Population Diversity of Small Rodents within Eucalyptus and Oak/Bay Woodlands in Tilden Regional Park, Alameda and Contra Costa County, California

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ABSTRACT

The recreational parks of the San Francisco Bay Area's Wildcat Canyon watershed are natively composed of Coast Live Oak (*Quercus agrifolia*) and California Bay Laurel (*Umbellularia californica*) mixed woodland with an understory of blackberry and poison oak. As a result of lumber investment in the late 1800s, Blue Gum Eucalyptus (*Eucalyptus globulus*) was transplanted from Australia along the coast of California. The invasive tree is found to create monocultures along hillsides, outcompeting native habitat vegetation. This study examines native small mammal populations across varying degrees of Eucalyptus invasion for trends in population distribution and species diversity to understand how Eucalyptus affects native rodent populations. The study was conducted from March 2015 until November 2015 using 40 Sherman trap transects across three plots generally categorized as: mainly Eucalyptus, mixed Eucalyptus and Oak/Bay woodland, and mainly Oak/Bay woodland. The distribution of rodents trapped across these three plots found an inverse relationship between *Peromyscus maniculatus* and *Peromyscus truei* populations with *P. maniculatus* favoring Eucalyptus and *P. truei* favoring Oak/Bay. The study also found *Neotoma fuscipes* populations to decline with increased Eucalyptus concentrations. Overall, the study found invading Eucalyptus to initially decrease ecosystem health in terms of small mammal distribution and species density, but then become a separate productive habitat generally favored by *P. maniculatus*.

KEYWORDS

Habitat resource use, Wildcat Canyon, population distribution, *Peromyscus maniculatus*, *Peromyscus truei*, *Neotoma fuscipes*

INTRODUCTION

The growth of invasive *Eucalyptus globulus* (Blue Gum Eucalyptus) changes the habitat composition of native Oak/Bay woodlands and may alter overall habitat health. Tilden Regional Park spans Alameda and Contra Costa counties in the Wildcat Canyon Watershed [Figure 1]. It is home to many native and invasive species that thrive alongside the public in this recreational park. Before human introduction of Eucalyptus, during the 19th and 20th centuries, Tilden Regional Park maintained woodlands primarily composed of Oak and Bay trees. Non-native Blue Gum Eucalyptus was introduced to California in 1886 for lumber sales in the range of 1-8 million trees; however, it was found to be unsuitable for lumber production and the trees were left to spread across the coast (Nowak 1993). In the following century, Eucalyptus was found to create monocultures where few other species could grow nearby due to tree induced habitat modification including the production of arid soils and erosive conditions (Graca 2002). Though Eucalyptus is found to produce less litter than other deciduous trees, the nutrients within the Eucalyptus litter is found to be substantially lower, potentially reducing overall ecosystem health (Graca 2002). Few studies have focused solely on Eucalyptus as the main cause of biological inhibition for mammal species, however it is hypothesized that Eucalyptus dominated habitat will shift the dispersion of small mammal species.

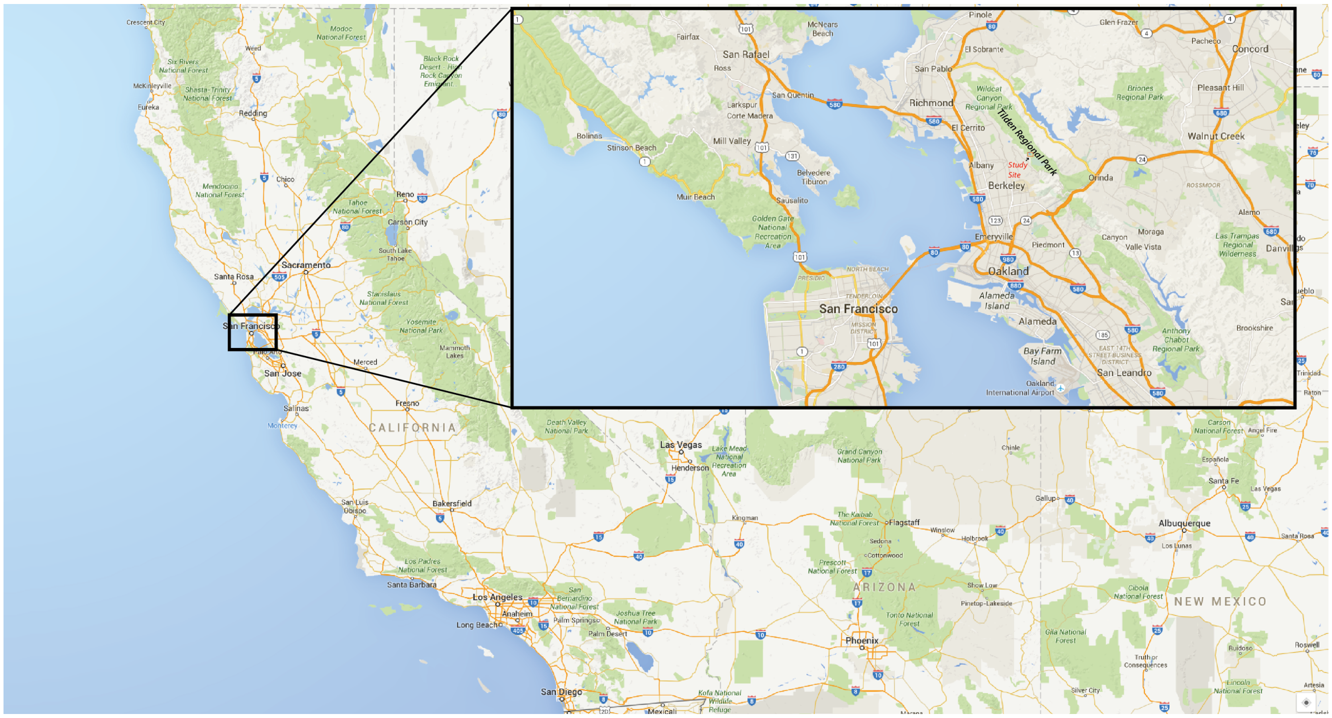


Figure 1. Map of Study Site Location. Shows position of Study site in the greater Bay Area and spatially in the State of California.

Small mammals can be used as biological indicators to gauge the health of this woodland habitat. Tilden contains a diverse rodent population whose presence can be used to understand habitat health and productivity. Key genera of interest in the park are *Peromyscus*, deer mice, and *Neotoma*, wood rats; all of whose presence in Bay Area habitats is correlated to a healthy ecosystem (Berry 1959). Two common species of *Peromyscus* in Tilden are *P. maniculatus* and *P. truei*, whose distribution may indicate spatial partitioning based on habitat composition. Disturbed habitats, such as the invasion of eucalyptus, has been correlated with higher *Peromyscus maniculatus* presence and lower for other *Peromyscus* species, such as the *P. truei* populations also found in Tilden (Lambert 2010). *Peromyscus maniculatus* is also a potential carrier of hantavirus, a deadly virus spread through dry rodent excrement (CDC 2012); know-ing the habitat preferences of *P. maniculatus* can help understand the virus threat. *Neotoma fuscipes* live in group nesting sites associated with heavy poison oak and blackberry habitats throughout the Oak/Bay woodland (Vestal 1938). They require dense habitat to construct their nests and are typically seen in Oak/Bay woodlands utilizing woody branch material for nest assemblage (Cranford 1982). *Neotoma* *fuscipes* rely strongly on habitat composition, their population will likely be correlated to native habitats and less to invasive Eucalyptus. Through a comparison of population distribution and overall diversity of these rodent species among varying habitat composition, I determined overall ecosystem health and trends in dispersion over space and time.

