

The Influence of Spatio-Temporal Factors on Small Mammal Trapping and Species
Distribution in the SAVA Region of Madagascar

by

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Thesis submitted in partial fulfillment of
the requirements for the degree of Master of Science
in the Duke Global Health Institute
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2021

ABSTRACT

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Abstract

As deforestation occurs, the contact between humans and wildlife is expected to increase, resulting in increased risk of disease spillover to humans. Landscape modification and other spatio-temporal variables will influence population dynamics of small mammals, directly influencing the risk and transmission of zoonotic disease between species and humans. The study aimed to assess the influence of spatio-temporal variables on the trapping of small mammals across habitats of varying disturbance in the SAVA Region of Madagascar. Additionally, the study sought to examine the distribution patterns of small mammals within habitats, as well as the species diversity across habitats and throughout seasons. Endemic and invasive small mammals were trapped in 100m x 100m grids and two 100m pitfall lines over six consecutive days, in rice fields, sugar cane fields, vanilla fields, *savoka*, primary forest and secondary forest. The findings of the study suggest that heavily disturbed habitats are associated with capturing invasive species, exhibit low species diversity, and instances of aggregation during the 'end of dry' and 'dry' seasons. Considering the findings, highly disturbed habitats, like agricultural habitats, have a higher risk of disease than in less disturbed habitats. Thus, the risk of disease spillover to humans is likely to be higher in these more disturbed habitats.

Dedication

I dedicate this project to the memory of my beloved grandmother, Joy Hale, who passed away before I could complete my graduate studies. I would also like to thank my parents, sisters, and aunt. Without their guidance and love, the completion of this work would not be possible.

Additionally, I would like to thank Dr. Charles Nunn, Kayla Kauffman, Dr. Gregory Gray, Dr. Paul Lantos, Dr. Toky Randriamoria, and all the members of Dr. Nunn's laboratory. Thank you all for your advice, support, and patience during this process. I could not have done it without you all.

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1. Introduction

1.1 Background

About 402 km off the coast of Africa lies the island of Madagascar, a biogeographic entity unique from any other place in the world (Burney et al. 2004). The country's geology, soil, and climate are similar to Africa, but Madagascar's isolation in the Indian Ocean created a rich ecological and evolutionary history (Burney et al. 2004). The landscape was once covered with dense forests, but due to rapid deforestation the only remaining forested areas are located on the east and fragmented in the west (Scale 2011). From 1950-2000, Madagascar experienced an estimated loss of 40% forest coverage with patches of forest dramatically shrinking (Harper et al. 2007). Land-use change for agriculture, logging, mining, and infrastructure are responsible for most of the deforestation in Madagascar (Goodman & Jungers 2014, Allnutt et al. 2013, Irwin 2010). The diminishing level of primary forest coverage is particularly concerning for small mammal populations that require primary forests to survive.

Anthropogenic land-use change is a predominant driver of zoonotic disease spillover to humans (Gibbs et al. 2020). As deforestation continues, the contact between humans and wildlife is expected to increase, resulting in increased risk of disease spillover to humans (Gibbs et al. 2020). The impact and burden of zoonotic disease spillover are exemplified by emerging disease outbreaks, such as SARS-CoV-19, and by continuing transmission of well-known pathogens, such as *Salmonella* spp. or

Leptospira spp (Plowright et al. 2017). Monitoring the ecological relationship between animals, the environment, and humans is necessary for learning more about the mechanisms of zoonotic disease transmission.

1.2 Agricultural Practices and Land-Use

Agriculture is a dominant sector in Madagascar with 70% of the rural population engaging in the agricultural industry (Minten & Barrett 2008). The SAVA region is located in the north-east section of Madagascar. The region experiences weather patterns and fertile soils favorable for high-level crop production (Goodman & Jungers 2014). The SAVA Region experiences a warm and rainy season between December and March followed by a cool and dry season that continues until September (Goodman & Jungers 2014). Vanilla, rice, and sugar cane are among the most common crops grown in the SAVA region and require land modification for cultivation.

Vanilla is grown on the trunks or stems of other types of vegetation requiring the modification of land for cultivation within or around secondary forests (Hending et al. 2018). Rice is cultivated using a terraced paddy technique or using a slash-and-burn technique called, *tavy* (Randrianarison et al. 2016). For the paddy technique, the landscape is altered by rice paddy construction on narrow terraces that ascend the sides of steep valleys (Randrianarison et al. 2016). *Tavy* is a historic agricultural production system in Madagascar that converts forests to agricultural land and remains a dominant technique in many parts of the island today (Randrianarison et al. 2016). The land is

used for cultivation of crops, like sugar cane, then left to fallow for 3-5 years, creating a grasslands and fragmented forests (Styger et al. 2009, Randrianarison et al. 2016).

Previously cleared agricultural land experiences a slow regrowth with brushy, invasive plants creating a brushy landscape called *savoka* (Goodman & Jungers 2014). Other landscapes observed in the SAVA region are primary and secondary forests. Primary forests experience minimal human disturbance while secondary forests are degraded primary forests or previously cleared land experiencing regrowth (Goodman & Jungers 2014).

1.3 Mammalian Biodiversity in Madagascar

The mammals of Madagascar are incredibly diverse due to the island's unique geography (Burney et al. 2004) with over 80% of wildlife estimated to be unique to the island, or endemic (Garbutt, Bradt, & Schuurman 2008). The five major groups of mammals are the order Chiroptera (bats), order Lypotyphia (tenrecs), order Rodentia (rats and mice), order Carnivora (civet-like carnivores), and order Primates (lemurs) (Garbutt, Bradt, & Schuurman 2008). Many of the mammals are endemic to Madagascar, but some species migrated or were brought to the island by humans (Behrens & Barnes 2016). When a non-native species is introduced to an ecosystem, the species is considered 'introduced.' If an introduced species is negatively impacting the ecosystem, it is classified as an 'invasive' species. This study will focus on two Families of endemic

species, Family *Tenrecidae* and Family *Nesomyidae*, and three non-native, invasive species, *Rattus rattus*, *Mus musculus*, and *Suncus* spp.

The *Tenrecidae* family consists of 32 known endemic species of tenrecs that are quite diverse ranging from shrew, hedgehog, to otter-like in appearance (Behrens & Barnes 2016). *Tenrecidae* are nocturnal with most species living in dry forests, lowland forests, and dry shrubland where they feed on terrestrial forest-dwelling insects (Behrens & Barnes 2016). Tenrecs have been able to adapt to the changing landscapes and have evolved to survive in secondary forests or agricultural land (Stephenson et al. 2019). *Tenrecidae* are typically seen during the wet season and known to aestivate, or experience prolonged dormancy, during the dry season (Behrens & Barnes 2016).

Family *Nesomyidae* consists of 27 species of endemic rodents that live in eastern rainforests. The rarely observed rodents are diverse ranging from diurnal to nocturnal and strictly terrestrial to strictly arboreal (Behrens & Barnes 2016). *Nesomyidae* rely on trees for survival and reproduction, restricting the species to living in areas like primary and secondary forests (Stephenson et al. 2019). Previous research suggests that *R. rattus* competes with *Nesomyidae* individuals for habitats and food resources (Lehtonen et al. 2001)

Invasive rats, mice, and shrews are prevalent in the SAVA region and thrive in a wide range of habitats (Duplantier et al. 2014, Brouat et al. 2014, Rissman et al. 1987). *R. rattus* and *M. musculus* are generalists, meaning the species can live in diverse habitats,

survive on a wide range of foods, and thrive when living close to human populations (Duplantier et al. 2014 Brouat et al. 2014). *Suncus spp.* also thrive in close association to humans in both urban and rural environments while breeding year-round (Rissman et al. 1987). Invasive rodents in Madagascar are competing with endemic species due to a decrease in resource availability from land modifications. The competition increases inter-species contact as animals compete for necessary resources (Lehtonen et al. 2001, Goodman 1995).

1.4 Small Mammal Population Dynamics

The abundance of small mammals is known to fluctuate in relation to spatio-temporal variables which alter seasonal weather patterns and resource availability (Stenseth et al. 2003). Currently, there is minimal research on small mammal population dynamics within the SAVA region. Because small mammals are drivers of zoonotic disease spillover to humans, it will be important to investigate how spatio-temporal factors influence small mammal population dynamics and how influence varies by species.

Small mammal populations are commonly investigated by trapping. Removal sampling methods within grids are often used to estimate ecological dynamics like spatial patterns and species interactions (Farnsworth et al. 2002, Davis et al. 2017). This study used a removal sampling method with Sherman, Tomahawk, and pitfall traps. The Sherman live trap is one of the most efficient live traps and consists of solid walls

with a trigger door (Barros et al. 2015). Like the Sherman, the Tomahawk uses a trigger door with wire siding for walls. Pitfall traps are useful for trapping small animals that are under 10 grams in size, like tenrecs and shrews (Barros et al. 2015). Sherman and Tomahawk traps are useful in capturing larger mammals like rats and mice.

