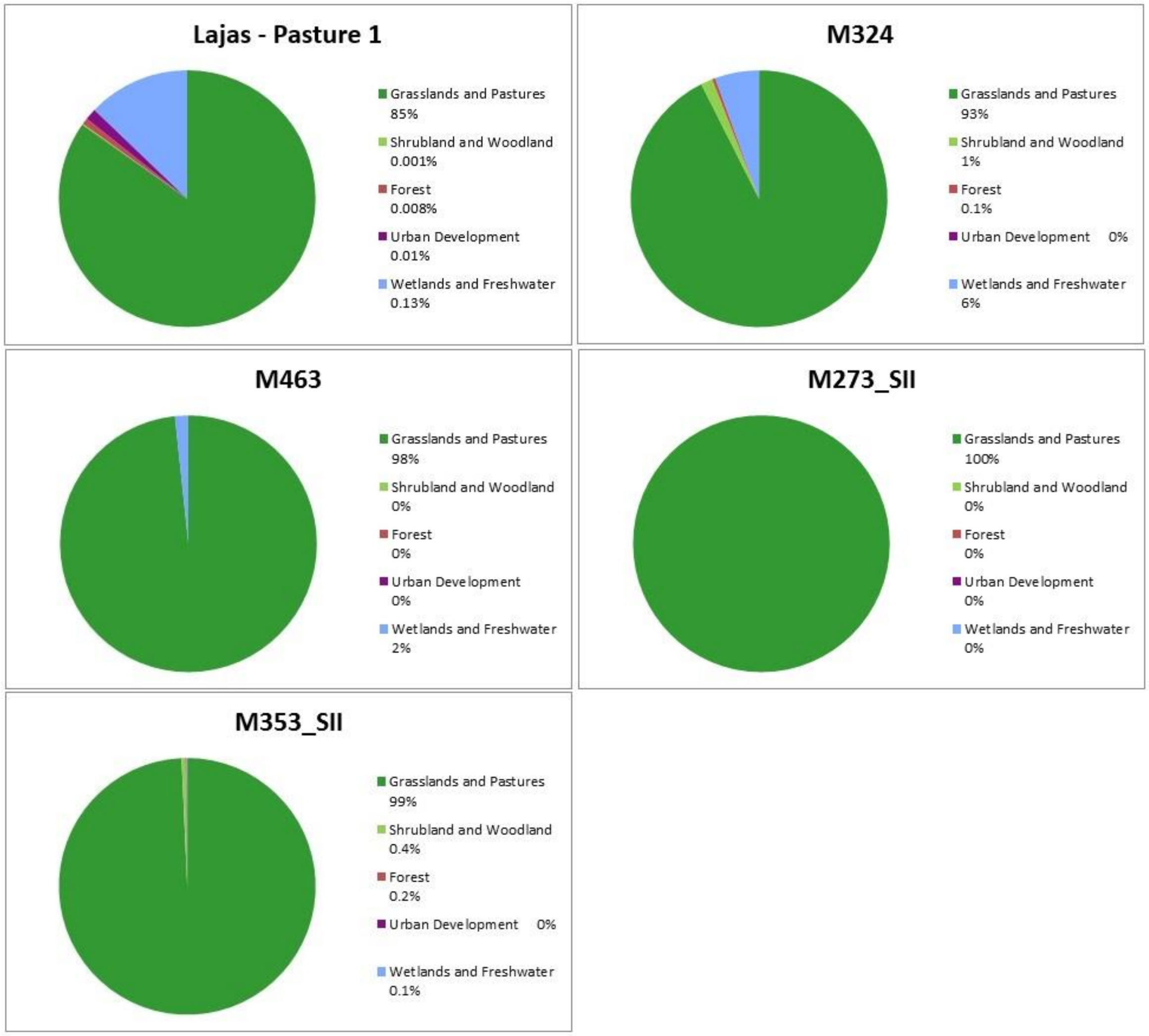


Figure 4. Habitat composition within the Lajas (Pasture 1) farm site (Upper left insert) and the minimum convex polygon (MCP) home ranges of the four radio-collared mongooses (individuals M324, M463, M273_SII, and M353_SII) from this site used in spatial analysis.

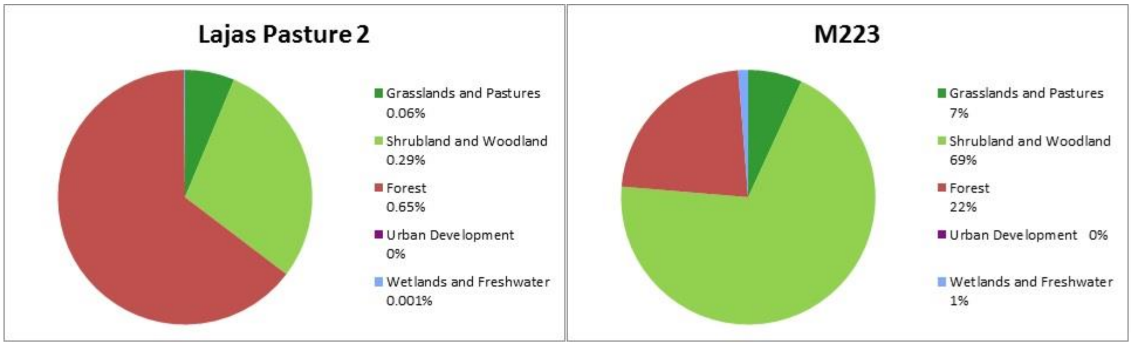


Figure 5. Habitat composition within the Lajas (Pasture 2) farm site (left) and the minimum convex polygon (MCP) home range of the one radio-collared mongoose (M223) from this site used in spatial analysis.

Statistical Analysis

For the 14 collared mongooses (***N***), I transformed the available (farm site area) and utilized (MCP home range) habitat compositions to log-ratios $\mathbf{y_0}$ and $\mathbf{y}$ using the proportion of grassland and pasture habitat (G) as the denominator, then calculated the difference $\boldsymbol{d} = \boldsymbol{y} - \boldsymbol{y_0}$ (Table 4). The hypothesis test is $\boldsymbol{d} \equiv \boldsymbol{0}$.

Table 4. Log-ratios and differences in log-ratios calculated for comparing habitat use based on minimum convex polygon (MCP) home ranges with availability in total study area.*

Log- ratios utilized habitat (*y*)				**Difference in log ratios ($\boldsymbol{d} = \boldsymbol{y} - \boldsymbol{y_0}$)**			
SW/GP	**F/GP**	**UD/GP**	**WF/GP**	**SW/GP**	**F/GP**	**UD/GP**	**WF/GP**
-3.289	-1.951	-2.176	-6.651	0.908	1.914455	2.175	0.209
-1.320	-3.784	-3.594	-6.632	2.877	0.082184	0.758	0.228
-3.450	-2.280	-2.627	-6.720	0.747	1.585929	1.725	0.140
-6.908	-6.908	-6.908	-6.908	-2.711	-3.04191	-2.556	-0.048
-6.908	-6.908	-6.908	-6.908	-1.514	-1.24241	-2.382	-0.019
-1.859	-3.101	-5.098	-6.720	3.535	2.564288	-0.572	0.169
-1.395	-2.375	-6.6145	-6.615	3.998	3.290439	-2.089	0.275
-6.908	-6.908	-6.90776	-6.908	-1.514	-1.24241	-2.382	-0.019
-1.714	-3.114	-5.529	-6.702	3.679	2.552	-1.004	0.187
-4.140	-5.440	-6.831	-2.812	0.524	1.253	-2.763	-0.926
-6.891	-6.891	-6.891	-4.066	-2.2271	-0.19895	-2.824	-2.180
-6.908	-6.908	-6.908	-6.908	-2.244	-0.216	-2.840	-5.021
-5.374	-6.473	-6.901	-6.878	-0.710	0.219	-2.833	-4.992
2.314	1.182	-4.230	-1.686	-0.014	-0.348	-0.088	1.977

*The log-ratios describing availability ($\boldsymbol{y_0}$) calculated by dividing the proportions of shrubland and woodland (SW), forest (F), urban development (UD), and wetlands and freshwater (WF) in the total study area by that of grasslands and pastures (GP), were -2.982, -3.673, -4.272, -4.825, respectively.