Specifically, I compared rodent population dynamics within Eucalyptus and Oak/Bay Woodland habitats, to understand Eucalyptus forests as possible biological inhibitors. I hypothesized that the invasion of Eucalyptus trees into native Oak/Bay woodland has changed the distribution of small mammals within these woodlands. Tilden is home to a diverse group of small mammals including: *Peromyscus maniculatus, Peromyscus truei, Neotoma fuscipes, Reithrodontomys megalotis, Rattus rattus, Mus musculus, Microtus californicus,* as well as others (Berry 1959) [Appendix 1]. Isolating specific species' distributions within Tilden's habitats, I examined concentrations of *Peromyscus maniculatus* versus *Peromyscus truei* in relation to Eucalyptus since literature describes *P. maniculatus* to prefer disturbed habitats (Lambert 2010). Secondly, I expected rodent populations to vary notably due to seasonal changes and reproductive cycles (King 1969). I also expected to find *Neotoma fuscipes* within the dense poison oak and blackberry environments as this species prefers this type of vegetation for nest building sites, and potentially given these plants, the habitat composition of Eucalyptus versus Oak/Bay has negligible effects on populations (Cranford 1982). Comparing rodent population dynamics within Eucalyptus and Oak/Bay Woodland habitats, helps to better understand Eucalyptus forests as possible biological inhibitors.

METHODS

Study System Description

Tilden Regional Park is situated within Alameda and Contra Costa counties of the Bay Area and is home to a diverse ecosystem of flora and fauna that coexist in this moderately dense landscape. Tilden

Regional Park was originally comprised of Oak/Bay Woodlands, however in the 20th century the landscape of the East Bay Hills has been transitioning due to invading Eucalyptus monocultures (Nowak 1993). The effect of this shift in habitat is still unknown in terms of rodent diversity and population dynamics in the woodland. For this study, I trapped once a month for nine months in three plots of woodland: 1. Mostly dense Eucalyptus stands and Poison Oak; 2. Mix of Oak/Bay, Eucalyptus, Blackberry, Ferns, and Poison Oak; 3. Typical Oak/Bay Woodland with no Eucalyptus. Each tree over 5cm diameter at breast height (DBH) as well as ground cover composition was mapped within a meter radius of each trap location allowing for rodent species comparison to habitat composition. By isolating rodent species data, I was able to identify patterns in rodent species distribution in relation to habitat composition spatially in order to determine general habitat use and preference towards tree species.

Data Collection

Studies conducted on rodent populations can be a basis for understanding the ecological processes in an area. There are many techniques that can be used to generate population models, some more disruptive to the ecosystem than others (Delany 1983). I created trapping transects of 40 traps within each of the three plots. The layout and methods of each transect was designed based on the variable being tested and the field being studied (Delany 1983). To account for seasonal variation in species' populations, I trapped once a month for nine months from March 2015 until November 2015: March through May (Spring), June through August (Summer), and September through November (Fall). Each plot contained 40 Sherman traps set in rough grids of 8 by 5 feet with traps set approximately 10 meters apart; variability of trap location was dependent on habitat layout [Figure 2]. This totaled 120 Sherman traps across the 3 plots with each trap location tagged with orange flagging tape, numbered, and GPS located. The traps were baited with approximately ⅕ cup of oats and set from 6pm until 8am the following morning. Each trap was recorded as 'open', 'closed', or 'rodent', and traps with rodents in them were collected and analyzed on site. Using a 1 gallon plastic bag, the rodent was scruffed using the dorsal neck skin and identified by species and sex. Weight was recorded using a 100g spring scale (pesola) and length measurements of pinna (ear), hind foot, tail, and total body were taken in millimeters. Images were taken of each rodent with a scale of measurement and trap number, and then the rodent was released next to the trap's initial location once all data had been collected.

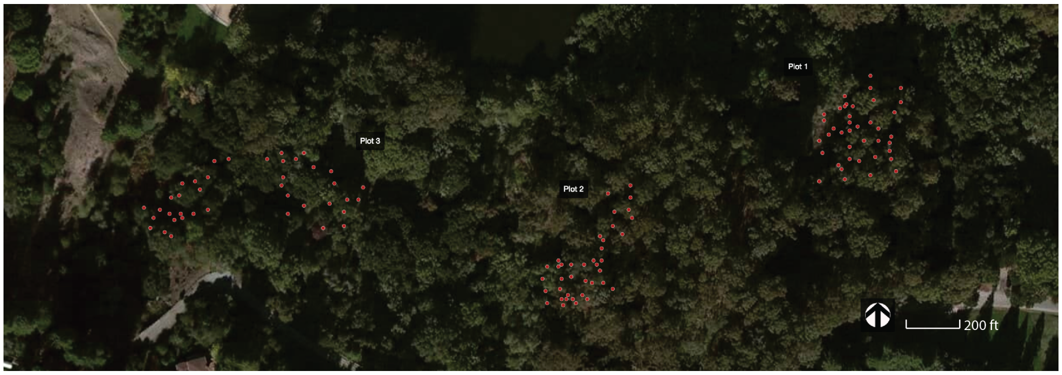


Figure 2. Aerial view Tilden Regional Park Trapping Sites - 120 Sherman Trap Locations 1. Dense Eucalyptus stands and Poison Oak; 2. Mix of Oak/Bay, Eucalyptus, Blackberry, Ferns, and Poison Oak; 3. Typical Oak/Bay Woodland with no Eucalyptus.

Data Analysis

I compared the population size and overall diversity of these rodent species among varying habitat composition to determine overall ecosystem health and trends in distribution. Analysis was run comparing different species' locations relative to the plant composition it was trapped in. Through initial trapping, trends between specific species and habitat composition became apparent and further highlighted through NMDS analysis, therefore I specifically analyzed *Peromyscus maniculatus* and *Peromyscus truei* population densities to understand habitat correlation of the *Peromyscus* species; this was later confirmed through Kruskal-Wallis analysis for non-normal data. Secondly, I examined *Neotoma fuscipes* distribution throughout the plots in relation to habitat composition, as this species is typically associated with healthy native habitat and can be used as an indicator of stability for this ecosystem (Cranford 1982). The analysis tests I used included display of mean populations per plot as well as similar graphic displays through RCommander™ and RStudio™ for individual species to vegetation relationships. Each test was run with data sorted by both individual species and total species caught, also by plot both over total time (nine months) and seasonally. I examined the density of species overall through the three plots; determined species and vegetation correlations; and analyzed aspects of overall ecosystem health.