The diversity and distribution of small mammal populations within an area has a significant impact on disease transmission and inter-species interactions (Wilschut et al. 2015). Species diversity includes two aspects: species richness and species evenness. Species richness refers to the number of unique species within an area while species evenness refers to relative abundance of individuals from each species. Species diversity increases as species richness and evenness increases (Kricher 1972) and can directly impact inter-species interactions (Allen et al. 2009). The Shannon index is a metric frequently used to characterize and compare species diversity of communities or ecosystems (DeJong 1975). The Shannon index takes both species abundance and evenness into account to provide an intuitive measure of diversity (DeJong 1975).

In addition to quantifying diversity, the distribution of animals in time and space is important for disease transmission. The structure of geographic distribution patterns can be described as aggregated, uniform, or random. An aggregated pattern occurs when individuals of a species tend to be closer than expected to one another under a null distribution (Chen 2014). An aggregated pattern is observed in response to clustered resources or the presence of conspecific competition (Bayard & Elphick 2010;

Stamps 1988). In contrast, a uniform distribution occurs when individuals of a species tend to avoid one another with large distances between them (Chen 2014). A random distribution occurs when individuals are independently distributed (Fletcher & Fortin, 2018). Random distributions are rare in nature because spatial factors typically cause species to cluster together due to resource competition or spread away from each other, utilizing different resources (Fletcher & Fortin, 2018). The spatial scale at which a distribution is viewed will affect the patterns detected and interpreted. Thus, the scale of a study must be considered when concluding spatial distributions in order to avoid incorrect applications of patterns at larger or smaller spatial scales (Wiens, Rotenberry, & VanHorne, 1987).

1.5 Species Interactions and Disease Transmission

Common zoonotic pathogens in Madagascar include, *Leptospira spp*, *Bartonella spp*, and *Yersinia pestis*. Invasive species, like *R. rattus*, *M. musculus*, and *Suncus*, are competent hosts and main reservoirs for a variety of zoonotic pathogens (Lagadec et al. 2016, Rahelinirina et al. 2010). Competent hosts of pathogens spread pathogens to other competent hosts while noncompetent hosts cannot spread these pathogens (Allen et al. 2009). Some species act as asymptomatic reservoirs for pathogens, spreading the disease while not become severely diseased (Allen et al. 2009). For the pathogen to spread, there must be interactions between competent hosts which will act as a carrier for the pathogen (Allen et al. 2009). As spatio-temporal factors alter small mammal populations,

the abundance of zoonotic reservoirs and risk of zoonotic disease will also be impacted (Keesing 2006). Determining which species are at the highest risk for interaction with a competent host is another critical factor in determining the risk of disease spillover.

The dilution effect is the concept that a high level of species diversity will result in decreased spread of disease within the host species (Roberts, M., & Heesterbeek, J., 2018). As the number of species in the community increases, the risk of interacting to spread disease is 'diluted' and risk for infection is decreased (Roberts, M., & Heesterbeek, J., 2018). However, the opposite effect, known as the amplification effect, has also been observed within ecosystems. A diverse habitat can lead to more interactions between competent hosts leading to higher rates of infection in animal populations (Keesing 2006). A recent study in the SAVA region indicated support for the dilution effect and determined the probability of disease was lowest in fragmented forests which had higher species diversity attributed to the presence of native and non-native species (Herrera et al. 2020). Investigating species diversity within habitats will provide insight into the mechanisms that encourage the spread of disease.

1.6 Study Aims and Hypotheses

This study sought to assess the influence of spatio-temporal variables on the probability of trapping small mammals and how these variables change by species. For my first aim, I hypothesized that small mammals will have a higher occurrence in heavily human-altered habitats as compared to less-disturbed habitats. Human-altered

habitats such as agricultural fields provide suitable conditions for a wider range of species as compared to minimally altered primary and secondary forests. Due to the generalist nature of invasive species, I predicted the occurrence of invasive species would be higher compared to endemic species within agricultural habitats.

Additionally, I hypothesized that fluctuating resource abundance would influence the occurrence of small mammals throughout the year according to variation of species behavior related to diet, reproduction, and habitat. I predicted the occurrence of each species would be highest during the post-wet season, given that their food resources are at the highest during the wet season and this corresponds to their activity patterns.

In my second aim, I investigated how distribution patterns and species diversity varied over space and time. I hypothesized that the distribution patterns and species diversity of each trapping grid would vary based on habitat type and species present. I predicted each small mammal species would exhibit aggregated distribution patterns due to the individuals of the same species exhibiting resource competition. I also predicted that endemic and invasive species would be aggregated with each other as due to resource competition and similar behaviors. Small mammals would be more prevalent on agricultural fields due to suitable conditions and resource abundance. Thus, I predicted a greater species diversity within agricultural habitats than non-disturbed habitats.

2. Methods

2.1 Field Site

Data was collected within 10km of Marojejy National Park near the rural community of Mandena, Madagascar (Figure 1) within the SAVA region (14°28'36" S 47°48'50" E). Marojejy National Park consists of dense, primary forest and is home to many endemic plants and animals. The land surrounding the protected park is often used for timber and agricultural crops like vanilla, rice, and cassava. The deforestation of land for human uses has significantly impacted the amount of primary forests or secondary forests in the area. The study location provides six unique habitats to study, which we classified as sugar cane fields, vanilla fields, rice fields, *savoka*, primary forests, and secondary forests.



Figure 1: Location of Mandena within the SAVA Region

2.2 Small Mammal Trapping

Trapping was conducted over three field seasons to evaluate seasonal abundance patterns of small mammals. Small mammals were trapped at the end of the dry season (September 30, 2019 – November 24th, 2019), the end of the wet season (March 1st, 2020 – April 24th, 2020), and the middle of the dry season (July 19th, 2020 – September 9th, 2020). During each season, a trapping grid was constructed in six unique habitats: primary forest, secondary forest, *savoka*, rice fields, sugar cane fields, and vanilla fields. Trapping was performed for six consecutive nights on each grid. The location of the six grids remained the same throughout the three field seasons.

Each grid was constructed using a total of 121 traps with 97 Sherman traps and 24 Tomahawk traps. The traps were arranged in an 11 x 11 pattern at 10m intervals (Figure 2). The traps were set on the ground in 1-3m high vegetation and baited with peanut butter. If an animal was captured, the traps were rebaited and reset during the subsequent visit to the grid. Between each grid, the traps were washed and dried.

Pitfall traps occur in various designs, but the method was first described in 1896 by Dahl (Dahl 1896). For this study, two pitfall lines were established running parallel outside the grid. The line consisted of 11 buckets dug into the ground at 10m intervals. A vertical plastic fencing was secured to vertical stakes to bisect each bucket. Organic material is placed on the rim of the bucket to camouflage the edge of the plastic bucket. Traps were checked at dawn and in the afternoon every day.

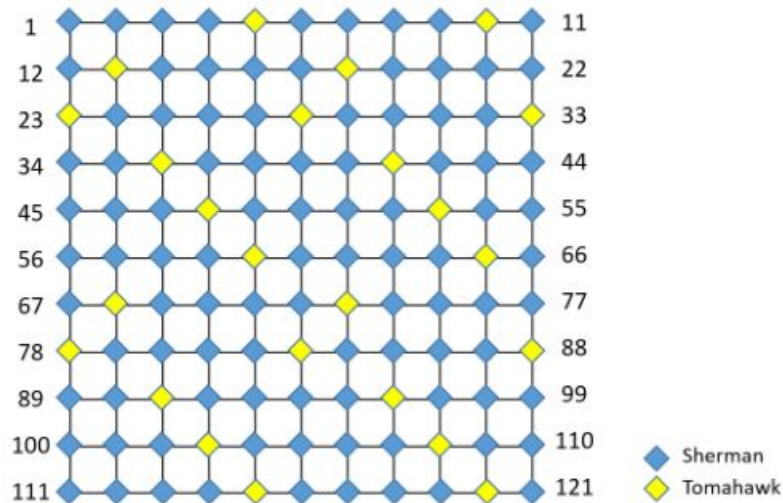


Figure 2: Arrangement of Sherman and Tomahawk in a Trapping Grid



Figure 3: Example of Pitfall Trap in Secondary Forest

2.3 Data Collection

When an animal was captured, the date, GPS coordinates, trap number, elevation, habitat of the grid, and other observational information about the location of the capture were recorded. Each animal was identified by the species and other information about the animal's physical condition were recorded. If a singular trap resulted in two animal captures, both animals were recorded. For endemic species, up to 25 individuals per species were euthanized for biological samples. All individuals considered invasive were euthanized for further studies on ectoparasites and endoparasites by the Nunn Lab. All animal handling procedures were approved by Duke's Institutional Animal Care and Use Committee under the protocol A262-19-12.