The generalized likelihood ratio statistic $\mathbf{\Lambda} = |\mathbf{R_1}| / |\mathbf{R_2}|$, where $\boldsymbol{R_1}$ is the matrix of mean-corrected sums of squares and cross-products calculated from $\boldsymbol{d}$ and $\boldsymbol{R_2}$ is the matrix of raw sums of squares and cross-products calculated from ***d*** (Figure 6). Then:

$$\mathbf{\Lambda} = \left|\mathbf{R}_1\right| / \left|\mathbf{R}_2\right| = \frac{\begin{vmatrix} 72.35379 & 90.18219 & 37.56807750 & 25.58358919 \\ 90.18219 & 40.59217 & 42.57378127 & 20.29578150 \\ 37.56808 & 42.57378 & 41.25141178 & -0.06052923 \\ 25.58359 & 20.29578 & -0.06052923 & 52.73850268 \end{vmatrix}}{\begin{vmatrix} 74.38577 & 332.08905 & 343.0802 & 350.61757 \\ 332.08905 & 44.26593 & 387.7457 & 387.52375 \\ 343.08022 & 387.74570 & 63.5674 & 463.72376 \\ 350.61757 & 387.52375 & 463.7238 & 59.90813 \end{vmatrix}} = 4.651094$$

Figure 6. Generalized likelihood ratio statistic results.

and $\boldsymbol{N} \ln \mathbf{\Lambda} = 14 \ln (4.651094) = 21.519$ yields $P < 0.001$ when compared to x^2 with 4 degrees of freedom. The level of significance obtained by randomization from the $\mathbf{\Lambda}$ cross-product matrix supports that habitat use by the fourteen mongooses was nonrandom.

Ectoparasite Prevalence

In total, 90 mongooses were euthanized and examined for ectoparasites. Of these, 28 were processed during Season 2014 and 62 during Season 2015, from which 378 ectoparasites were collected: 108 during Season 2014 and 270 during Season 2015. Ectoparasite samples identified by the NVSL consisted of 4 different species, predominantly Caribbean rat ticks (*Carios puertoricensis*), followed by Cat fleas (*Ctenocephalides felis*), and Domestic rat mites (*Laelaps nuttalli*), and an undetermined mite species (Table 5).

Table 5. Prevalence of ectoparasites sampled from mongooses during both field seasons.

Ectoparasites	**2014**	**2015**	**Total**	**Prevalence**
Ticks				
Carios puertoricensis	76	227	303	0.17
Mites				
Laelaps nuttalli	1	0	1	0.01
Fleas				
Ctenocephalides felis	1	20	21	0.13
Unidentified species				
Laelapidae	1	0	1	0.01

*Prevalence = number of infested animals/number of animals examined

IV. DISCUSSION

Based on my sampling of *H. auropunctatus*, it is highly unlikely the invasive mongoose is acting as a biologically meaningful host for CFT populations in Puerto Rico. The tick *Rhiphicephalus* (*Boophilus) microplus* was not found on mongoose ectoparasite loads in this study, even though this tick species has been found on livestock at all these properties. However, a previous study on St. Croix found 3 larval *R. microplus* on mongooses with a sample size of 351 mongooses (Corn et al. 2009). My study had a sample size of 90 processed mongooses; thus, a larger sample size may increase the likelihood of finding CFT on mongooses in Puerto Rico. Still, even if found on this host species it seems unlikely that they will be present in large numbers (or in many individual hosts) to be a significant factor to affect cattle production in Puerto Rico. However, given that *R. microplus* has a one-host lifecycle not limited to a single host species and may be able to persist in infected or quarantined pastures with use of an alternate host (Burridge 2011, George 1990), other potential host species at farm sites must be assessed before successful CFT management and eradication will be possible. One possible host species to consider is feral or stray dogs which are prevalent throughout the island. Pet and/or stray dogs were present on all five farm sites, many times seen moving transient between pastures. A previous study in Brazil found *R. microplus* on a sample of rural dogs (Lima de Miranda et al. 2011). While the invasive monkey species found on the island could serve as a potential host, it is likely not a probable widespread host because of the restricted distribution of the species on the island (Gonzalez-Martinez 2004).

In spite of not being a relevant host for CFT, mongooses are known reservoirs of rabies, leptospirosis, and salmonella (Dryer et al. 2014, Benavidez 2016, Jobbins et al.

2014, Miller et al. 2015), posing a threat to both wildlife and human populations. Understanding spatial movements and habitat use of the SIM is crucial to implement effective management strategies. Manually collecting radio tracking data presents inherent difficulties for spatial analyses. Potential sources of triangulation error in this study included signal interference via mountainous terrain or urban development, inaccessible adjacent property, and mongooses dispersing beyond telemetry range. For future studies, the use of GPS telemetry collars would significantly decrease bias in triangulation. Mongoose mortalities were another source of problem for my study. The majority of lost signals and all mongoose mortalities occurred at Lajas which had the most arid climate of all the sites and was surrounded by busy roads, increasing the likelihood of a vehicle hitting a mongoose and destroying a transmitter.

Minimum Convex Polygon was chosen as the home range estimator to look at movement across a landscape and include the outer limits of mongoose ranges. Small Indian mongoose MCP estimates of 7 - 89.8 ha were consistent with SIM home range sizes from previous studies which vary from 1.1 ha to over 100 ha, as found in a study on lava fields in Hawaii which ranged from 8-191 ha (Keith et al 1986), a study in Fiji which found ranges 22 to 39 ha (Gorman 1979), and a study in St. Croix which found averaged home ranges of 2.2 - 4.2 ha (Nellis and Everard 1983). Another radio-telemetry study conducted on SIM in Puerto Rico estimated home ranges between 3.9-19.4 ha (Quinn 1998). The smaller home range size and low variation in this latter study may be explained by a greater concentration of food and availability of resources at the study’s site location in El Yunque rainforest. Mongooses may have to travel farther distances and utilize more time to find sufficient resources in open cattle pastures and more arid sites.

The study sites used in the habitat composition analysis were divided into two of the ecological lifezones: Subtropical Wet Forest and Subtropical Dry Forest. San Sebastian and Isabela, both in the subtropical wet zone, had the greatest habitat composition of grasslands and pastures. Lajas (Pasture 1 and Pasture 2), found in the subtropical dry zone, had lower habitat composition consisting of grasslands and pastures. The greater annual precipitation in subtropical wet forests is a primary factor for the differences of habitat composition when compared to sites occuring in the dry forest. Agriculture in the subtropical dry zone relies heavily on irrigation systems due to low annual precipitation (Ewel and Whitmore 1973). Lajas had an extensive irrigation system and was the only site in which wetlands and freshwater comprised a portion of the habita. Also, the irrigation system at Lajas could potentially serve as areas of increased zoonotic disease transmission as it creates a limited shared source of water for wildlife.