RESULTS

Species Distribution Across Plots

To examine if invasive Eucalyptus into Oak/Bay woodlands caused a change in rodent species distribution from the original native ecosystem, I distinguished Eucalyptus as a gradient variable between 3 plots to determine if the invasive species would cause a change in overall population distribution or species diversity based on vegetation composition. I found little variation between habitat composition and rodent population density. Eucalyptus forests had an average count of 2.0 individuals per species type and generated an average of 50% of the rodents trapped over 9 months as apposed to Oak/Bay woodlands which had an average count of 2.6 individuals per species type and found 54.2% of the rodents trapped throughout 9 months, both habitat types supported a similar number of individuals overall. Mixed Eucalyptus and Oak/Bay woodlands had a lower density of individuals with an average count of 1.0 and averaged 45.8% of the individuals trapped across 3 plots [Figure 3 (4)]. Mixed Eucalyptus and Oak/Bay woodlands were found to have a higher proportion for one or two individuals per trap over 9 months across the 40 trap transect; Eucalyptus had a slightly higher proportion of individuals caught in the same location: three to five rodents per trap over 9 months; whereas Oak/Bay woodlands have highest concentrations of individuals per trap – higher proportion for four to six individuals – but less traps over the 40 trap experimental landscape over 9 months [Figure 4]. Species diversity was generally stable between plots with indication that all species were found in proximity to all vegetation composition types studied, the only differences in species distribution for *Microtus californicus* favoring

Plot 3 (pure Oak/Bay woodland) and *Mus musculus* favoring Plot 2 (mixed Eucalyptus and Oak/Bay) [Figure 5].

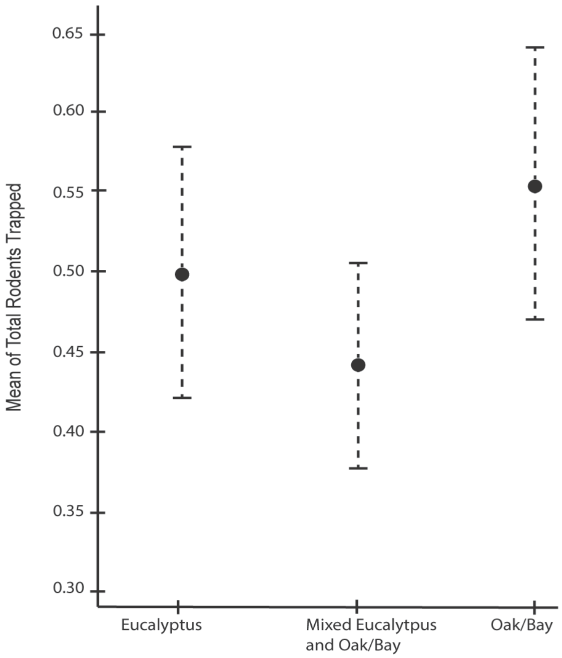


Figure 3. Percentage of Individuals per Plot against Total Trapping Area Trap success rate normalized against overall trap total for 3 habitat types. Average count of rodents individuals per species trapped over nine months between three habitat composition plots normalized by 40 traps (120 traps total). Eucalyptus – 2.0, mixed Eucalyptus and Oak/Bay – 2.6 Oak/Bay woodlands - 1.0

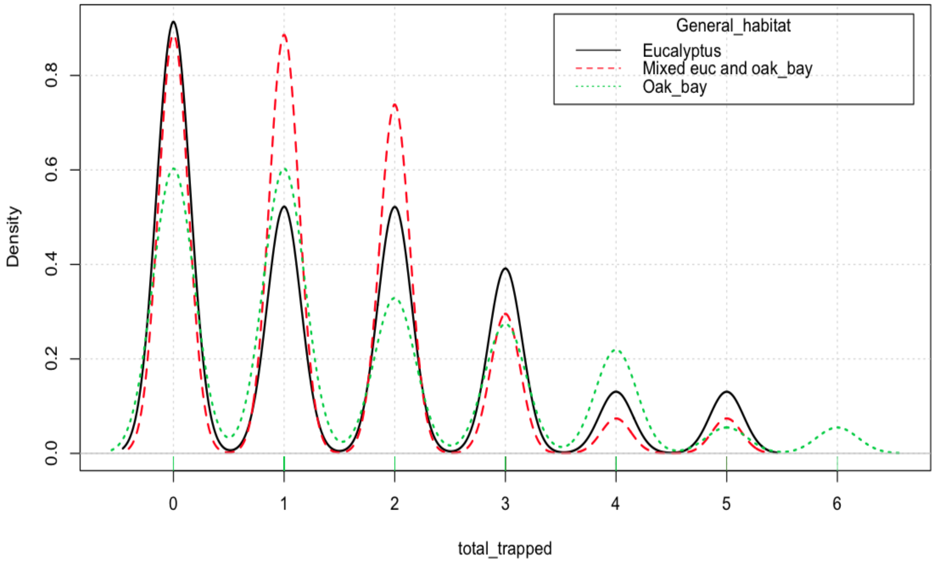


Figure 4. Total Trap Density by General Habitat Plot Relative spatial density of the total rodents trapped over nine months by each 120 trap locations across three plot vegetation compositions: Eucalyptus - higher proportion of trap density

around 4 rodents per trap; mixed Eucalyptus and Oak/Bay - higher proportion of trap density between 1 to 2 rodents per trap; Oak/Bay - higher proportion of trap density between 4 to 6 rodents per trap.

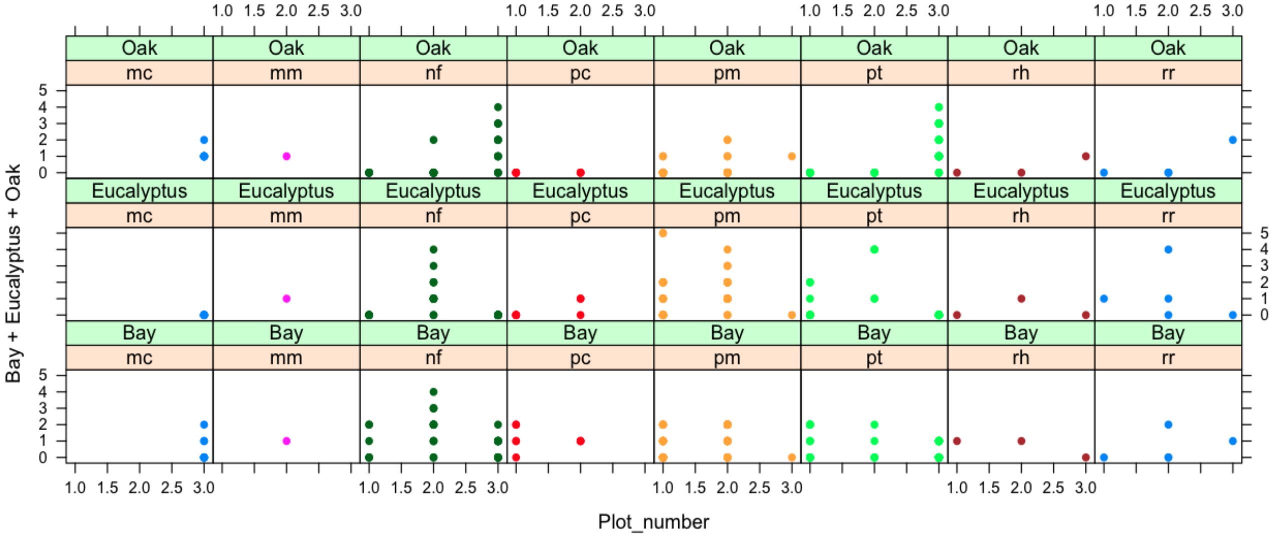


Figure 5. Specific Trap Tree Composition by Species Individual tree composition and relative density in relation to each rodent species trapped over 9 month: mc - *Microtus californicus,* mm - *Mus Musculus*, nf - *Neotoma fuscipes*, pc - *Peromyscus californicus*, pm - *Peromyscus maniculatus*, pt - Peromyscus truei, rh - *Reithrodontomys megalotis*, and rr - *Rattus rattus*.