2.4 Data Analysis

Data collected from animal processing was entered in an Excel spreadsheet and analyzed using R. Studio (version 1.3.1073). Descriptive statistics were used to summarize characteristics of trapping outcomes and determine general trends of predictor variables using ‘gtsummary’, and ‘tidyverse’. The data was summarized for each aim of the study. Unfortunately, the data for the ‘dry’ season was not available for analyses of investigating spatio-temporal variables. Therefore, the first aim, which investigated the influence of investigating spatio-temporal variables, could only incorporate data collected during the ‘end of the dry’ season and ‘end of the wet’ season. The second aim, which determined distribution patterns and species diversity, incorporated data collected within all three seasons. In this study, variables of interest were season, trap type, day of trapping, and grid habitat.

Before modeling, spatial autocorrelation was assessed for the raw presence/absence data and for individual traps. Spatial autocorrelation was analyzed using the ‘ncf’ package. Spline correlograms were plotted with pointwise confidence intervals for the correlogram, where spatial dependence was assumed when the confidence interval did not equal 0, and with a bootstrap approach to account for uncertainty in estimates (Fletcher, R. & Fortin, M.J., 2018). The correlograms did not show significant evidence for spatial autocorrelation.

Additionally, spatial autocorrelation was measured for the day of trapping with a correlogram that plotted autocorrelation coefficients between the lagged values of a time

series. Day of trapping demonstrated violation of independence indicating high autocorrelation at the beginning of the time series which decreases over the six days of trapping. To control for the variation and autocorrelation, day of trapping was included as a random effect. The variation between days could be due to unknown weather events or lingering animal scent within traps. The type of trap was excluded as a predictor from the models since capture is confirmed to vary by trap type according to species behavior and morphology.

A logistic mixed effects model was used to assess the influence of spatio-temporal variables of trapping small mammals. The model was built with packages ‘lmer’, ‘lme4’ and ‘MuMIn’. Models were compared, assessed for interactions, and averaged. The best fit model was selected based on the lowest Akaike information criterion (AIC) (Burnham et al. 2011). After selecting a model, the goodness of fit was assessed by plotting the model residuals using a QQ plot, nonparametric dispersion test, and an outlier frequency test.

The logit coefficients of the model were determined with a 95% confidence interval and assessed at a significance level of $\alpha = 0.05$. The logit coefficients were then exponentiated to odds ratio (OR) with a 95% confidence interval, where an $OR < 1$ indicated a positive influence and $OR > 1$ indicated a negative influence when compared to the reference group.

To determine the how spatio-temporal variables differ by species, a binomial response variable was used that reflected the capture for each species (ex. *R. Rattus*

captured = 1; no capture or capture of other animal = 0). When modeling overall small mammal captures, trapping that resulted in two animals were analyzed as a single event. When modeling capture for each species, trapping that resulted in two animals were analyzed as separate events.

Spatial distributions were created with the ‘spatstat’ package. The distribution patterns could only be estimated for captures within the trapping grid of Sherman and Tomahawk traps; therefore, captures from pitfall lines were excluded from analysis. Edge effects, which arise near plot boundaries and can introduce bias (Fletcher, R. & Fortin, M.J., 2018) were corrected using an isotropic correction to correct for boundary effects with a weighting function (Fletcher, R. & Fortin, M.J., 2018, Ripley 1988).

A univariate point pattern was generated for each grid by linearizing Ripley’s K , also called the L -function. The L -function calculates the degree of spatial aggregation between points within a radius r such that the expected value under the null of complete spatial randomness (CSR) equals 0 (Ripley 1988). The L -function was performed for each grid during each season and for each grid across seasons. To determine if the observed distribution differs from the expected distribution, a simultaneous envelope was calculated under CSR. The envelope was created with 99 simulations which estimated the maximum simulated deviation from the Poisson point process across all r . If the observed $L(r)$, fell outside the envelope at any point on r , the null was rejected and implies that the observed pattern does not follow the expected pattern under CSR (Fletcher, R. & Fortin, M.J., 2018). If the $L(r)$ fell outside the envelope and $L(r) > 0$, there was evidence

of aggregation. If the $L(r)$ fell outside the envelope and $L(r) < 0$ there was evidence for a more uniform pattern (Fletcher, R. & Fortin, M.J., 2018).

A bivariate marked point pattern was generated to interpret the spatial covariance between endemic and invasive species. Captures that resulted in endemic species were marked as “native” while captures that resulted in invasive species were marked as “non-native.” The L-function of a marked point process estimated the distribution of endemic species conditional on the distribution of invasive species. The marked point process comparing the groups of species could only be performed when seasons were combined due to low number of captures within individual seasons. The distribution pattern was determined using the previously mentioned assessment of the plotted L-function within the simultaneous envelope.

To evaluate species diversity, the Shannon diversity index was estimated using the ‘vegan’ package. The Shannon-Index was calculated by taking the natural log of the sum of proportion of individuals (n/N) of a particular species abundance (n) divided by the total number of individuals found, species evenness, (H') (DeJong 1975). The index ranges between 0 to 1 with larger numbers indicating higher diversity (DeJong 1975). The R script for all statistical analysis can be found in Appendix A.

3. Results

3.1 Small Mammals

A total of 450 small mammals were captured during ‘end of wet’ and ‘end of dry’ season (Table 1, Figure 4). Of these, *Tenrecidae* and *R. rattus* were trapped the most, accounting for 44% and 33% of the captures, respectively (Table 1). Invasive species (*R. rattus*, *M. musculus*, and *Suncus*) accounted for 53% of the captures and native species (*Tenrecidae* and *Nesomyidae*) accounted for the remaining (Table 1). Trapping within primary forests resulted in the least captures (6.2%) while trapping within sugar cane fields resulted in the most captures (25%) (Table 1). The number of captures was similar with the ‘end of dry’ season resulting in 53% of captures and ‘end of wet’ resulting in 47% (Table 1). The data summarized in Table 1 reflects the data set used to model the first aim of the project.

Table 1: Summary of Captures for 'End of Dry' and 'End of Wet' Seasons

Species		(n=450)
<i>Mus musculus</i>		59 (13%)
<i>Nesomyidae</i>		11 (2.4%)
<i>Rattus rattus</i>		148 (33%)
<i>Suncus</i>		32 (7.1%)
<i>Tenrecidae</i>		200 (44%)
Grid Type		
<i>Primary forest</i>		28 (6.2%)
<i>Secondary forest</i>		51 (11%)
<i>Savoka</i>		85 (19%)
<i>Rice Field</i>		97 (22%)
<i>Sugar Cane</i>		114 (25%)
<i>Vanilla</i>		75 (17%)
Season		
<i>End of Dry</i>		238 (53%)
<i>End of Wet</i>		212 (47%)

Species Classification	
<i>Native</i>	211 (47%)
<i>Invasive</i>	239 (53%)

*An asterisk indicates species classified as invasive

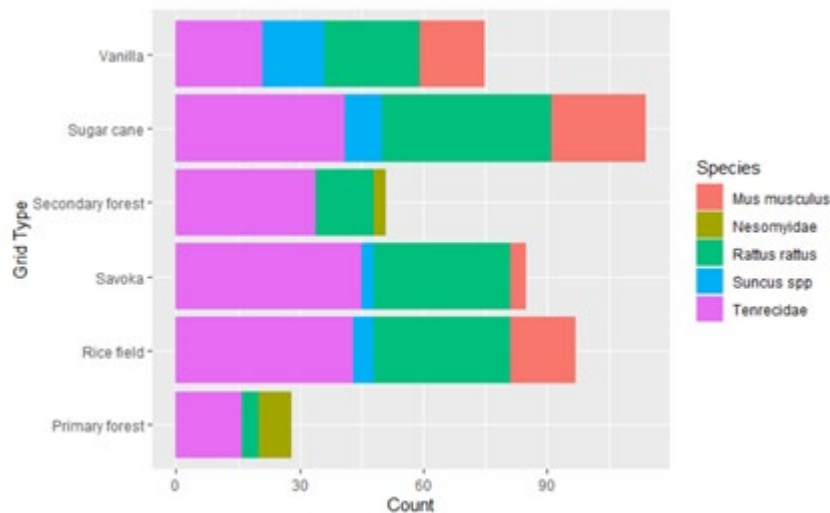


Figure 4: Bar Plot Comparison of Captures for the 'End of Dry' and the 'End of Wet' Seasons

A total of 697 small mammals were captured during all three field seasons (Table 2; Figure 5). The data summary across all three seasons was similar to the data summary for data collected within 'end of dry' and 'end of wet' seasons. The two species captured the most remained *R. rattus* and *Tenrecidae*, accounting for 44% and 35% of captures respectively (Table 2). The majority of small mammals captured were invasive species (62%) (Table 2). The least captures (6.5%) remained consistent in primary forest grids while trapping on sugar cane grids resulted in the most captures (24%) (Table 2). The number of small mammals captured was similar between seasons, each representing 30-

35% of captures (Table 2). The data summarized in Table 2 reflects the data set used to model the second aim of the project.