Compositional analysis indicated mongooses non-randomly selected grasslands and pastures as a major component of their utilized habitat. Thirteen of the fourteen mongoose MCPs were comprised of greater than or equal to 75% grasslands and pastures. One mongoose with low association with grasslands and pastures was tracked in Lajas Pasture 2, the smallest pasture primarily comprised of (>60%) shrub land and woodland. The average overlap of MCPs within farm area was 53.4% and three mongoose MCPs were completely within their corresponding farm perimeter. Based on the spatial analysis and overlap between MCPs and farm sites, it is evident mongooses will utilize cattle pastures as a portion of their home range.

Other studies have found that mongooses have an affinity for human associated habitats such as farms because of increased food availability (Mahmood et al. 2011, Miller et al. 2015). A study by Mahmood et al. (2011) found mongooses preferred poultry farms likely due to the availability of different species of rodents as a food source. Due to the high density of livestock and rodents, farms and cattle pastures are likely a source of disease for mongooses (Miller et al. 2015).

Understanding habitat preferences of the SIM will aid in the advancement of zoonotic disease management programs such as the ongoing development of an oral rabies vaccination program for mongooses on Puerto Rico (Johnson et al. 2016). In addition to the development of such programs, control of mongoose populations on the island needs to be intensified and efforts increased to promote public awareness about the threats the mongoose poses for wildlife and human health.

This research suggests the Small Indian Mongoose is not spreading and maintaining Cattle Fever Tick populations and provides a baseline for mongoose habitat use in different localities in Puerto Rico. Ecological information on the SIM mongoose in Puerto Rico is still limited. More studies need to be conducted on this invasive species to fill knowledge gaps and better understand its impact on ecological systems and implications for zoonotic diseases.

APPENDIX SECTION

Provided below is data collected for each collared mongoose, estimated area of the buffer zones, and images illustrating MCP and farm overlap, along with an aerial view of each farm site used in the spatial analysis with their corresponding MCPs and buffer zones.

Appendix Table 1. Sex, body mass, number of telemetry fixes*, and recapture (R), non-recapture (--), and mortality (M) events for all radio-collared mongooses. *(X indicates lost signal)

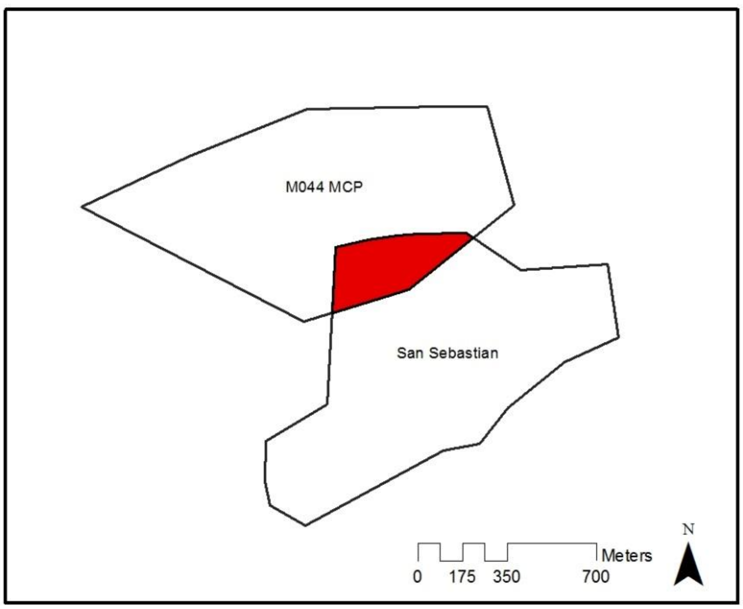
Site/Mongoose ID	Sex	Body Mass (g)	# Fixes	Recapture or Mortality
Naguabo				
M022	M	660	0	--
M343	M	600	0	--
M334	F	525	0	--
M474	M	800	0	--
San Sebastian				
M184	M	725	29	--
M243	F	450	33	R
M453	M	800	2	--
M314	M	700	2	--
M044	M	700	32	--
M362	M	830	0	--
M284	F	475	31	--
Isabela				
M423	M	650	29	R
M383	M	600	28	--
M394	M	745	26	--
M433	M	700	27	--
M372	F	500	27	R
Lajas Season I				
M353	M	800	X	M
M055	F	550	4	--
M273	F	630	X	M
M443	M	730	X	M
M414	M	650	X	M
M163	M	760	0	--
M223	M	730	33	--
M463	F	550	34	--
M324	M	880	20	--
Lajas Season II				
M273	M	570	32	--
M372	M	700	7	--
M353	M	690	29	--
M443	M	520	0	--

Appendix Table 2. Total area of 1.7km buffer zones around each farm site.

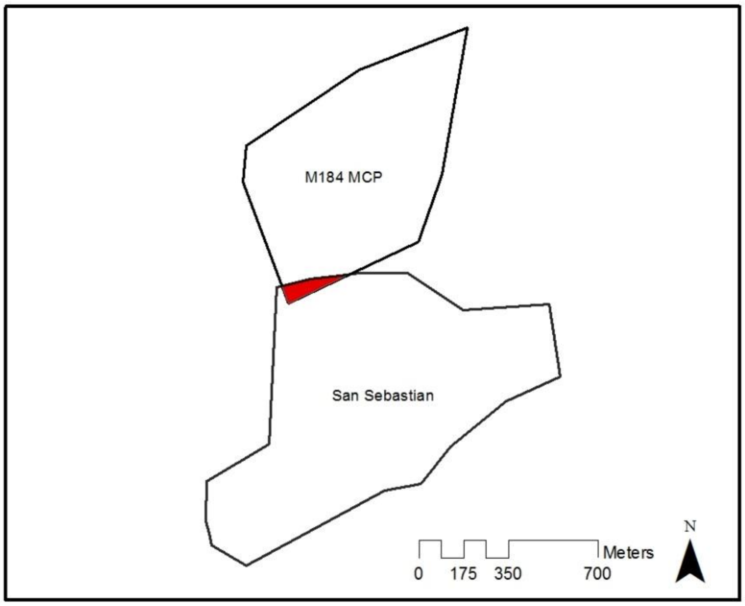
Site	Buffer Area (ha)
Isabela	1840.041351
San Sebastian	1693.33186
Lajas Pasture 1	1834.055879
Lajas Pasture 2	1202.592745

Appendix Figure 1. (A-N) Shown in red is the area of overlap between each mongoose minimum convex polygon (MCP) and corresponding farm site.

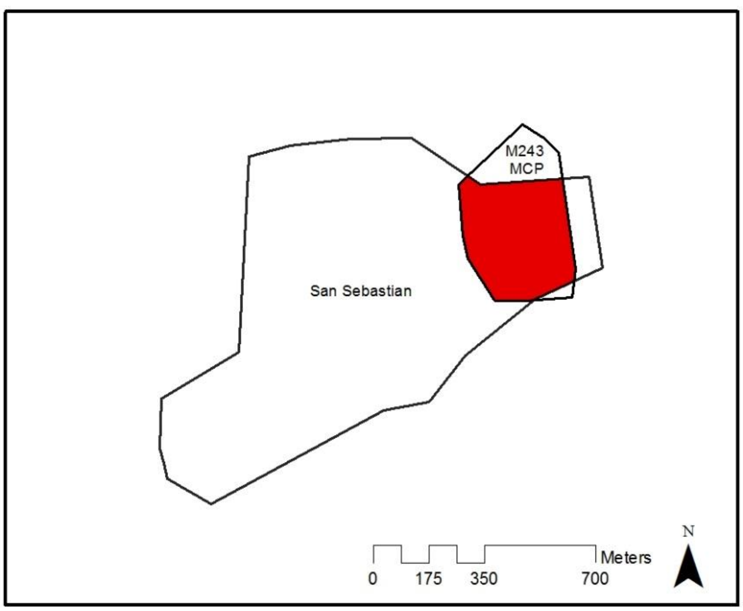
A.