NMDS variable analysis test was run to demonstrate species relationships with species as test vectors and plot and season as test factors [Figure 6]. A goodness of fit test found Pr(>r) = 0.001 for Plot as a factor, but was not statistically significant for season (Pr(>r) = 0.599) [Appendix 2]. Species examined as vectors found Pr(>r) statistically significant for *Peromyscus truei, Peromyscus maniculatus*, *Peromyscus californicus*, and *Neotoma fuscipes,* all other species were statistically insignificant and *P. californicus* was further excluded due to low sample size [Appendix 3].

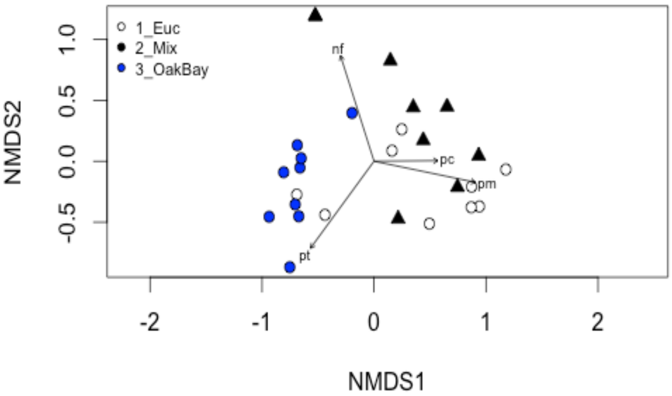
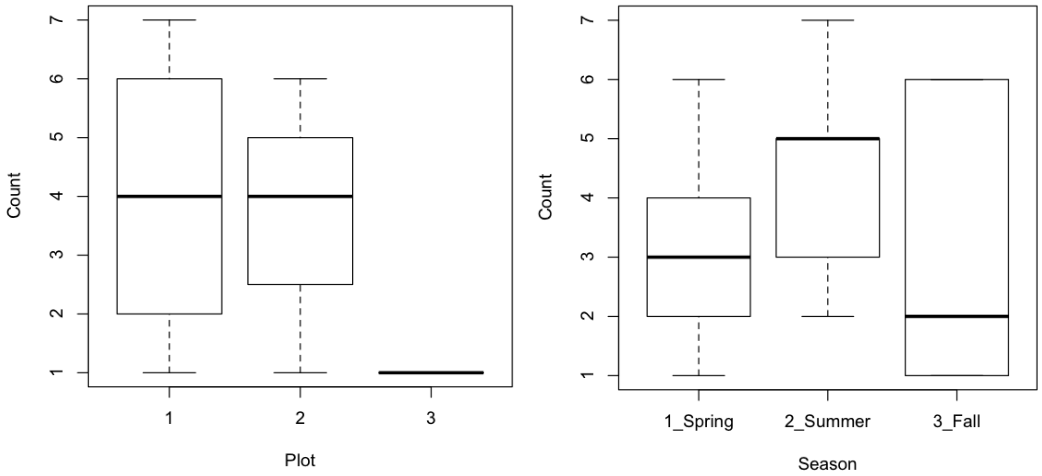


Figure 6. NMDS Analysis of Significant Species and Plot Variation. This graph demonstrates the correlation of species against general habitat variations. Goodness of fit found significant factor between Plot [Pr(>r) = 0.001] and significant vectors for *Peromyscus maniculatus*, *Peromyscus truei*, *Peromyscus californicus*, and *Neotoma fuscipes* [Pr(>r) < 0.002].

Trends in Individual Species Distribution

An Anova Model test for plot type against all individual occurrence, found p = 0.0429 demonstrating significant variation between species in each plot. Similarly, Anova Model testing the count of all species found throughout this study showed variation p = 0.0017 for all species and p = 0.0014 for *Peromyscus maniculatus*, *Peromyscus truei*, and *Neotoma fuscipes*. Further analysis of these three key species examined count variation demonstrated as total number of individuals per species for each month displayed in relation to Plot and Season; season was categorized by three month periods [Figure 7]. In regards to individual species variation, *Peromyscus maniculatus* showed no statistical significance [Appendix 4]. *Peromyscus truei* occurrence demonstrated statistical significance for individual count against plot with p = 0.0115 [Table 1][Appendix 5]. *Neotoma fuscipes* occurrence demonstrated statistical significance for individual count against season with p = 0.0317 [Table 1][Appendix 6].

<u>*Peromyscus maniculatus:*</u>



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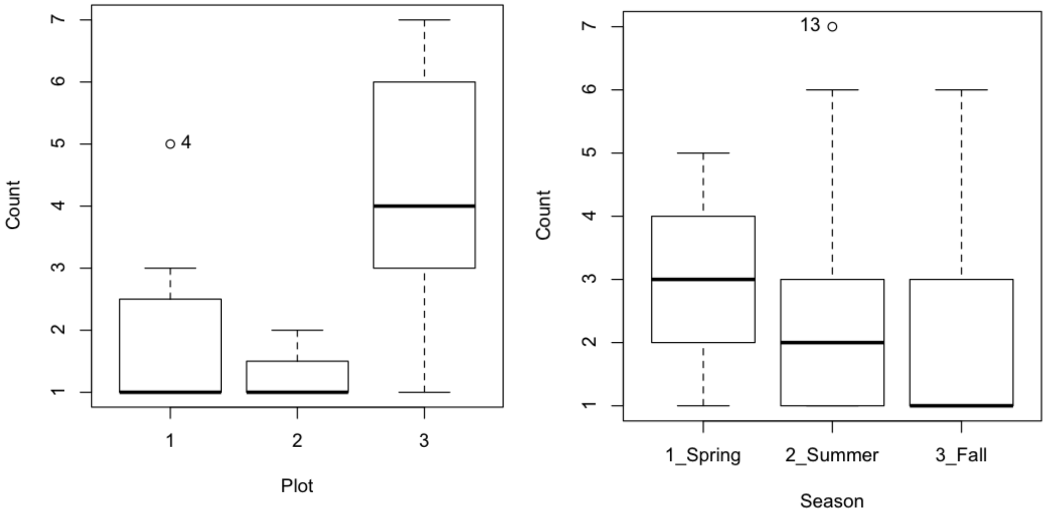

Neotoma fuscipes:

