PEROMYSCUS POPULATION DYNAMICS AND SEED PREDATION OF *LUPINUS PERENNIS* IN AND NEAR OAK SAVANNAS OF NORTHWEST OHIO

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A Thesis

Submitted to the Graduate College of Bowling Green
State University in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE

August 2009

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ABSTRACT

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Wild blue lupine (*Lupinus perennis*) in the Oak Openings Region of Northwest Ohio is an important nitrogen fixer and serves as an essential food source for the federally endangered Karner Blue butterfly (*Lycaeides melissa samuelis*). We focused on potential factors that might be affecting mice predation on wild blue lupine seeds in oak savannas. Previous studies have found that: wild blue lupine responds favorably to prescribed burns (Grigore and Tramer 1996); mice *(Peromyscus spp.)* foraging success decreases with increased leaf litter depth (Reed et al. 2005); mice seed predation on bush lupine (*Lupinus arboreus*) showed decreased seedling recruitment, seed bank size, and adult numbers (Maron 2005, Kaufmann 2006); and seed predation increases when an herb/shrub layer is present at edges (Kollmann and Buchard 2002). This suggests that management practices and vegetation affect foraging behavior. We used seed trays placed in the open or the edge of oak savannas to estimate predation rate, estimated mice abundance with a mark-recapture study, and used tracking tubes to evaluate mice distribution. We performed vegetation surveys, recorded weather and management histories, and used GIS to find spatial variables to assess how they affect seed predation. Our major findings were that mice seed removal for the summer averaged at 22 percent, seed removal varied significantly across time ($P < 0.05$), was more likely in areas with increased crypto-biotic crust ($P < 0.0001$) and rates varied under different management histories ($P < 0.05$). Only *P. leucopus* was found during live trapping and they were trapped in similar numbers for both woodlands and oak savannas. Mice abundance estimates were similar when comparing the use of live trapping versus tracking tube data. Mice tracks were influenced by bare ground (June) ($P = 0.0002$), distance from water ($P = 0.0032$), and vegetation sheltering the tracking tubes ($P = 0.0115$). There were also a few hot spots of mice activity and seed predation, although they were not influenced by any environmental variables. Overall, this study increased our understanding of the relationship between mice and lupine populations in this globally rare ecosystem.

AKNOWLEDGEMENTS

I would like to thank my encouraging and enlightening advisor, Dr. Karen Root, for her dedication to this project. My committee members, Dr. Helen Michaels and Dr. Enrique Gomezdelcampo, were of great assistance with their wealth of knowledge that I hope to have soaked up. Dr. Peter Gorsevski for assisting and pointed me in the right direction with GIS. The project would not have been possible without the help of my volunteers, Sarah Woods, Rebecca Witters, and Jeff Barger, who spent many hours outdoors with me gathering data. I am also grateful to the Metroparks of the Toledo area, especially all those at Oak Openings Preserve, who enabled me to perform my experiments and gave me valuable data. I am thankful to also have the undying support of my husband Anthony and my family members. The other members of the Root lab; Melanie Coulter, Hillary Harms, Amanda Kuntz, Jessica Sewald, Tim Schetter, Steve Wilson, and Lauren Yarrish, have been a great group to work with and have all pitched in on this project in one way or another. Thank you all.

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INTRODUCTION

The Oak Openings Region of Northwest Ohio has many different ecosystems intermixed in a mosaic of small to large habitat patches which have been diminished by human settlement and fire suppression. It contains globally rare communities such as sand barrens, wet/sand prairie, white and pin oak flatwoods, black oak/lupine barrens (oak savanna), and oak woodland that were formed from deposits of postglacial lake sand (EPA 2006). Many endangered or threatened species are dependent on these rare natural communities found in the Oak Openings Region, such as the Karner blue butterfly (*Lycaeides melissa samuelis*), spotted turtle (*Clemmys guttata)*, lark sparrow (*Chondestes grammacus*) and barn owls (*Tyto alba*) (Ohio Division of Wildlife 2008).

This study will focus mainly on oak savannas where wild blue lupine (*Lupinus perennis*) is found, and at the edges of these areas where they transition into oak woodland. The perennial wild blue lupine (lupine) is found in full to partially sunny areas with nutrient poor and sandy soils (Gleason and Cronquist 1991). It disperses its seeds through dehiscing, which means the seedpod will dry and curl to eventually break open under heat and throw the seeds as it breaks. The related bush lupine (*Lupinus arborius*) has a hard seed coat that allows it to stay dormant in a seed bank for up to three years (Maron and Simms 2001). Similarly, wild blue lupine also has a hard seed coat, but it is unknown how long their seeds can remain dormant. Lupine also serves as an essential food source for the larval stage of the federally endangered Karner Blue (*Lycaeides melissa samuelis*), and is a nectar source for state endangered Frosted Elfin (*Incisalia irus*), and Persius Dusky Wing (*Erynnis persius*) butterflies (USFWS 2003). Vegetation density, canopy cover, and aspect are factors that are known to affect the lupine nutritional quality upon which the Karner Blue butterflies depend (Pickens 2006; Pickens and Root 2008).