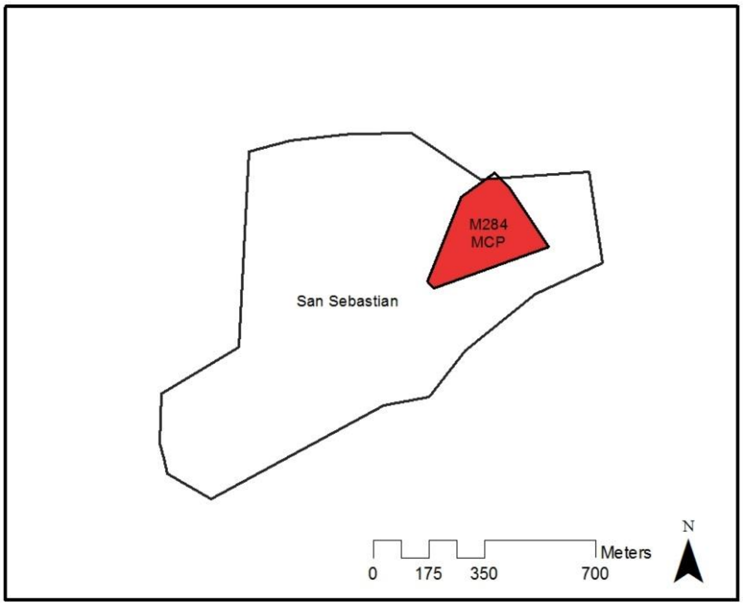
B.


M184 MCP
San Sebastian
Meters
0
175
350
700
N

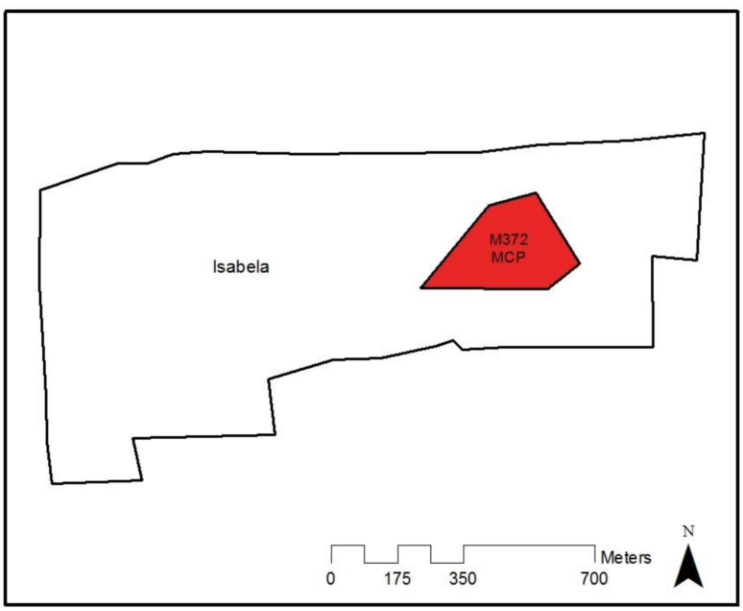
C.


M243
MCP
San Sebastian
Meters
0
175
350
700
N

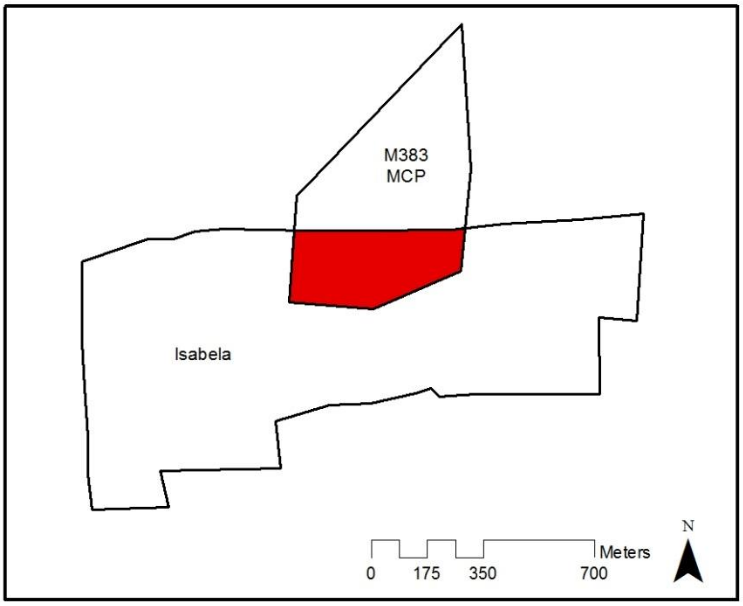
D.


M284
MCP
San Sebastian
0
175
350
700
Meters
N

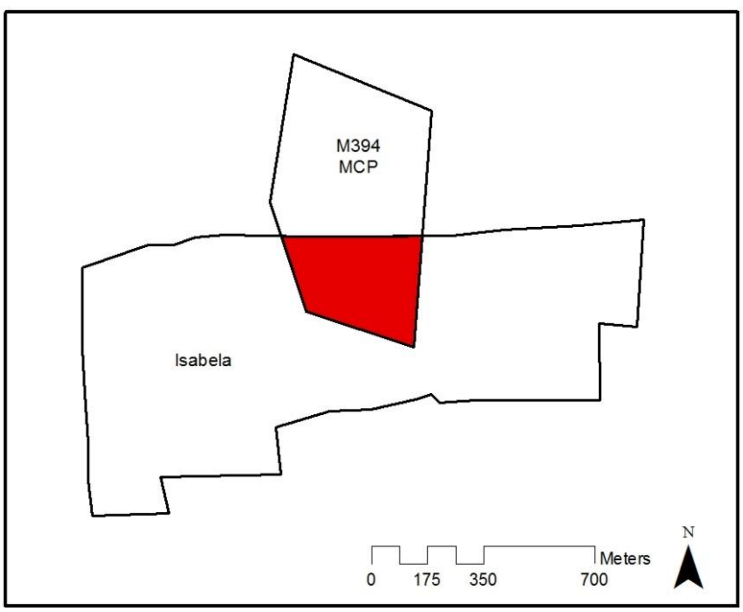
E.


M372
MCP
Isabela
0
175
350
700
Meters
N

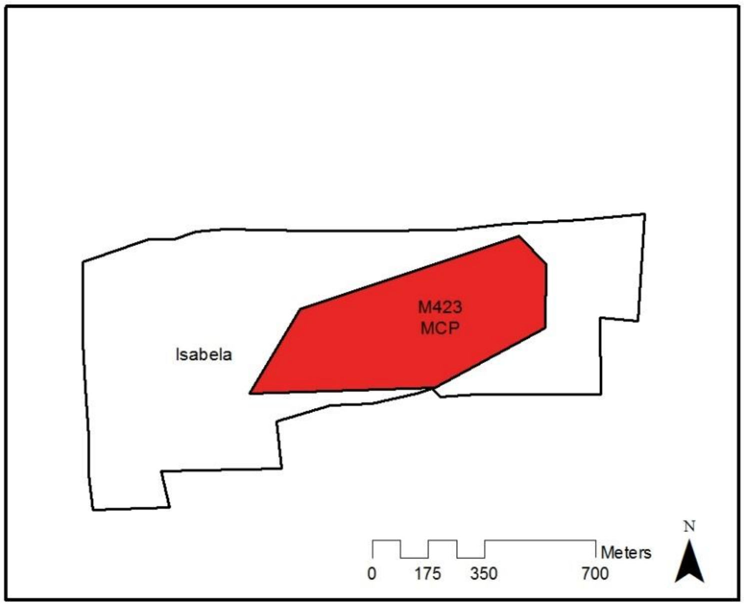
F.