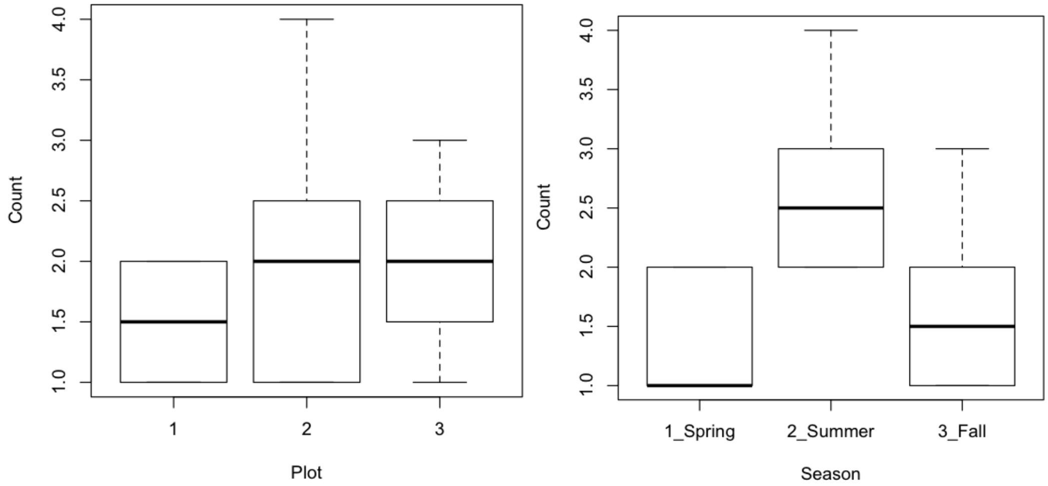

Figure 7. Analysis of species count by Plot and Season. Count data for total number of *Peromyscus maniculatus*, *Peromyscus truei,* and *Neotoma fuscipes* based on Plot composition (left) and Seasonal variation (right) based on three month intervals (See Table # for (p) levels of statistical significance).

Species	*Peromyscus maniculatus*	*Peromyscus truei*	*Neotoma fuscipes*
Plot (p)	0.3412	0.01152	0.5986
Season (p)	0.5139	0.6635	0.03167

Table 1. Summary of p-values between Species and Plot/Season. Kruskal-Wallis analysis for non-normal data. Highlighted are statistically significant values, which includes: plot variation between *Peromyscus truei* populations and seasonal variation for *Neotoma fuscipes* populations.

Though all species trapped were found in each habitat type, specific trends in *Peromyscus maniculatus, Peromyscus truei*, and *Neotoma fuscipes* distributions showed gradient changes in respect to Eucalyptus density. There was an abundance of *Peromyscus maniculatus* trapped in Plot 1, however an absence of this species in Plot 3 (only one *Peromyscus maniculatus* trapped in 40 traps/9 months). *Peromyscus truei* was found abundantly in all three plots; this species was found in higher density in pure Oak/Bay habitat [Figure 8]. *Peromyscus maniculatus* and *Peromyscus truei* distributions were inversely correlated to tree composition between plots based on Eucalyptus and Oak composition, both species were prevalent in correlation with Bay trees.

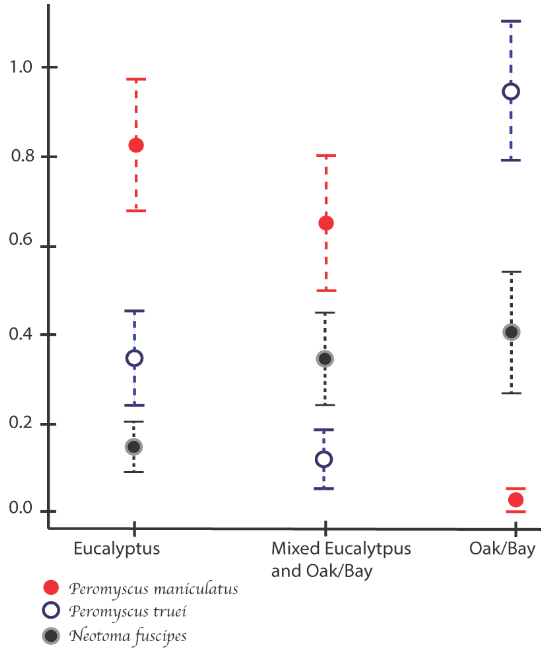

Figure 8. Mean Percentage of Total Trapped *Peromyscus maniculatus*, *Peromyscus truei, and Neotoma fuscipes*. Mean of total pt/pm/nf individuals per plot composition over nine months.

The presence of *Neotoma fuscipes*, as an indicator of ecosystem health, was examined to determine if invasive Eucalyptus alters the stability of the Oak/Bay ecosystems as a gradient across the three habitat composition plots. *Neotoma fuscipes* was found in all three habitat compositions, which initially indicated a generally stable environment, however overall individual species totals decreased with increased Eucalyptus presence [Figure 8]. *Neotoma fuscipes* was found to favor poison oak ground cover with Eucalyptus and more open ground habitat in Oak/Bay woodlands. The preferred ground cover for *Neotoma fuscipes* was 40-95% open ground, 0-100% poison oak, 50-75% blackberry, 0-40% other, 0-10% fern [Figure 9].