Table 2: Summary of Captures Across All Seasons

Species		(n=697)
<i>Mus musculus</i> *		86 (12%)
<i>Nesomyidae</i>		18 (2.6%)
<i>Rattus rattus</i> *		307 (44%)
<i>Suncus</i> *		42 (6%)
<i>Tenrecidae</i>		244 (35%)
Grid Type		
<i>Primary forest</i>		45 (6.5%)
<i>Secondary forest</i>		79 (11%)
<i>Savoka</i>		129 (19%)
<i>Rice Field</i>		153 (22%)
<i>Sugar Cane</i>		165 (24%)
<i>Vanilla</i>		126 (18%)
Season		
<i>Dry</i>		247 (35%)
<i>End of Dry</i>		238 (34%)
<i>End of Wet</i>		212 (30%)
Species Classification		
<i>Native</i>		262 (38%)
<i>Invasive</i>		435 (62%)

*An asterisk indicates species classified as invasive

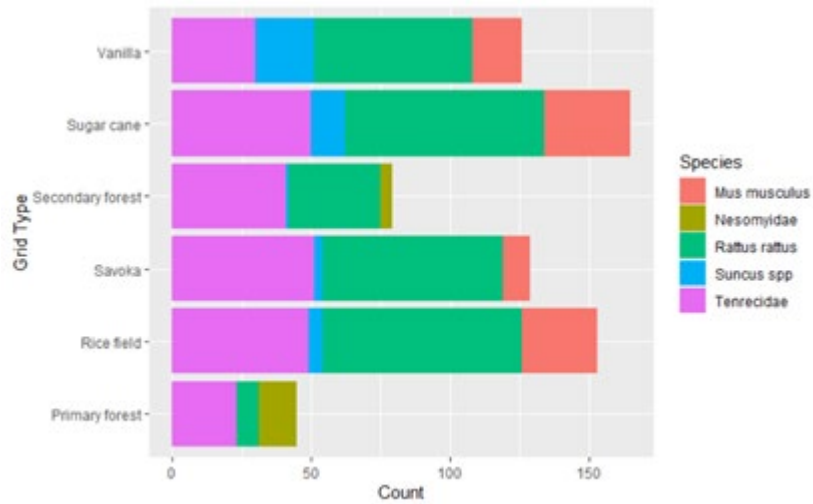


Figure 5: Bar Plot Comparison of Captures Across All Seasons

3.2 Spatio-Temporal Influences on Small Mammal Occurrence

The selected model used grid type (G) and season (S) to estimate influences on trapping a small mammal (C). The intercept of the model used primary forest and ‘end of dry’ season as factors. Grid type was the only statistically significant predictor (Table 3). Sugar cane fields, vanilla fields, rice fields, and *savoka* demonstrated a significant influence on capture as compared to primary forest. The odds of capturing a small mammal were greater in sugar cane fields by a factor of 4.21 than in primary forests, followed by vanilla fields by a factor of 2.74 (Table 4).

$$\text{Mixed Effects Model 1: } C \text{ of small mammals} \sim \beta_0 + \beta_1 G + \beta_2 S + v_d + \varepsilon$$

Table 3: Logit Coefficients Summary for Model 1

<i>Coefficients</i>	<i>β Estimate</i>	<i>Standard Error</i>	<i>z-value</i>	<i>Pr(> z)</i>
<i>Intercept</i>	-4.090	0.219	-18.681	<2e-16*
<i>Grid Type = Rice Field</i>	1.256	0.222	5.666	1.46e-08*
<i>Grid Type = Savoka</i>	1.159	0.224	5.172	2.31e-07*
<i>Grid Type = Secondary Forest</i>	0.610	0.242	2.521	0.0117*
<i>Grid Type = Sugar Cane</i>	1.438	0.218	6.604	4.01e-11*
<i>Grid Type = Vanilla</i>	1.01	0.228	4.426	9.62e-06*
<i>Season = End of Wet</i>	-0.147	0.099	-1.486	0.1374
<i>Random Effect (Day of Trapping) variance = 0.0489 with standard deviation (s.d.) 0.2211</i>				

AIC = 3504.5 with 10288 residual degrees of freedom

* An asterisk indicates a statistically significant factor ($\alpha = 0.05$)

Table 4: Odds Ratio for Model 1

<i>Predictor</i>	<i>OR</i>	<i>95% CI</i>	<i>p-value</i>
<i>Grid Type = Primary forest</i>	–	–	–
<i>Grid Type = Rice Field</i>	3.51	2.27, 5.42	<0.001
<i>Grid Type = Savoka</i>	3.19	2.05, 4.94	<0.001
<i>Grid Type = Secondary Forest</i>	1.84	1.15, 2.96	0.012
<i>Grid Type = Sugar Cane</i>	4.21	2.75, 6.46	<0.001
<i>Grid Type = Vanilla</i>	2.74	1.75, 4.29	<0.001
<i>Season = End of Dry</i>	–	–	–
<i>Season = End of Wet</i>	0.86	0.71, 1.05	0.80
OR = Odds Ratio, CI = Confidence Interval			

Additionally, mixed effect models were fit for each species to determine how the influence of spatio-temporal variables varies by species.

3.2.1 *Rattus rattus*

The selected model used grid type (G) and season (S) as predictor variables to estimate influences on trapping *R. rattus*. The intercept of the model used primary forest and end of dry season as factors. Both grid type and season were determined to be significant predictors in the model (Table 5). The odds ratio of capturing *R. rattus* was highest in sugar cane fields (10.4), rice fields (8.37), and *savoka* (8.39) than in vanilla fields (5.81) and secondary forest (3.52) (Table 6). The odds of capturing *R. rattus* was lower by a factor of 0.68 during the ‘end of the wet’ season compared to during the ‘end of dry’ season.

$$\text{Mixed Effects Model 2: } C \text{ of } Rattus \text{ rattus} \sim \beta_0 + \beta_1G + \beta_2S + \nu_d + \epsilon$$

Table 5: Logit Coefficients Summary For Model 2

<i>Coefficients</i>	<i>β Estimate</i>	<i>Standard Error</i>	<i>z-value</i>	<i>Pr(> z)</i>
<i>Intercept</i>	-5.883	0.505	-11.644	<2e-16*
<i>Grid Type = Rice Field</i>	2.215	0.531	4.004	6.23e-05*
<i>Grid Type = Savoka</i>	2.127	0.531	4.009	6.10e-05*
<i>Grid Type = Secondary Forest</i>	1.258	0.568	2.216	0.027*
<i>Grid Type = Sugar Cane</i>	2.347	0.525	4.470	7.83e-06*
<i>Grid Type = Vanilla</i>	1.76	0.543	3.242	0.001*
<i>Season = End of Wet</i>	-0.39	0.169	-2.311	0.208*
<i>Random Effect (Day of Trapping) variance = 0.0 with standard deviation (s.d.) 0.0</i>				

AIC = 1513.8 with 10308 residual degrees of freedom

* An asterisk indicates a statistically significant factor ($\alpha = 0.05$)

Table 6: Odds Ratio for Model 2

<i>Predictor</i>	<i>OR</i>	<i>95% CI</i>	<i>p-value</i>
<i>Grid Type = Primary forest</i>	–	–	–
<i>Grid Type = Rice Field</i>	8.37	2.96, 23.7	<0.001
<i>Grid Type = Savoka</i>	8.39	2.97, 23.7	<0.001
<i>Grid Type = Secondary Forest</i>	3.52	1.16, 10.7	0.027
<i>Grid Type = Sugar Cane</i>	10.4	3.73, 29.2	<0.001
<i>Grid Type = Vanilla</i>	5.81	2.01, 16.8	0.001
<i>Season = End of Dry</i>	–	–	–
<i>Season = End of Wet</i>	0.68	0.49, 0.94	0.021