M383
MCP
Isabela
0
175
350
700
Meters
N

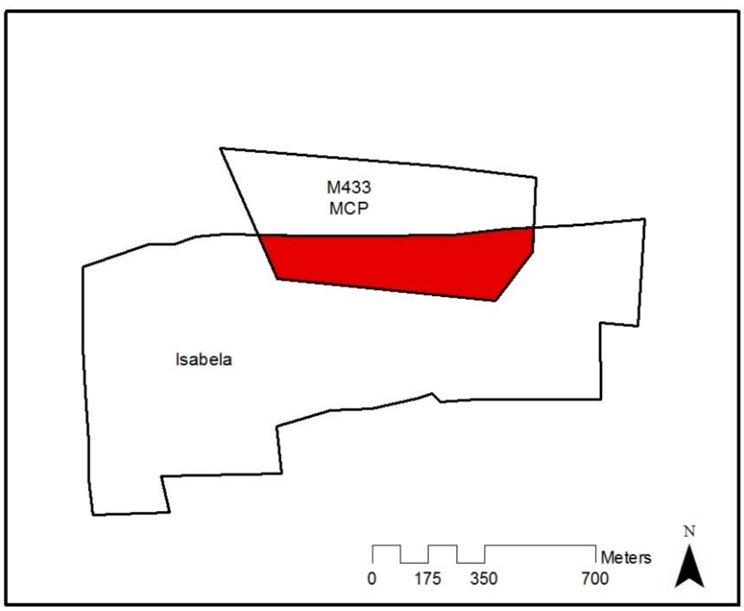
G.


M394
MCP
Isabela
0
175
350
700
Meters
N

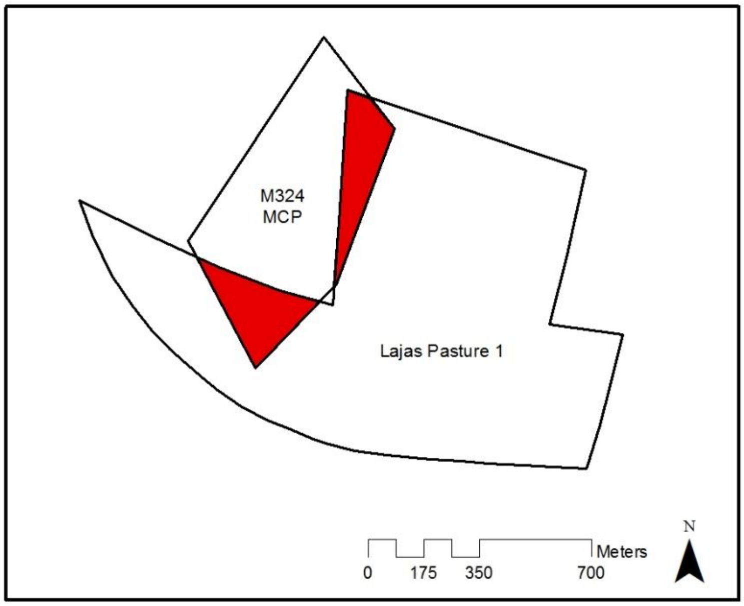
H.


M423
MCP
Isabela
0
175
350
700
Meters
N

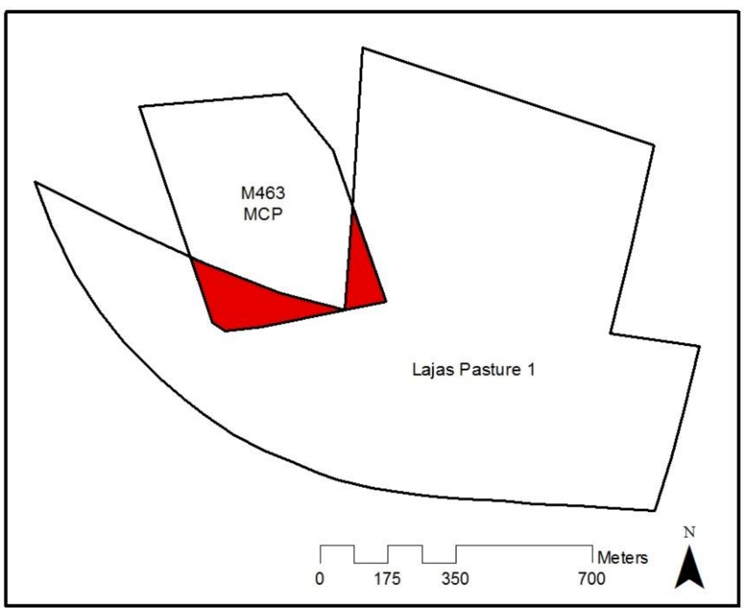
I.


M433
MCP
Isabela
0
175
350
700
Meters
N

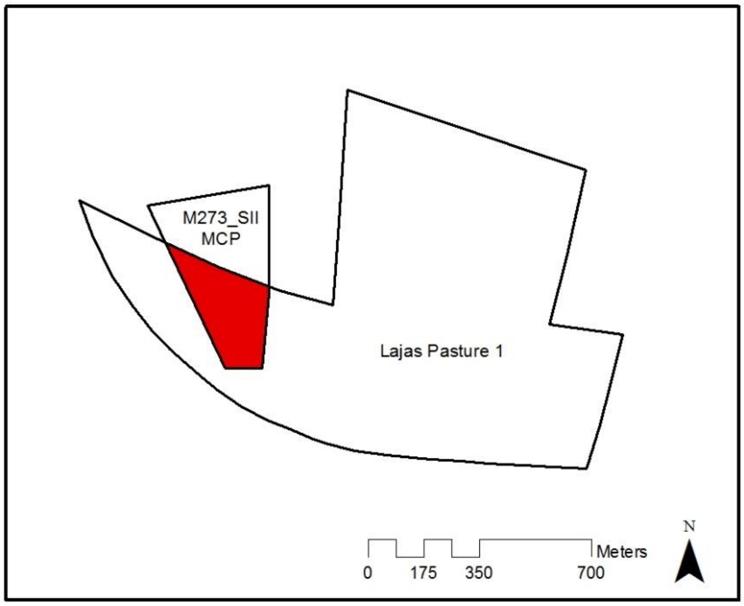
J.


M324
MCP
Lajas Pasture 1
Meters
0
175
350
700
N

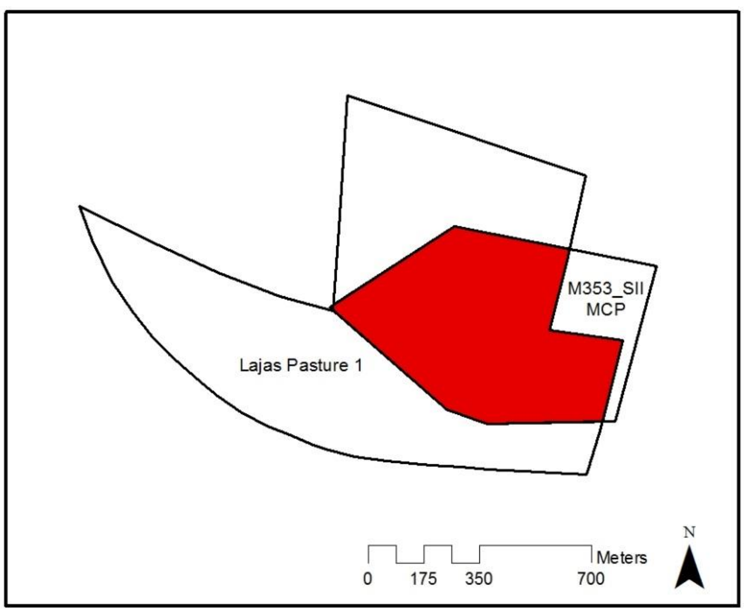
K.