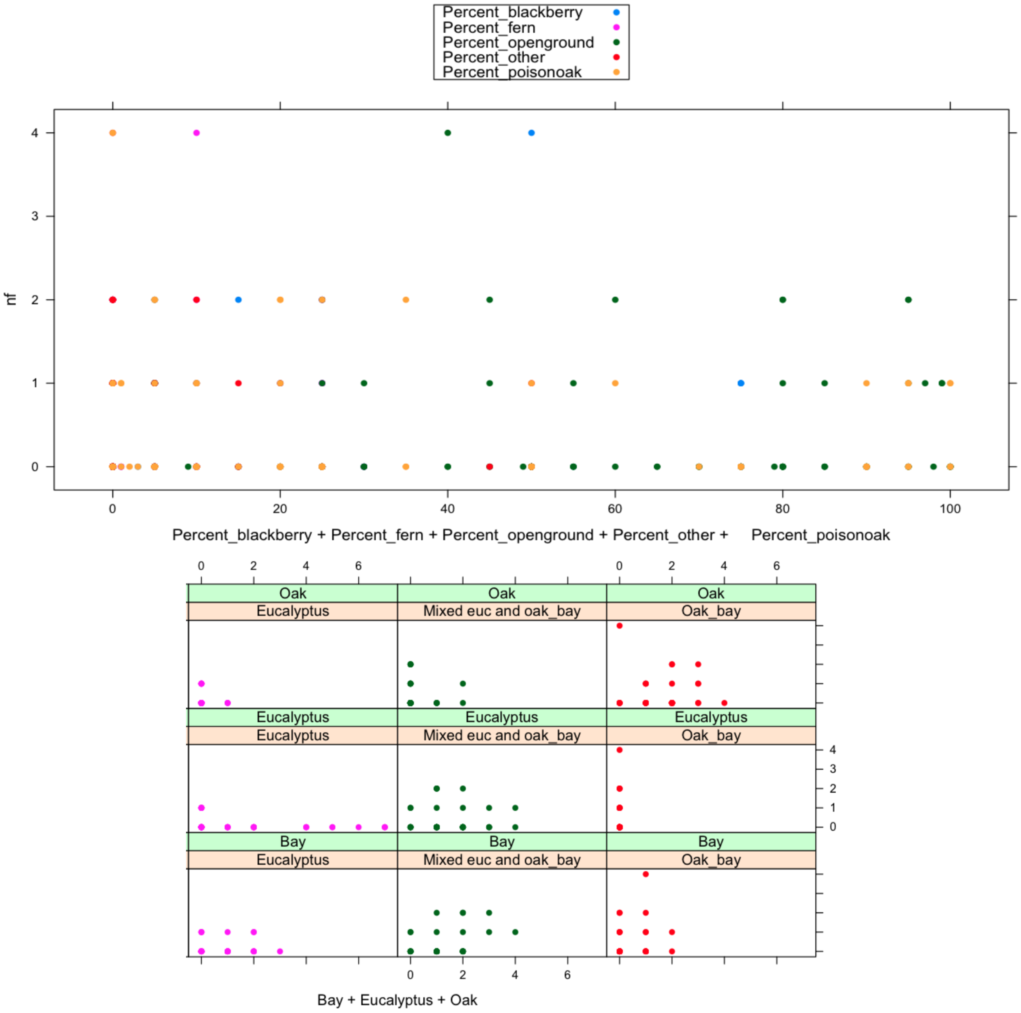

Figure 9. *Neotoma fuscipes* Preferred Habitat Composition nf - *Neotoma fuscipes.* (top) Presence of nf individuals in relation to tree composition of each trap of nf over nine months. (bottom) Ground cover composition where each trapped nf individual was collected over nine months.

DISCUSSION

General Habitat Composition and Total Species Distribution

To understand overall habitat health and ecosystem stability, I examined factors of rodent distribution correlated to habitat vegetation in respect to both overall plot composition and specific rodent species habitat at individual trap locations. With an initial focus on invasive Eucalyptus as the cause of habitat disruption to original native ecosystem structure, I found that Eucalyptus forests and Oak/Bay Woodlands support a similar number of individuals overall; while mixed Eucalyptus and Oak/Bay Woodlands had a lower total number of individuals. I found insignificant variation between habitat composition and total number of rodent individuals in each plot. I found Eucalyptus forests to have a mean of 2.0 (50%) rodents over 9 months, and Oak/Bay woodlands with a mean of 2.6 (54.2%), which demonstrated that both habitats supported a similar number of individuals overall; however, mixed Eucalyptus and Oak/Bay woodlands have a lower density of individuals of 1.0 (45.8%), highlighting a period of transitionary ecological depression as Eucalyptus grows into Oak/Bay altering the habitat.

When examining how the rodents were distributed through the respective area of each plot, I found mixed Eucalyptus and Oak/Bay woodlands to have a higher proportion for 1 to 2 individuals per trap over 9 months, indicating a less dense population spread out over more area. Whereas Oak/Bay woodlands had the highest concentrations of individuals per trap with a higher proportion for 4 to 6 individuals over 9 months, demonstrating denser population groups with restricted or lower dispersal use of the habitat in Plot 3. The Eucalyptus monoculture habitat had a higher proportion of trap densities around 4 rodents to the same relative traps over 9 months, indicating overall habitat density higher than mixed transitional habitat but lower than native Oak/Bay woodlands. The density and distributuion of rodents across a landscape does not necessarily speak to ecosystem health, but it can be used as a comparative factor between rodent species and possible allocation of resources across the landscape (Lynch 1994).

In regards to species diversity across the three tested habitat types and three main tree species (Eucalyptus, Oak, and Bay), I found all rodent species to reside in the general proximity to all tree types with the exception of *Microtus californicus* and *Mus musculus. Microtus californicus* was found to favor Plot 3 (pure Oak/Bay woodland), and was never trapped in Plot 1 or Plot 2. *M. californicus* favor grassland habitat with access to water for increased lush vegetation, the main component of their diet (Berry 1959). The lack of *M. californicus* in the plots with Eucalyptus may be the results of the Eucalyptus invasive habitat change itself or just a results of seasonal cyclical population densities of *Microtus* (Ostfeld 1985). Arvicoline rodents, such as *Microtus californicus*, follow a little understood cyclical density pattern where the species will remain at low densities for many years and then increase dramatically in density for a few months only to return back a low density (Ostfeld 1985). This cyclical behavior may explain why *Microtus californicus* were found in low or absent from portions of the test site. The concentration of this species in Plot 3, Oak/Bay woodland, can be explain by the herbaceous diet of voles relying on particularly lush green vegetation (Ostfeld 1985). *M. californicus* were trapped in German Ivy (*Delairea odorata*), a highly invasive plant, and mixed grasses, in close proximity to Poison Oak (*Toxicodendron diversilobum*) and Western Sword Fern (*Polystichum munitum*); I concluded that the location of *M. californicus* is another example of species distribution based on resource location (creek, ivy, and grasses), which correlated with the increased focal density at this location but did not form any direct causative relationship between Eucalyptus trees and species location.

Mus musculus, a common house mouse, which is typically more related to human association rather than species specific social patterns, was found to favor Plot 2 (mixed Eucalyptus and Oak/Bay) (Brown 1953). Though this does not explain why *M. musculus* was not trapped in other plots, the correlation to human inhabitants of Lake Anza, and the more open and trail trodden area of Plot 2 explains the location of this species in relation to the overall test site. According to a study conducted on the social behavior, reproduction, and population changes in *Mus musculus*, the species are extremely adaptable and are found in many diverse habitat including cold storage warehouses and open fields (Brown 1953). Across my trapping transects, I only found *Mus musculus* in the mixed Eucalyptus and Oak/Bay habitat; in addition, within this 40 trap transect, *Mus* were only trapped in the more “open” areas with increased grasses on the forest floor and decreased poison oak and blackberry. Though I would expect to have trapped more *Mus* overall throughout my three trapping plots, only catching *Mus* in the open grassland region of this transect is further resource association of the landscape by the rodents; this concept may be explored further in future studies.

The data demonstrated a change in species diversity and distribution between habitat composition across general habitat types. Invasive Eucalyptus (Plot 1) was slightly lower than Oak/Bay woodlands (Plot 3) in species diversity and distribution, but both generally higher than mixed Eucalyptus and Oak/Bay woodlands (Plot 2). The lowest diversity and distribution rates were found in the mixed Eucalyptus and Oak/Bay plots which are facing a shift in habitat composition and represented the effect of native species coping with habitat change and negative alteration of a previously productive habitat.

Trends in Individual Species Distribution

Of all species trapped throughout the study site, *Peromyscus maniculatus, Peromyscus truei*, and *Neotoma fuscipes* demonstrated strong habitat distribution trends in correlation with Eucalyptus density. The abundance of *Peromyscus maniculatus* trapped in Plot 1 and not Plot 3 indicates a preference towards invasive Eucalyptus forests; whereas *Peromyscus truei* was found in all three plots, this species favoring the native pure Oak/Bay habitat. Examining NMDS1 and NMDS2 community ordination showed clear separation of three plot habitat types as well as preference for *Peromyscus maniculatus* and *Peromyscus californicus* to favor Plot 1 and 2, *Peromyscus truei* favoring Plot 3, and *Neotoma fuscipes* found to favor Plot 2 and 3 [Figure 6].