OR = Odds Ratio, CI = Confidence Interval

3.2.2 *Mus musculus*

The selected model used grid type (G) and season (S) as predictor variables to estimate influences on trapping *M. musculus*. Since some trapping grids experienced zero captures of *M. musculus*, the intercept was refactored to the grid that resulted in the most captures of *M. musculus*. Refactoring allowed for a model that could be better interpreted. The intercept in this model was sugar cane and ‘end of dry’ season. Sugar cane fields and *savoka* were the only habitats considered to be significant predictors of capture (Table 7). The odds of capturing *M. musculus* was lower by a factor of 0.69 in both rice fields and vanilla fields compared to in sugar cane fields (Table 8). Since there were no captures of *M. musculus* within primary forests and secondary forests, an OR greater than 0 could not be calculated.

$$\text{Mixed Effects Model 3: } C \text{ of } \textit{Mus musculus} \sim \beta_0 + \beta_1 G + \beta_2 S + v_a + \varepsilon$$

Table 7: Logit Coefficients for Model 3

<i>Coefficients</i>	<i>β Estimate</i>	<i>Standard Error</i>	<i>z-value</i>	<i>Pr(> z)</i>
<i>Intercept</i>	-4.114	0.246	-16.70	<2e-16*
<i>Grid Type = Rice Field</i>	-0.3672	0.327	-1.123	0.262
<i>Grid Type = Vanilla</i>	-0.365	0.327	-1.116	0.265
<i>Grid Type = Savoka</i>	-1.758	0.542	-3.243	0.001*
<i>Grid Type = Primary Forest</i>	-17.356	18.709	-0.928	0.354
<i>Grid Type = Secondary Forest</i>	-17.731	21.132	-0.839	0.401
<i>Season = End of Wet</i>	-0.453	0.268	-1.690	0.091
<i>Random Effect (Day of Trapping) variance = 0.02632 with standard deviation (s.d.) 0.1622</i>				

AIC = 676.7 with 10308 residual degrees of freedom

* An asterisk indicates a statistically significant factor ($\alpha = 0.05$)

Table 8: Odds Ratio for Model 3

<i>Predictor</i>	<i>OR</i>	<i>95% CI</i>	<i>p-value</i>
<i>Grid Type = Sugar Cane</i>	–	–	–
<i>Grid Type = Rice Field</i>	0.69	0.36, 1.32	0.300
<i>Grid Type = Vanilla</i>	0.69	0.37, 1.32	0.300
<i>Grid Type = Savoka</i>	0.17	0.06, 0.50	0.001
<i>Grid Type = Primary Forest</i>	0.00	0, 244070165	0.400
<i>Grid Type = Secondary Forest</i>	0.00	0, 19387361986	0.400
<i>Season = End of Dry</i>	–	–	–
<i>Season = End of Wet</i>	0.64	0.38, 1.07	0.091

OR = Odds Ratio, CI = Confidence Interval

3.2.3 *Tenrecidae*

The selected model only used grid type (G) as a predictor variable to estimate the influence on trapping *Tenrecidae*. Grid type was a statistically significant influence on the capture for tenrecs (Table 9). The intercept in the model used primary forest as a factor. The odds of capturing *Tenrecidae* were greater by a factor of 2.87 in *savoka*, 2.60 in sugar cane fields, 2.72 in rice fields, 2.15 in secondary forests, and 1.31 in vanilla fields as compared to primary forests (Table 10).

Mixed Effects Model 4: C of *Tenrecidae* ~ $\beta_0 + \beta_1G + \nu_d + \epsilon$

Table 9: Logit Coefficients for Model 4

<i>Coefficients</i>	<i>β Estimate</i>	<i>Standard Error</i>	<i>z-value</i>	<i>Pr(> z)</i>
<i>Intercept</i>	-4.721	0.285	-16.55	<2e-16*
<i>Grid Type = Rice Field</i>	1.004	0.294	3.414	0.0006*
<i>Grid Type = Savoka</i>	1.053	0.292	3.605	0.0003*
<i>Grid Type = Secondary Forest</i>	0.766	0.304	2.517	0.012*
<i>Grid Type = Sugar Cane</i>	0.954	0.296	3.225	0.0013*
<i>Grid Type = Vanilla</i>	0.274	0.334	0.823	0.411
<i>Random Effect (Day of Trapping) variance = 0.1083 with standard deviation (s.d.) 0.3291</i>				

AIC = 1949.3 with 10309 residual degrees of freedom

* An asterisk indicates a statistically significant factor ($\alpha = 0.05$)

Table 10: Odds Ratio for Model 4

<i>Predictor</i>	<i>OR</i>	<i>95% CI</i>	<i>p-value</i>
<i>Grid Type = Primary forest</i>	–	–	–
<i>Grid Type = Rice Field</i>	2.73	1.53, 4.85	<0.001
<i>Grid Type = Savoka</i>	2.87	1.62, 5.08	<0.001
<i>Grid Type = Secondary Forest</i>	2.15	1.18, 3.90	0.012
<i>Grid Type = Sugar Cane</i>	2.60	1.45, 4.64	0.001
<i>Grid Type = Vanilla</i>	1.31	0.69, 2.52	0.4
OR = Odds Ratio, CI = Confidence Interval			

3.2.4 *Suncus*

The selected model only included grid type (G) as a predictor variable to estimate the influence on trapping *Suncus*. Since some grids experienced zero captures of *Suncus*, the intercept was refactored to the grid that resulted in the most captures of *Suncus*. Refactoring allowed for a model that could be better interpreted. The intercept in this model was vanilla fields. The habitats determined to be significant predictors of capture were vanilla fields, rice fields, and *savoka* (Table 11). The odds of capturing *Suncus* were lower by a factor of 0.33 in rice fields and by 0.20 in *savoka* as compared to

vanilla fields (Table 12). Since there were no captures of *Suncus* within primary forests and secondary forests, an OR greater than 0 could not be calculated.

$$\text{Mixed Effects Model 5: } C \text{ of } Suncus \sim \beta_0 + \beta_1 G + v_a + \varepsilon$$

Table 11: Logit Coefficients for Model 5

<i>Coefficients</i>	<i>β Estimate</i>	<i>Standard Error</i>	<i>z-value</i>	<i>Pr(> z)</i>
<i>Intercept</i>	-4.733	02.593e-01	-18.249	<2e-16*
<i>Grid Type = Sugar Cane</i>	-5.16e-01	4.23e-01	-1.220	0.223
<i>Grid Type = Rice Field</i>	-1.106	5.175e-01	-2.137	0.033*
<i>Grid Type = Savoka</i>	-1.616	6.334e-01	-2.551	0.011
<i>Grid Type = Primary Forest</i>	-3.207e01	1.620e06	0.000	1.000
<i>Grid Type = Secondary Forest</i>	-3.386e01	1.619e06	0.000	1.000

Random Effect (Day of Trapping) variance = 8.52e-13 with standard deviation (s.d.) 9.23e-07

AIC = 411.1 with 10309 residual degrees of freedom

* An asterisk indicates a statistically significant factor ($\alpha = 0.05$)

Table 12: Odds Ratio for Model 5

<i>Predictor</i>	<i>OR</i>	<i>95% CI</i>	<i>p-value</i>
<i>Grid Type = Vanilla</i>	–	–	–
<i>Grid Type = Sugar Cane</i>	0.60	0.26, 1.37	0.20
<i>Grid Type = Rice Field</i>	0.33	0.12, 0.91	0.033
<i>Grid Type = Savoka</i>	0.20	0.06, 0.69	0.011
<i>Grid Type = Primary Forest</i>	0.00	0.00, inf	>0.9
<i>Grid Type = Secondary Forest</i>	0.00	0.00, inf	>0.9

OR = Odds Ratio, CI = Confidence Interval

3.2.5 *Nesomyidae*

The selected model used type (G) and season (S) as predictor variables to estimate the influences on capturing *Nesomyidae*. While some trapping grids did not capture any *Nesomyidae* individuals, refactoring the levels for this species was not necessary since the intercept already reflected the grid with the most captures. The intercept, which was statistically significant, used primary forest and ‘end of dry’ season

as factors (Table 13). The odds of capturing *Nesomyidae* was greater by a factor of 0.37 in secondary forest than in the primary forest (Table 14). Since *Nesomyidae* were only captured within primary forests and secondary forests, an OR greater than 0 could not be calculated for rice fields, vanilla fields, sugar cane fields, or *savoka*.

$$\text{Mixed Effects Model 6: } C \text{ of } Nesomyidae \sim \beta_0 + \beta_1 G + \beta_2 S + v_d + \varepsilon$$