M463
MCP
Lajas Pasture 1
Meters
0
175
350
700
N

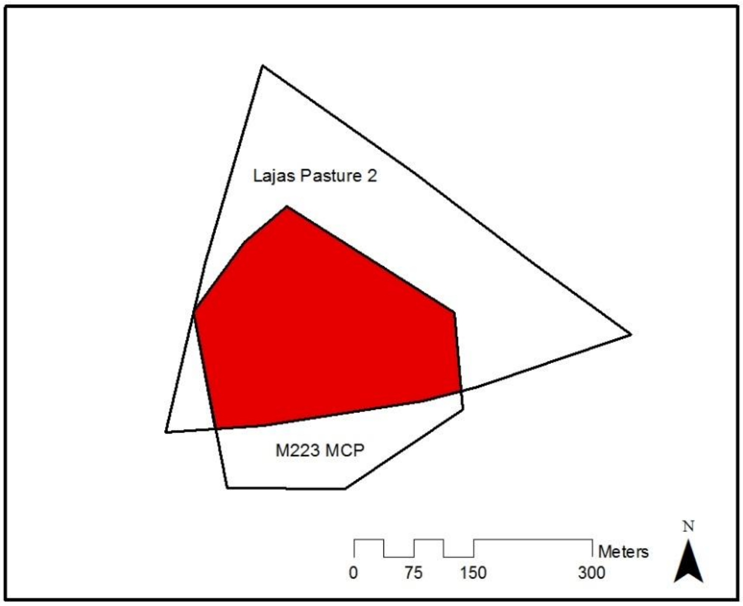
L.

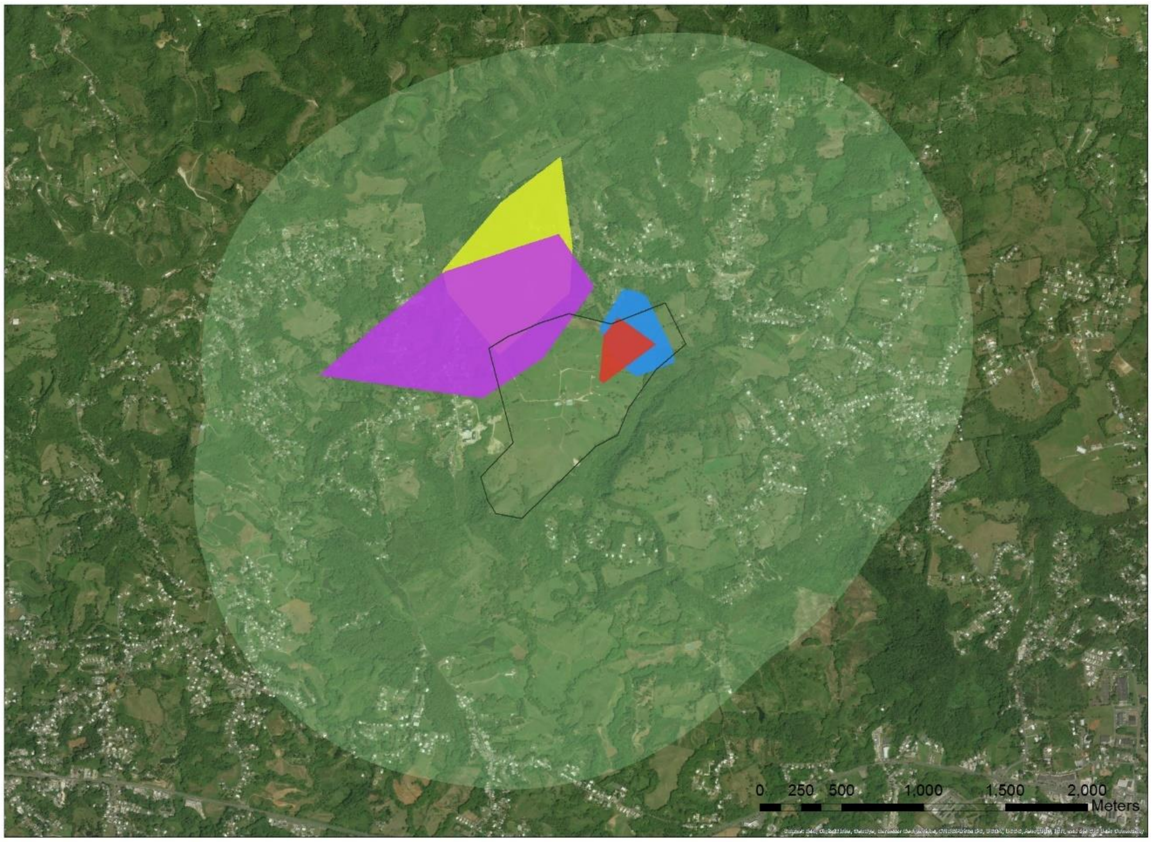

M273_SII
MCP
Lajas Pasture 1
Meters
0
175
350
700
N

M.

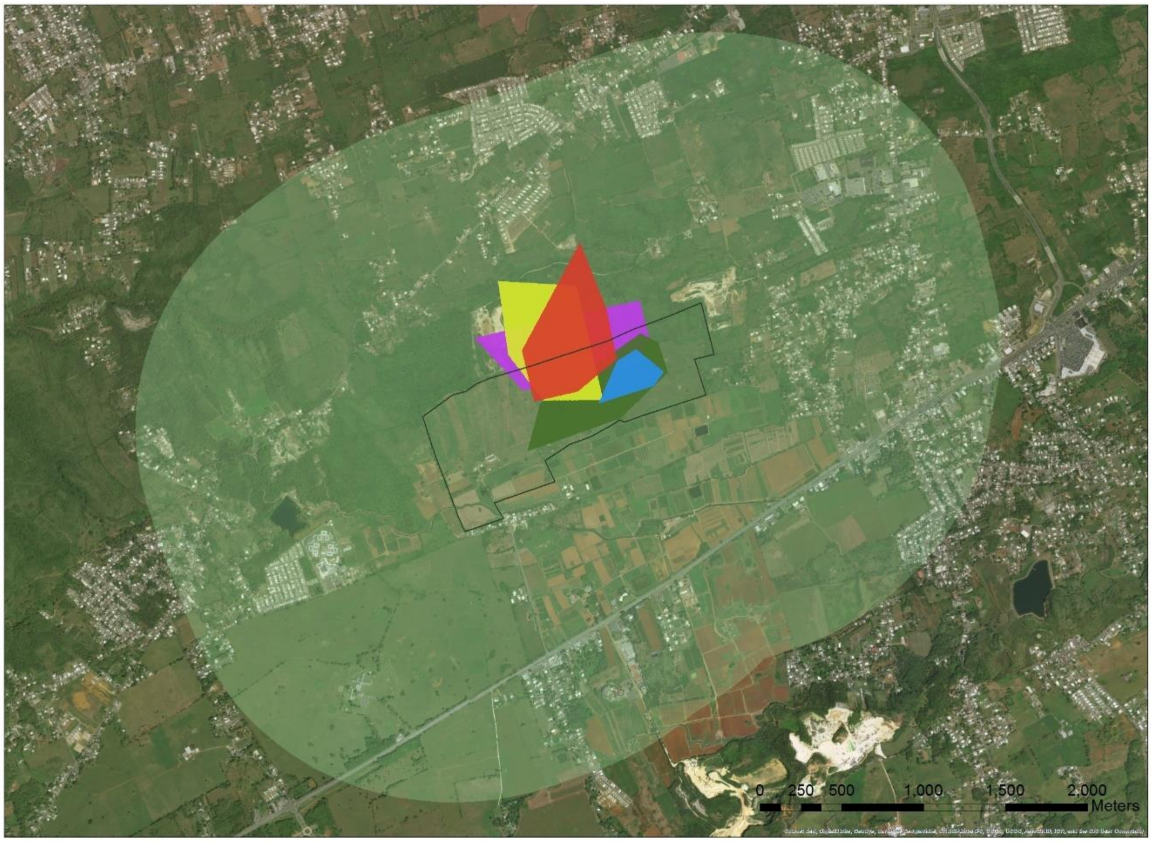

M353_SII
MCP
Lajas Pasture 1
Meters
0
175
350
700
N

N.