Peromyscus maniculatus and *Peromyscus truei* distributions were inversely correlated to tree composition between plots – based on Eucalyptus and Oak composition – both generally favoring Bay trees [Figure 8]. *Peromyscus maniculatus* favored Eucalyptus habitat, explained the studied and documented ability of *P. maniculatus* to thrive in recently disturbed habitats (Lambert 2010). *Peromyscus truei* are tree climbing mice and rely more on native tree composition for survival (Berry 1959).

Neotoma fuscipes were found in all three habitat compositions in relatively abundant numbers indicating a generally stable environment (Martino et al 2005). However, the proportion of *Neotoma fuscipes* continuously decreased with increased Eucalyptus tree density. This depression in population suggests that Eucalyptus presence reduces ecosystem health. Rodents, such as *Neotoma fuscipes*, utilize components of foliage excess that is shed from the tree including bark, sticks, sap, and other biological material (Martino et al 2005). *Neotoma fuscipes* lives, feeds, and breeds in colony style nests of sticks and bark ranging in size from under a foot to a few meters (Lynch 1994). Without these component materials, the species would not be able to successfully establish due to Eucalyptus litter flooding the understorey in Eucalyptus monotypic habitats. *Neotoma fuscipes* species richness is typically associated with distribution and abundance in relation to a moderate canopy and moderate to dense understory (Marino et al 2005). As Eucalyptus alters the canopy and understory composition, *Neotoma fuscipes* face a habitat shift against their current niche preference resulting in decreased abundance.

Ecosystem Health Summary

The summary of overall ecosystem health takes into account general plot productivity, rodent spatial density, foliage composition relative to trap location, as well as individual species examples of preference towards Oak/Bay habitat over invasive Eucalyptus. When examining general plot productivity, I found Oak/Bay woodlands to contain a higher population density throughout the ecosystems studied. The population density then decreased as the ecosystem enters a stage of invasion from Eucalyptus into a mixed habitat with combined low population totals and low species diversity. This population and speciation decrease in the mixed habitat stabilizes as the ecosystem shifts into a Eucalyptus monoculture allowing the population and species densities to rise, though still remaining lower than the productivity of Oak/Bay woodlands. *Peromyscus maniculatus* and *P. truei* demonstrated individual species habitat use partitioning due to invasive Eucalyptus disturbance of the habitat. These species demonstrated an inverse relationship based on tree composition. Generally, increased Eucalyptus led to decreased species diversity and decreased proportion of population totals, particularly in regards to ecological health indicator species *Neotoma fuscipes*. In conclusion, invasive Eucalyptus into Oak/Bay woodlands has an overall negative effect on ecosystem health and small mammal productivity in Tilden Regional Park, and as initial invasion progresses into a monotypic Eucalyptus habitat has a positive effect on *Peromyscus maniculatus* populations.

Limitations and Future Directions

This research was limited by general trapping equipment available, interactions with the public, and overall trap success. I was only able to utilize 80 Sherman traps (40 per trap set) to run 120 traps over 2 day trapping periods. Ideally, I would have set all traps on the same night to avoid weather fluctuations affecting overall trap success. Public interaction while collecting data resulted in the loss of 11 traps over 9 months, all from Plot 3, assumed to be stolen. This loss in traps affected my data for the respective months where data was collected for less than 40 traps. Overall, trap success fell to a minimum of 1 out of 40 (5%) in late fall (November) and rose to 13 out of 40 (32.5%) in mid summer (August), this fluctuation was possibly a result of breeding season and general seasonality, but trap success remained relatively low throughout the 9 month period of data collection; which could possibly affect the validity of my conclusions due to small sample size. Limitations of experiments that use trapping transects generally occur through some trap error; in this study, the overall limiting factor would be relative sample size derived from trap success or sample size of habitats tested in Tilden Regional Park.

Continued study of the effect of invasive Eucalyptus into native Oak/Bay Woodland habitat is recommended through a larger sample size, more test sites with habitat variation, and longer study time with examination of seasonal variation. This study examined three generalized habitat types with varying degrees of Eucalyptus invasion. Future studies might increase the total number of traps used as well as increase the sampled area to include more variation of Eucalyptus invasion. The study might also be conducted with varying equipment such as Tomahawk traps to catch larger mammals or change of bait ingredients. Future studies might also test for population change over time with increased Eucalyptus concentration growth or against seasonal weather pattern fluctuations such as El Nino rains and the past drought conditions.

Broader Implications

Eucalyptus is a prevalent invasive plant species throughout California and easily dominates much of the native plant habitat (McBride 2015). It is also a major fire concern because of its heavy litter composition and prominent oils which can burn very hot and for long periods of time (Lambert

2010). Understanding species diversity within the Eucalyptus stands versus a typical Oak/Bay Woodland can help community members gain a better understanding over the micro-ecosystems created by the Eucalyptus. Eucalyptus increases fire risk for communities in wildland interface zones; understanding the effect of this invasive may further efforts to remove this tree as a fire reduction precaution without disrupting species that may utilize this habitat. As well as understanding the effect of the Eucalyptus on rodent diversity, this study found connection between *Peromyscus maniculatus*, a prominent carrier of Hantavirus, and increased Eucalyptus composition (CDC 2012). Increased populations of *Peromyscus maniculatus* could be another strong argument in the reduction of Eucalyptus trees as the species is more prominent there. Understanding the Eucalyptus micro-ecosystem can help support restoration decisions and make judgments over the ecosystem health, possibly through removal of the Eucalyptus stands.

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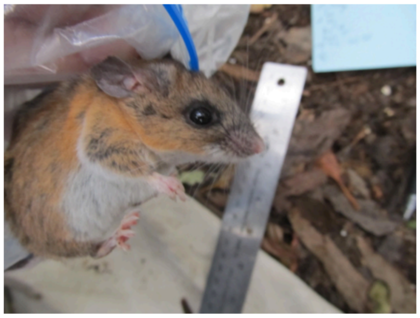
Appendix

Appendix 1. Rodent species trapped in Tilden Regional Park.

Peromyscus maniculatus

Peromyscus truei



Peromyscus californicus

Neotoma fuscipes

Rattus rattus

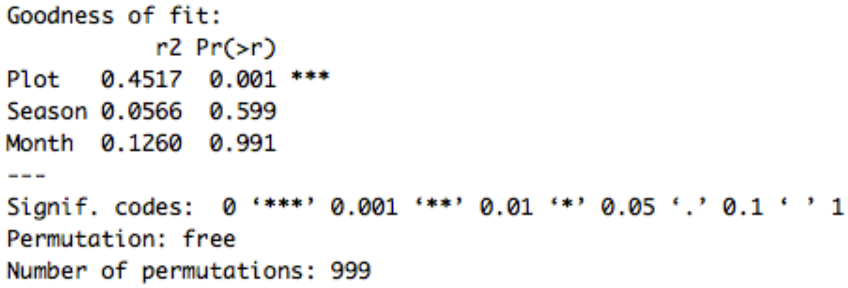
Microtus californicus

Reithrodontomys megalotis

Mus musculus

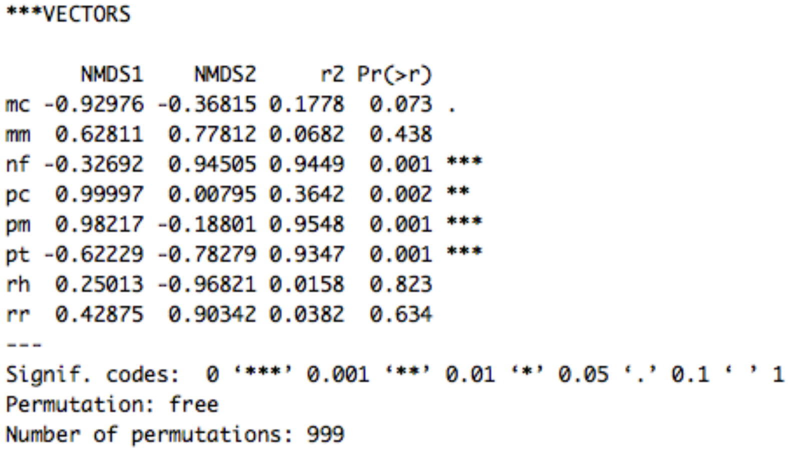
Appendix 2. NMDS analysis of factor and vector significance.