Table 13: Logit Coefficients Summary for Model 6

<i>Coefficients</i>	<i>β Estimate</i>	<i>Standard Error</i>	<i>z-value</i>	<i>Pr(> z)</i>
<i>Intercept</i>	-5.972	6.068e-01	-9.840	<2e-16*
<i>Grid Type = Rice Field</i>	-3.434e01	1.617e06	0.000	1.000
<i>Grid Type = Savoka</i>	-9.013e01	1.619e06	0.000	1.000
<i>Grid Type = Secondary Forest</i>	-9.847e-01	8.780e-01	-1.452	0.146
<i>Grid Type = Sugar Cane</i>	-3.768e01	1.617e06	0.000	1.000
<i>Grid Type = Vanilla</i>	-2.906e01	7.196e05	0.000	1.000
<i>Season = End of Wet</i>	9.835e-01	6.780e-01	1.451	0.147
<i>Random Effect (Day of Trapping) variance = 0.0 with standard deviation (s.d.) 0.0</i>				

AIC = 159.6 with 10308 residual degrees of freedom

* An asterisk indicates a statistically significant factor ($\alpha = 0.05$)

Table 14: Odds Ratio for Model 6

<i>Predictor</i>	<i>OR</i>	<i>95% CI</i>	<i>p-value</i>
<i>Grid Type = Primary forest</i>	–	–	
<i>Grid Type = Rice Field</i>	0.00	0.00, infinity	>0.9
<i>Grid Type = Savoka</i>	0.00	0.00, infinity	>0.9
<i>Grid Type = Secondary Forest</i>	0.37	0.10, 1.41	0.15
<i>Grid Type = Sugar Cane</i>	0.00	0.00, infinity	>0.9
<i>Grid Type = Vanilla</i>	0.00	0.00, infinity	>0.9
<i>Season = End of Dry</i>	–	–	
<i>Season = End of Wet</i>	2.67	0.71, 10.1	0.15

OR = Odds Ratio, CI = Confidence Interval

3.3 Distribution Patterns

I investigated the distribution patterns of small mammals across each grid for each season separately, as well as the pattern when seasons were combined. The distributions for each grid during the 'end of wet' season appear consistent with the null CSR and indicate a random pattern (Figure 6). Most of the distribution patterns for the 'end of dry' season were random except for evidence of aggregation within vanilla fields (Figure 7). During the 'dry' season, the distribution of small mammals was slightly aggregated within sugar cane while the remaining grids indicate a random distribution (Figure 8). When combining patterns across seasons, small mammal distribution appeared aggregated on all grid types associated with high levels of human disturbance with significant deviations from the envelope under CSR (Figure 9). The distribution across seasons remained random, in accordance with the CSR, for primary and secondary forests (Figure 9).