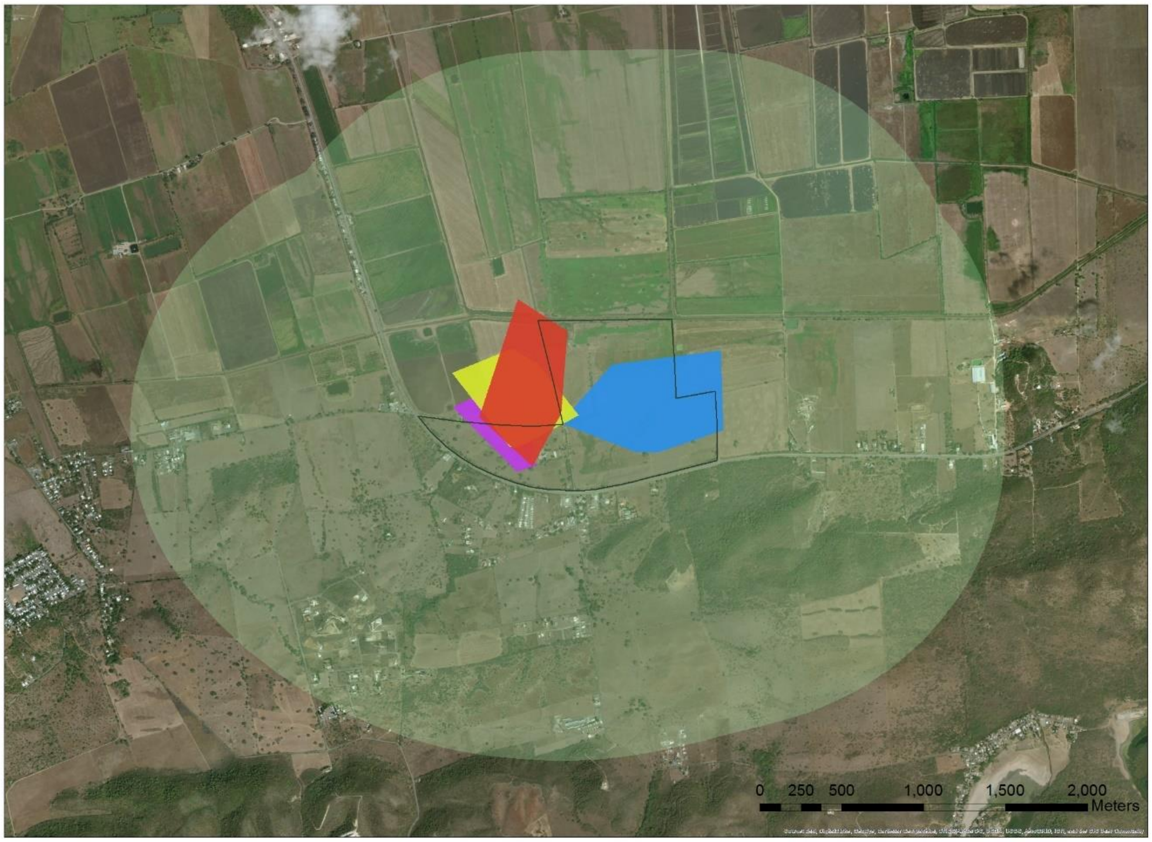




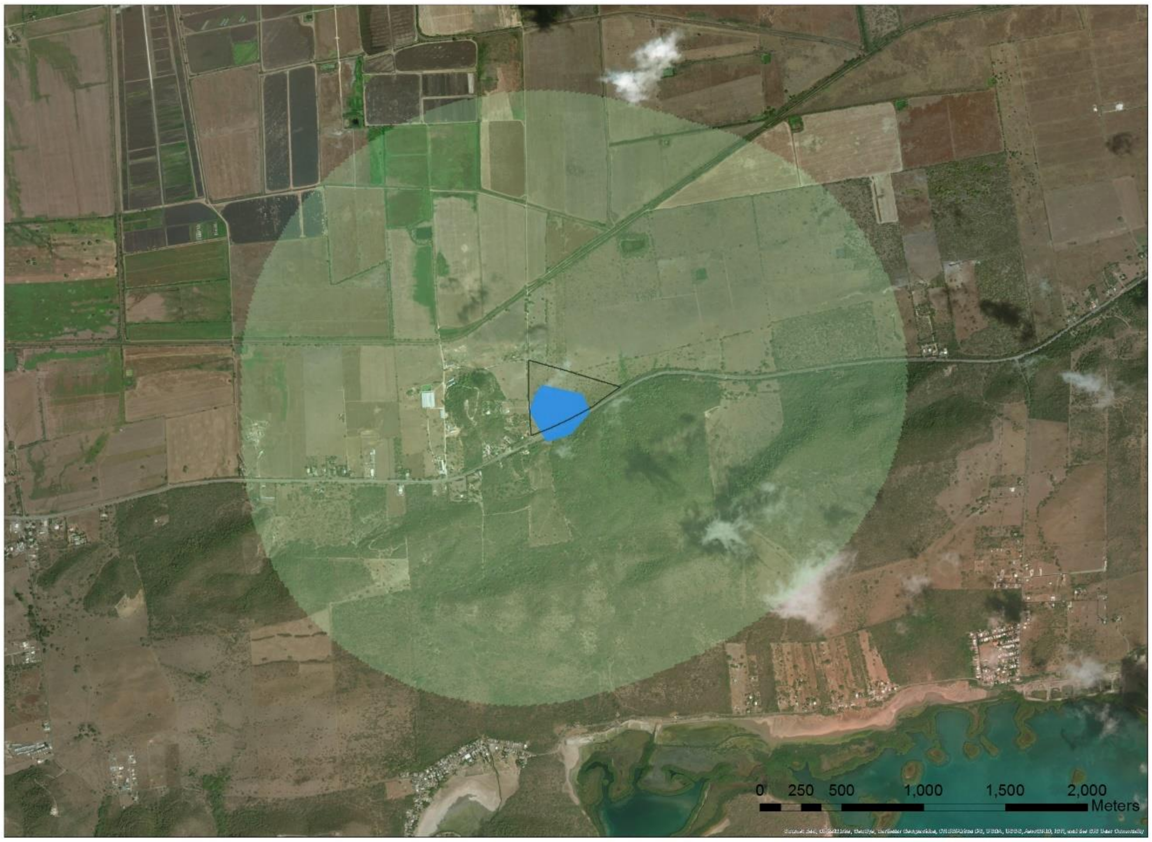
Appendix Figure 2. Minimum convex polygons within the San Sebastian farm site and the minimum convex polygon (MCP) home ranges of the five radio-collared mongooses from this site used in spatial analysis and the 1.7km site buffer.