***Factors:



```
Goodness of fit:
           r2 Pr(>r)
Plot   0.4517  0.001 ***
Season 0.0566  0.599
Month  0.1260  0.991
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Permutation: free
Number of permutations: 999
```

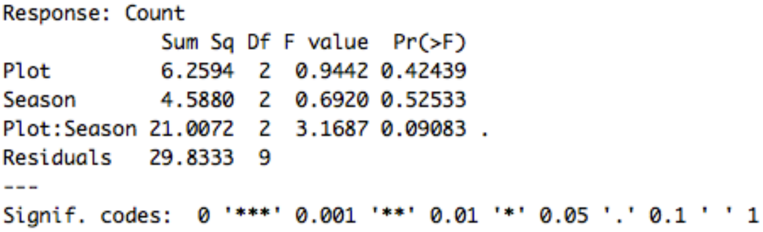
Appendix 3. NMDS analysis of factor and vector significance.



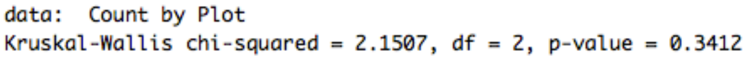
```
***VECTORS

      NMDS1    NMDS2     r2 Pr(>r)
mc -0.92976 -0.36815 0.1778  0.073 .
mm  0.62811  0.77812 0.0682  0.438
nf -0.32692  0.94505 0.9449  0.001 ***
pc  0.99997  0.00795 0.3642  0.002 **
pm  0.98217 -0.18801 0.9548  0.001 ***
pt -0.62229 -0.78279 0.9347  0.001 ***
rh  0.25013 -0.96821 0.0158  0.823
rr  0.42875  0.90342 0.0382  0.634
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Permutation: free
Number of permutations: 999
```

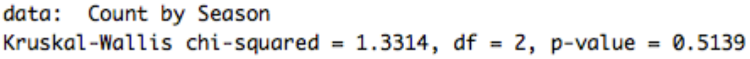
Appendix 4. P maniculatus:



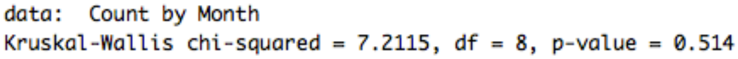
```
Response: Count
             Sum Sq Df F value  Pr(>F)
Plot         6.2594  2  0.9442 0.42439
Season       4.5880  2  0.6920 0.52533
Plot:Season 21.0072  2  3.1687 0.09083 .
Residuals   29.8333  9
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```



```
data:  Count by Plot
Kruskal-Wallis chi-squared = 2.1507, df = 2, p-value = 0.3412
```

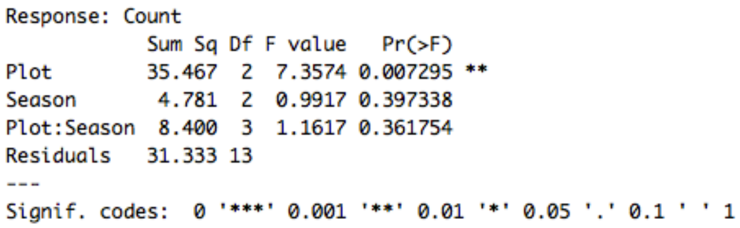


```
data:  Count by Season
Kruskal-Wallis chi-squared = 1.3314, df = 2, p-value = 0.5139
```



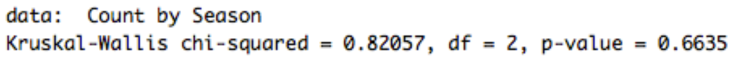
```
data:  Count by Month
Kruskal-Wallis chi-squared = 7.2115, df = 8, p-value = 0.514
```

Appendix 5. P. Truei:

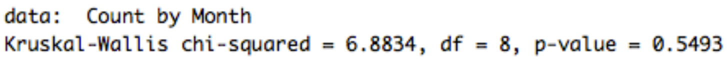


```
Response: Count
            Sum Sq Df F value   Pr(>F)
Plot        35.467  2  7.3574 0.007295 **
Season       4.781  2  0.9917 0.397338
Plot:Season  8.400  3  1.1617 0.361754
Residuals   31.333 13
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

```
data:  Count by Plot
Kruskal-Wallis chi-squared = 8.9282, df = 2, p-value = 0.01152
```

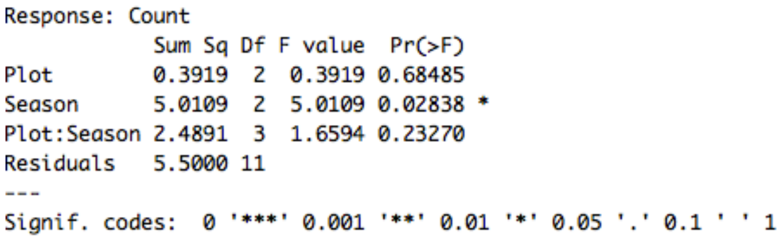


```
data:  Count by Season
Kruskal-Wallis chi-squared = 0.82057, df = 2, p-value = 0.6635
```

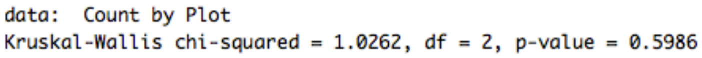


```
data:  Count by Month
Kruskal-Wallis chi-squared = 6.8834, df = 8, p-value = 0.5493
```

Appendix 6. Neotoma fuscipes:

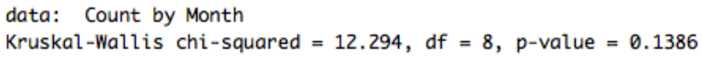


```
Response: Count
            Sum Sq Df F value  Pr(>F)
Plot        0.3919  2  0.3919 0.68485
Season      5.0109  2  5.0109 0.02838 *
Plot:Season 2.4891  3  1.6594 0.23270
Residuals   5.5000 11
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```



```
data:  Count by Plot
Kruskal-Wallis chi-squared = 1.0262, df = 2, p-value = 0.5986
```

```
data:  Count by Season
Kruskal-Wallis chi-squared = 6.9047, df = 2, p-value = 0.03167
```



```
data:  Count by Month
Kruskal-Wallis chi-squared = 12.294, df = 8, p-value = 0.1386
```