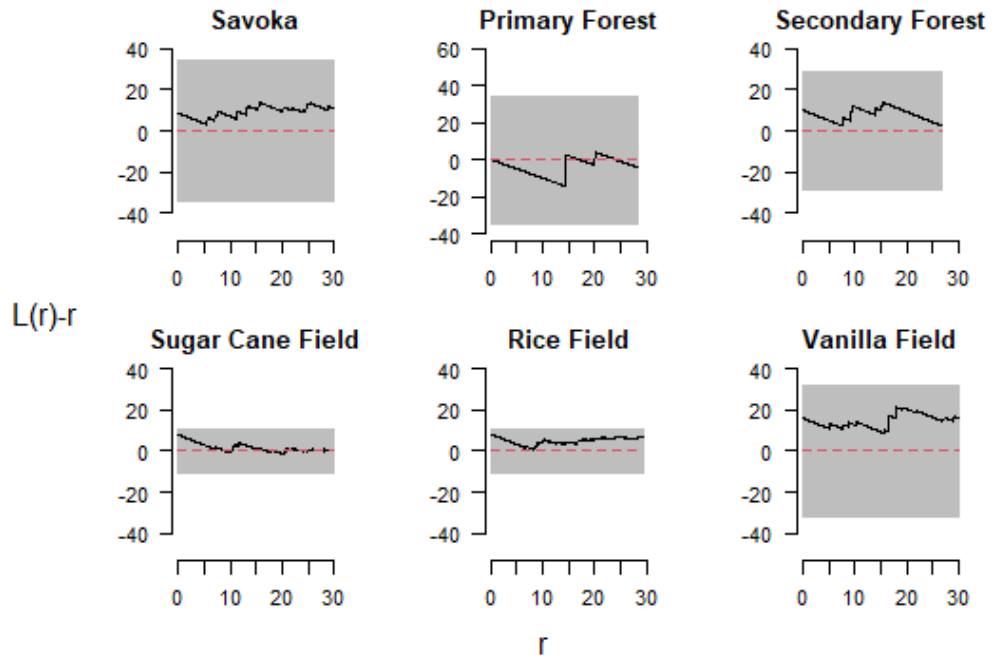


Figure 6: Distribution of Small Mammal Captures for 'End of Wet' Season

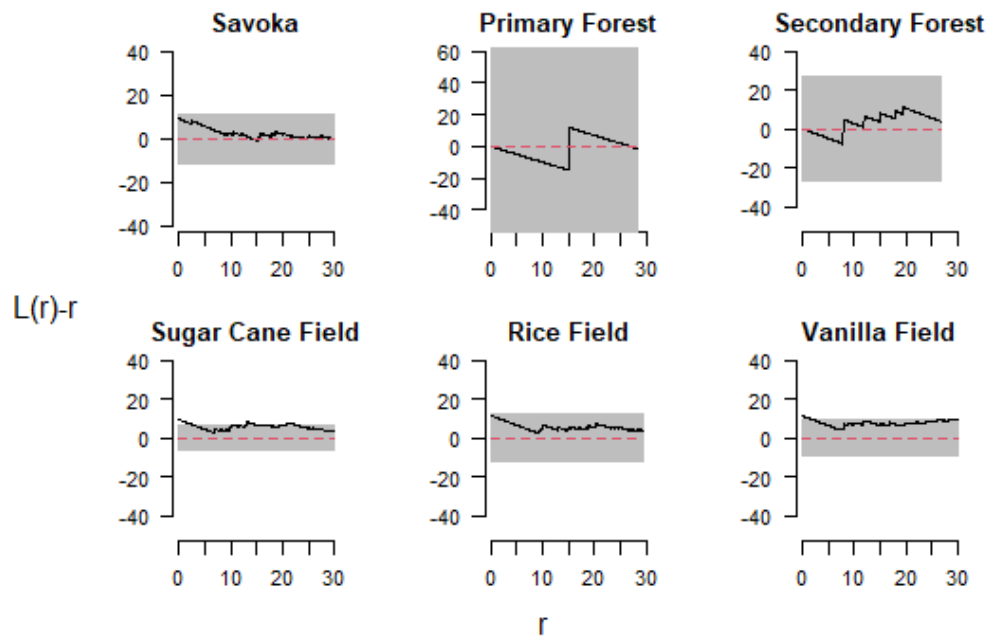


Figure 7: Distribution of Small Mammal Captures for 'End of Dry' Season

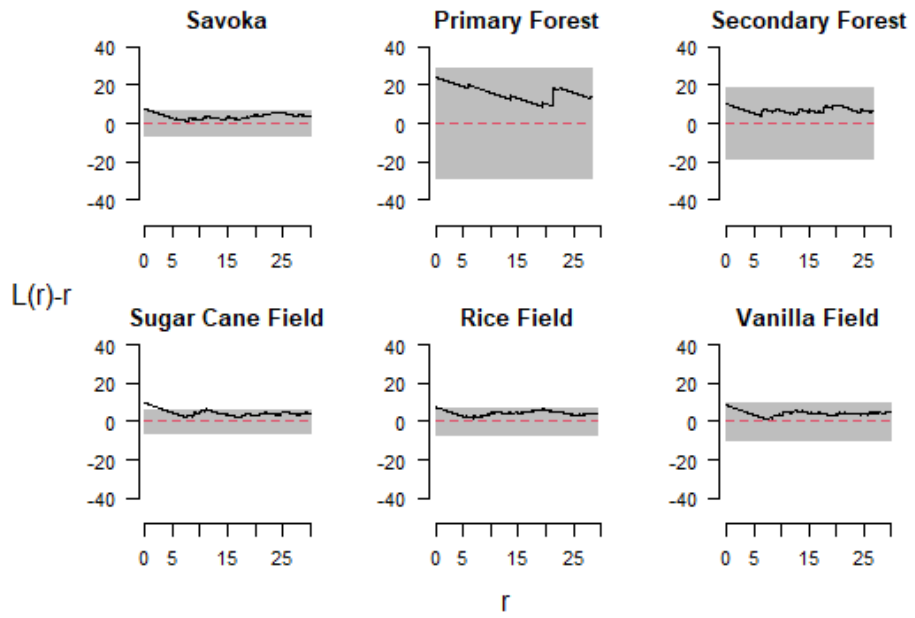


Figure 8: Distribution of Small Mammal Captures 'Dry' Season

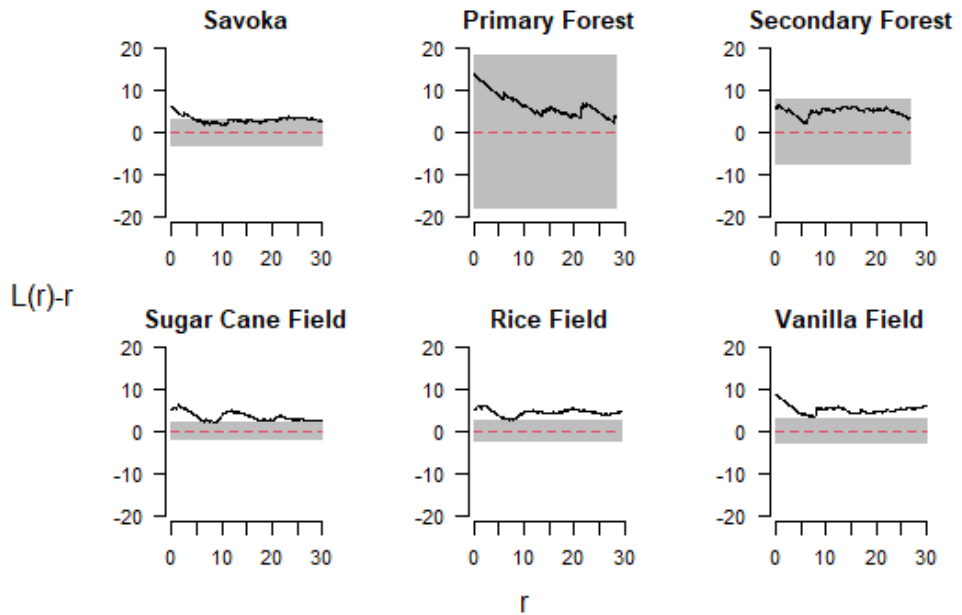


Figure 9: Distribution of Small Mammal Captures Across All Seasons

Marked point processes were performed to estimate the distribution of endemic small mammals given the underlying distribution of invasive species. The results indicate that the distributions of endemic species in relation to invasive species is random across all grids (Figure 10).

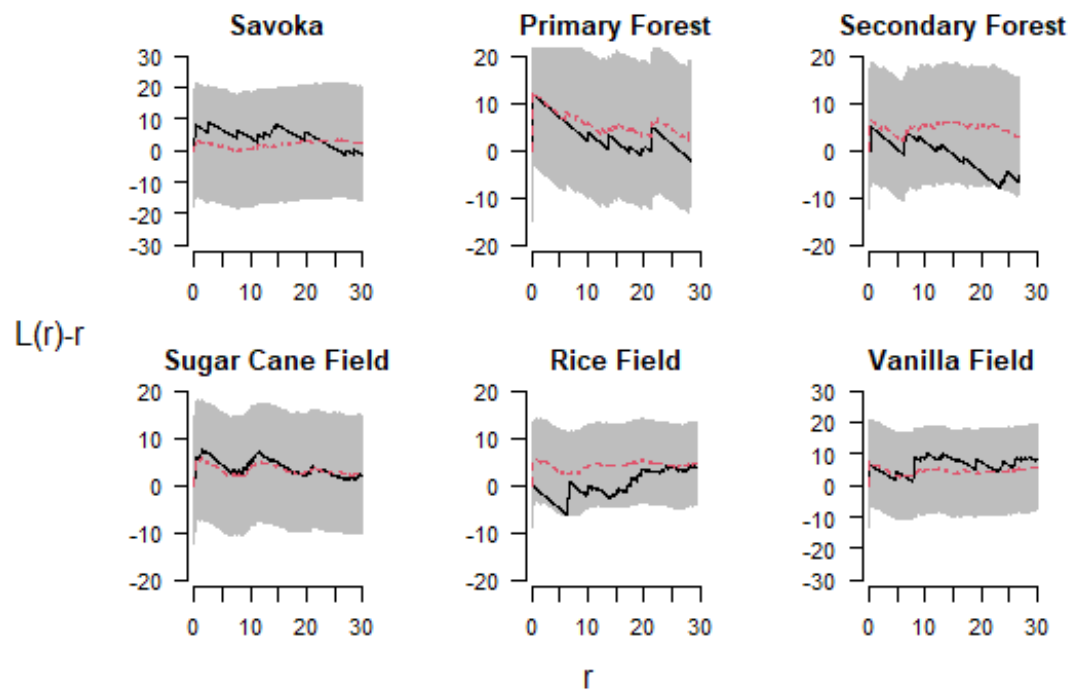


Figure 10: Bivariate Analysis of Captured Native Small Mammals Conditioned on the Distribution of Invasive Small Mammals

3.3 Species Diversity

The Shannon diversity index was calculated across grids to estimate diversity for each season, as well as across season to estimate diversity for each grid. The greatest diversity was observed during the 'dry' season with an index 0.332 (Figure 13). However, the variation in diversity among seasons was small. When comparing the total diversity of each grid, the diversity of primary forest was the highest with an index of 0.452 (Figure 14). The lowest diversity (0.249) was observed within sugar cane fields (Figure 14). The diversity was lower within all habitats considered heavily disturbed than compared to the diversity in the less disturbed habitats of primary forest and secondary forest.

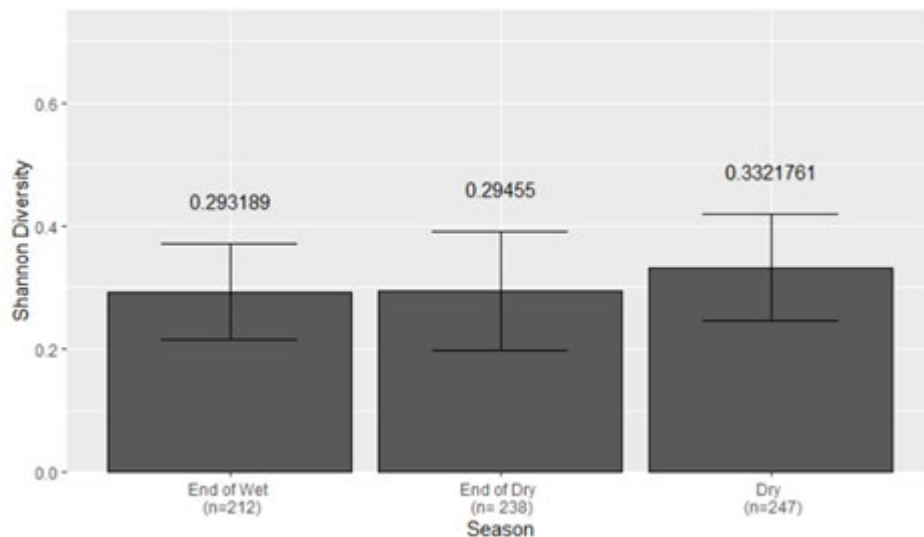


Figure 11: Shannon Diversity Index for Each Season Across Habitats

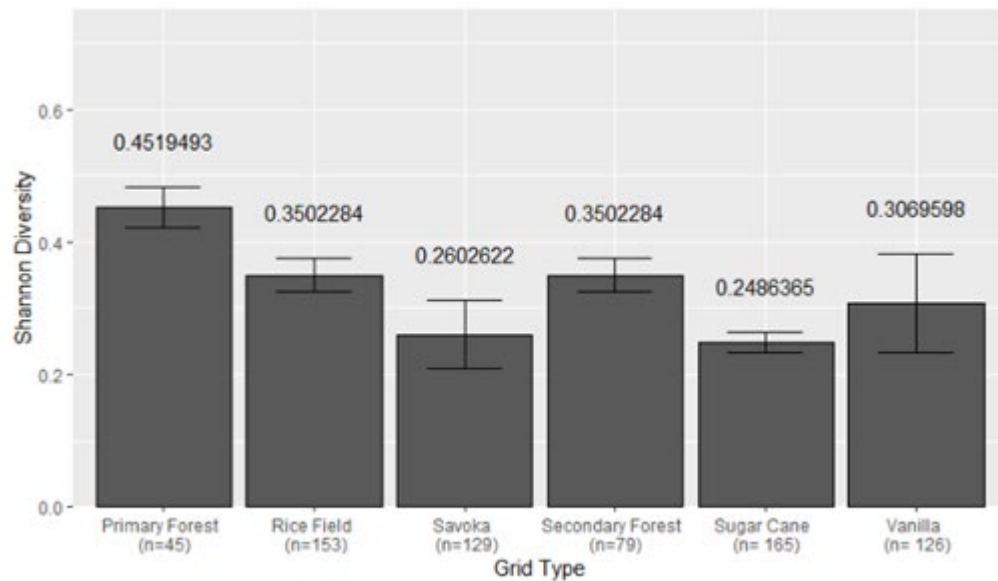


Figure 12: Shannon Diversity Index for Each Habitat Across Season

4. Discussion

4.1 Heavily Disturbed Habitats Influence the Occurrence of Small Mammals

The anthropogenic disturbances on sugar cane fields, vanilla fields, rice fields, and *savoka* create landscapes which are easily navigated and have greater food availability for many small mammal species in Madagascar, especially invasive species (Rahelinirina et al. 2010). The occurrence and capture of invasive species (*R. rattus*, *Mus musculus*, and *Suncus*) appeared to be more likely within agricultural habitats as compared to forested habitats, consistent with my hypothesis. *R. rattus*, *Mus musculus*, and *Suncus* have all been associated with hosting zoonotic pathogens and zoonotic

disease spillover to humans (Rahelinirina et al. 2010, Lagadec et al. 2016.) My findings support previous research that suggests heavily disturbed habitats are associated with an increased species richness of animals that serve as hosts for zoonotic diseases (Gibb et al. 2020).