Appendix Figure 3. Minimum convex polygons within the Isabela farm site and the minimum convex polygon (MCP) home ranges of the five radio-collared mongooses from this site used in spatial analysis and the 1.7km site buffer.



Appendix Figure 4. Minimum convex polygons within the Lajas P1 farm site and the minimum convex polygon (MCP) home ranges of the five radio-collared mongooses from this site used in spatial analysis and the 1.7km site buffer.



Appendix Figure 5. Minimum convex polygons within the Lajas Pasture 2 farm site and the minimum convex polygon (MCP) home ranges of the five radio-collared mongooses from this site used in spatial analysis and the 1.7km site buffer.

REFERENCES

Aebischer, N. J., P. A. Robertson, and R. E. 1993. Kenward. Compositional analysis of habitat
use from animal radio-tracking data. Ecology 74(5): 1313-1325.

Benavidez, K. M. 2016. The prevalence of *Leptospira* in small mammals on five Puerto Rican cattle farms. Thesis, Texas State University, San Marcos, USA.

Burridge, M. J. 2011. Non-native and invasive ticks. University Press of Florida, Gainsville, USA.

Corn, J. L., P. Berger, and J. W. Mertins. 2009. Surveys for ectoparasites on wildlife associated with *Amblyomma variegatum* (acari: ixodidae)- infested livestock in St. Croix, U.S. Virgin Islands. Journal of Medical Entomology 46:1483-1489.

Dyer, J. L., P. Yager, L. Orciari, L. Greenberg, R. Wallace, C. A. Hanlon, and J. D. Blanton. 2014. Rabies surveillance in the United States during 2013. Journal of the American Veterinary Medical Association 245(10): 1111-1123.

Estrada-Peña, A. 2001. Climate warming and changes in habitat suitability for *Boophilus microplus* (Acari: Ixodidae) in Central America. The Journal of Parasitology 87(5): 978-987.

Ewel, J. J., and J. L. Whitmore. 1973. The ecological life zones of Puerto Rico and the U.S. Virgin Islands. United States Department of Agriculture, Service Research 72.

George, J. E. 1990. Wildlife as a constraint to the eradication of *Boophilus* spp. (Acari:Ixodidae). Journal of Agricultural Entomology 7:119-125.

Geri, L., F. Vollmerhausen, D. Wilson, G. Garris, and T. Popham. 1989. Puerto Rico tick eradication program benefit-cost analysis. USDA, APHIS, Hyattsville, MD.

Gonzalez-Martinez, J. 2004. The introduced free-ranging rhesus and patas monkey populations of southwestern Puerto Rico. Puerto Rico Health Sciences Journal 23(1): 39-46.

Gorman, M. L. 1979. Dispersion and foraging of the small Indian mongoose, *Herpestes auropunctatus* (Carnivora: Viverridae) relative to the evolution of social viverrids. Journal of Zoology 187: 65-73.

Hoagland, D. B., G. R. Horst, and C. W. Kilpatrick. 1989. Biogeography and population biology of the mongoose in the West Indies. Biogeography of the West Indies 611-634.

Jobbins, S. E., C. E. Sanderson, and K. A. Alexander. 2014. *Leptospira interrogans* at the human wildlife interface in northern Botswana: a newly identified public health threat. Zoonoses Public Health 61(2): 113-23.

Johnson, S. R., A. R. Berensten, C. Ellis, A. Davis, and K. C. Vercauteren. 2016. Estimates of small Indian mongoose densities: implications for rabies management. The Journal of Wildlife Management 80(1): 37-47.

Jones, K. E., N. G. Patel, M. A. Levy, A. Storeygard, D. Balk, J. L. Gittleman, and P. Daszak. 2008. Global Trends in emerging infectious diseases. Nature 451: 990-993.

Keith, O. J., D. N. Hirata, and D. L. Espy. 1986. Control of mongoose predation on endangered Hawaiian birds. Unpublished progress report to the United States Department of Agriculture: Animal, Plant and Health Inspection Services (USDA-APHIS). 23pp.

Krebs, J. W., H. R. Noll, C. E. Rupprecht, and J. E. Childs. 2002. Rabies surveillance in the United States during 2001. Journal American Veterinary Medical Association 221:1690-1701.

Lima de Miranda, R., J. Ribeiro de Castro, M. M. Martins Olegário, M. E. Beletti, A. V. Mundim, L. H. O'Dwyer, O. Eyal, D. Talmi-Frank, M. C. Cury, and G. Baneth. 2011. Oocysts of *Hepatozoon canis* in *Rhipicephalus (Boophilus) microplus* collected from a naturally infected dog. Veterinary Parasitology 5698: 1-5. (Article in press)

Mahmood, T., I. Hussain, 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 43:103–111.

Miller, R. J., F. Guerrero, M. Messenger, F. Soltero, J. Urdaz, C. Oliver-Canabal, M. Comas Pagan, and A. Pérez de León. 2014. Research project for integrated control of the Southern Cattle Fever Tick in Puerto Rico. Resist Newsletter 2:4.

Miller, S., U. Zieger, C. Ganser, S. A. Satterlee, B. Bankovich, V. Amadi, H. Hariharan, D. Stone, and S. M. Wisely. 2015. Influence of land use and climate on Salmonella carrier status in the small Indian mongoose (*Herpestes auropunctatus*) in Grenada, West Indies. Journal of Wildlife Diseases 51(1): 60-68.

Nellis, D. W. 1989. *Herpestes auropunctatus*. Mammalian Species 342:1-6.

Nellis, D.W., and C.O.R. Everard. 1983. The biology of the mongoose in the Caribbean. Studies on the fauna Curaçao and other Caribbean islands. Utrecht 64:1-162.

Penzhorn, B. L. 2006. Babesiosis of wild carnivores and ungulates. Veterinary Parasitology 138:11-21.

Pérez de León, A. A., P. D. Teel, A. N. Auclair, M.T. Messenger, F. D. Guerrero, G. Schuster, and R. J. Miller. 2012. Integrated strategy for sustainable cattle fever tick eradication in USA is required to mitigate the impact of global change. Frontiers in Physiology 3:1-17.

Pierce, M. A. 2000. A taxonomic review of avian piroplasms of the genus *Babesia* Starcovici, 1893 (Apicomplexa: Piroplasmorida: Babesiidae). Journal of Natural History 34:3 317-332.

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

Quinn, J. H. 1998. Spatial ecology of the small Indian mongoose *Herpestes auropunctatus* in a subtropical rainforest: the influence of human activity and management implications. Thesis, University of California, Santa Barbara, USA.

Rodríguez-Vivas, R. I., L. C. Pérez-Cogollo, J. A. Rosado-Aguilar, M. M. Ojeda-Chi, I. Trinidad-Martinez, R. J. Miller, A. Y. Li, A. Pérez de León, F. Guerrero, and G. Klafke. 2014. *Rhipicephalus (Boophilus) microplus* resistant to acaricides and ivermectin in cattle farms of Mexico. Brazilian Journal of Veterinary Parasitology 23(2): 113-122.

Sikes, R. S., W. L. Gannon, and The Animal Care and Use Committee of the American Society of Mammalogists. 2011. Guidelines of the American Society of Mammalogists for the use of wild mammals in research. Journal of Mammalogy 92(1): 235-253.

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

Zintl, A., G. Mulcahy, H. E. Skerrett, S. M. Taylor, and J. S. Gray. 2003. *Babesia divergens*, a bovine blood parasite of veterinary and zoonotic importance. Clinical Microbiology Reviews 16(4): 622-636.