Contrary to my prediction, the probability of trapping endemic species was not always greatest within less-disturbed habitats. The occurrence of *Tenrecidae* varied regardless of the amount of disturbance within habitats. My results are consistent with previous findings that tenrecs occur outside of less-disturbed habitats and show tolerance to deforestation (Stephenson 1995; Goodman et al. 2013). However, the occurrence of *Nesomyidae* was greatest within non-disturbed habitats and consistent with my prediction of trapping endemic species. The findings surrounding *Nesomyidae* suggest that the endemic rodent species cannot tolerate disturbed areas and thus, continue to be restricted to forested habitats (Stephenson 1994). It also supports previous evidence that *R. rattus* are threatening *Nesomyidae* due to resource competition and similar arboreal behaviors (Lehtonen et al. 2001).

The influence of seasonal variation remained relatively consistent throughout seasons with the 'end of wet' season only influencing the trapping of *R. rattus* and *Nesomyidae*. Contrary to previous research (Murphy et al.; Stephenson 1994) and known species behaviors that suggest seasonal variation influences occurrence of small mammals (Behrens and Barnes 2008), my findings demonstrate that the occurrence is

relatively consistent between seasons. The lack of seasonal variation may be attributed to limitations in data analysis described below.

4.2 Small Mammal Distribution Patterns

The distribution of small mammals compared across habitats yielded similar patterns when modeled for season separately. Most of the distribution patterns appeared random within trapping grids, but there is evidence that patterns may fluctuate due to seasonal variation and become more aggregated within sugar cane fields and vanilla fields during certain seasons. When seasons are combined over time, distributions appear aggregated within all the highly disturbed habitat while remaining random within the less disturbed habitats. The evidence of aggregation within agricultural grids demonstrates that small mammals within these grids are using similar resources and living within the close distance to one another (Bayard et al. 2017; Stamps 1988). As small mammals clump together within habitats, there is a greater chance of intra- and inter-species interactions which increases disease risk (Chen 2014).

A marked point process revealed that the distribution of endemic species given the distribution of invasive species were random across all grids without evidence of aggregation or uniformity. The random pattern of endemic and invasive species in relation to one another may be explained by different behaviors, causing species to use varying resources within similar spaces (Duplantier et al. 2005, Brouat et al. 2014). However, the random pattern between invasive and endemic species still suggests that

animals are moving and making similar use of the space (Kattas et al. 2013). The risk of disease transmission between endemic and invasive species when distributed randomly will be lower than if aggregated within habitats (Chen 2014) If interactions are limited, the risk of disease spillover to humans will also be limited. Monitoring the distribution patterns of endemic and invasive species will be important for disease surveillance within habitats.

4.3 Species Diversity and Disease Transmission

I predicted that agricultural fields would have the highest species diversity, but diversity was highest in primary forest, followed by secondary forest. Previous studies indicate that species diversity is predictive of pathogen prevalence within habitats and thus, high diversity is associated with a lower risk of disease (Haas et al. 2011; Hall et al. 2009). The species diversity within agricultural fields was lower and thus, may be associated with an increased risk of disease. The landscape of forested habitats has more vegetation and trees that hinder the interaction between mammals (Gibb et al. 2020). Considering the forested landscape along with my finding of a high species diversity, there may be support for the dilution effect, indicating a lower risk of disease (Keesing 2006). Additionally, most species captured within forested habitats were considered endemic. Previous research suggests that habitats with a high species diversity contain a lower number of competent hosts (Han et al. 2015), further supporting evidence of the dilution effect. Therefore, the risk of disease spillover to humans would be lowest within

forested habitats. The diversity remained fairly consistent across seasons, indicating seasonal variation has little impact on diversity and risk of disease.

4.4 Study Limitations and Moving Forward

Models investigating the influence of spatio-temporal factors on small mammal trapping are limited because data from the 'dry' season was unavailable for analysis. It is possible that seasonal variation would demonstrate a stronger influence on trapping small mammals when all seasons are considered. The lack of seasonal variation, which differed from previous research, may be explained by this limitation. The 'dry' season should be incorporated into the model in the future for a more accurate estimation of seasonal variation and how it influences trapping small mammal.

Additionally, some species of small mammals, like *Nesomyidae*, *M. musculus*, and *Suncus*, had low number of captures and some were not captured at all within specific habitats. The models for these species may not be true estimations of spatio-temporal factors due to issues in model convergence which were associated with the low or zero captures. Future research could attempt to increase capture numbers by extending the duration of trapping within habitats or including more trapping grids within each habitat.

The distribution patterns of each grid may also be limited. The true distribution may not be reflected due to small number of captures for certain species within seasons. The distributions were analyzed across seasons to navigate the issue of small capture

numbers. However, combining captures across seasons may also lose some of the temporal variation occurring over time and by seasons. Additionally, the exclusion of animals trapped within pitfall traps also contributed to the small numbers of capture. The marked point process of endemic species conditional to invasive species experienced similar restrictions and may also be limited. Since endemic tenrecs are typically captured in pitfall traps due to their small size, the spatial covariance between endemic and invasive species does not reflect the true distribution between the groups of species.

The small spatial scale and extent of trapping grids used in this study must be considered when assessing the findings. If a study area is too small, distribution patterns may not be accurate or meaningful due to a lack of variability in the data (Fletcher & Fortin 2018). The small spatial scale (100m x 100m) could explain why most distribution patterns appear random, a pattern that is typically rare due to spatial factors (Fletcher & Fortin 2018). Future studies could increase the scale of trapping grids to investigate how distribution patterns vary at a larger, global scale.

5. Conclusion

We trapped small mammals for six consecutive days within six different habitats near Mandena, Madagascar over three seasonal periods. The data were used to investigate the influence of spatio-temporal factors on the trapping of small mammals overall and within each species group. Additionally, data were used to determine

distribution patterns and species diversity throughout habitats and seasons. The results suggest that habitats with a higher amount of human disturbance, like agricultural grids, were associated with capturing all invasive species and one endemic species (*Tenrecidae*). Additionally, habitats with higher disturbance were associated with lower species diversity, with some species aggregating within sugar cane fields and vanilla fields during certain seasons.

The analyses revealed that highly disturbed habitats are associated with a higher risk of disease than less disturbed habitats due to the low species diversity, occurrence of host species, and instances of aggregation. Therefore, the risk of disease spillover to humans is likely to occur. However, the study experienced several limitations within data analysis, and the findings may not reflect the true influence of spatio-temporal factors on trapping small mammals or true distribution patterns of small mammals.

Appendix A: Links to Raw Data and R Code

The raw data for the analysis are available at the following link:

https://docs.google.com/document/d/1Bp0oUHboqH-Qqc4zZoeJo0D4cXasvUIQDnE5TJIU_KM/edit?usp=sharing

The R code to generate mixed effect models is available at the following link:

<https://docs.google.com/document/d/14NnVaIRRPO4s0DuAJHqonqq76XLYvwNT6qE-pjV8xOU/edit?usp=sharing>

The R code to generate species distributions is available at the following link:

<https://docs.google.com/document/d/1UMXFNPXLV-yIQCA3W8hQoliLMcg5PjDDWJCT6wGuWjQ/edit?usp=sharing>

The R code to generate species diversity is available at the following link:

<https://docs.google.com/document/d/1edepjRvCmnjA38OBR0TOMBILVKgM4E9Lc-4tTTtBEoY/edit?usp=sharing>

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