The white footed mice *(Peromyscus leucopus noveboracensis)* and deer mice *(Peromyscus maniculatus bairdii)* are omnivorous and have a diet that consists of seeds, insects, fungi, flowers, and nuts. They gather seeds/nuts in a cache for winter, and will be active unless they are in extremely low temperatures (Whitaker 1996). In the Midwest, white footed mice are usually found in woodlands or brush land bordering agriculture, and deer mice are usually found in prairies, or brush land (Whitaker 1996). The appearance of the two species is very similar; both have young with grey pelage and adults with brown pelage, but they can be distinguished by the tail, body, and ear length, as well as weight (S. H. Vessey, Bowling Green State University, personal communication). Reproduction is highest in the spring and fall, with a litter of 3-5 for white footed and 2-7 for deer mice (Whitaker 1996). They are a prey species for many larger species of the area such as snakes, hawks, owls, foxes, opossums, raccoons, and badgers.

The ecosystems in the Oak Openings Region occur as a mosaic, where many of the habitats are patchy and dominated by edges. Edge can be defined as the transition zone between one habitat type to the next. More specifically, edge can be the border between herbaceous cover of open habitats such as grasslands and the higher shrub and tree densities of the woodland. Edge effect is described as the changes occurring on the edge because of its presence. Edge effect can be a result from abiotic or biotic factors such as a change in sunlight and soil moisture or seed predation and density (Murcia 1995). This edge transition can be measured locally at the first meter into the interior

(Kollmann and Buschor 2002), and at a 10-15 m margin where vegetation is denser and mice are more abundant (Chauvet and Forget 2005). The temperate forest edge effect on vegetation is no more than a 50 m wide margin into the forest (Matlack 1993).

Understanding the interaction between mice and lupine in ecotones can further help us protect the lupine population and other species that depend on it. Chapter 1 assessed mice seed predation rates upon lupine, as well as the influences environmental variables had on seed predation at different scales. In Chapter 2 we have estimated the abundance, survival and recapture probabilities for mice. We compared the estimates from live trapping and tracking tube sampling to see if they were similar. Areas of above average traffic and seed predation, as well as mice and track presence were assessed for influences from environmental variables. With this information, we then predicted where mice and lupine seed predation was likely to be based on the environmental variables that influence them. We also assessed what effect mice had on the lupine population through seed predation and made recommendations to manage lupine in response to mice seed predation.

CHAPTER I. MICE SEED PREDATION FACTORS

INTRODUCTION

The Oak Openings Region of Northwest Ohio has many different ecosystems intermixed in a mosaic of small to large habitat patches which have been diminished by human settlement and fire suppression. Currently oak savannas are only found on 0.02 % of the landscape in the Midwest Region of the United States (Nuzzo 1985). Oak Savannas can be described as an area of scattered oak dominated canopy cover (5-80%) on well-drained, sandy soils created from glacial outwash, and have an understory consisting of graminoids and shrubs with indicator species such as little blue stem and wild blue lupine (Faber-Langendoen 2001).

This study focused mainly on oak savannas where wild blue lupine (*Lupinus perennis*) is found, and at the edges of these areas where they transition into oak woodland. We describe oak woodland as an oak dominant area with 80 - 100% canopy cover based on the Faber-Langendoen's (2001) description of Black Oak – White Oak / Blueberry Forests. The perennial wild blue lupine (lupine) is found in full to partially sunny areas with nutrient poor and sandy soils (Gleason and Cronquist 1991). Lupine also has a hard seed coat, but it is unknown how long their seeds can remain dormant in a seed bank. Lupine is an important indicator of oak savanna and valuable for its nitrogen fixing ability, which increases nitrogen availability for associated non-fixing species (Lee et al. 2003, USFWS 2003). It also serves as an essential food source for the larval stage of the federally endangered Karner Blue butterfly (*Lycaeides melissa samuelis*) (USFWS 2003). Lupine grows best in full sun, but Karner Blue butterfly larvae have been shown to grow faster on lupine in partial sun (Grundel et al. 1998). The effects of small mammal seed predation, specifically white footed mice (*Peromyscus leucopus*) and deer mice (*Peromyscus maniculatus*) on wild lupine have not been studied in this area. We hypothesized that lupine seed predation by mice does occur and that this factor contributes to the lupines' potentially threatened status (Ohio Division of Natural Areas and Preserves 2009) in Ohio.

Current rodent population dynamics and their distribution are unknown for the Oak Openings Region. Previous research on mice in Northwest Ohio has been mostly on woodland population demographics and behavior (Jacksy 1997, Jacquot and Vessey 1998, Lewellen and Vessey 1999). Preliminary data indicated that mice eat lupine seeds, although the rate of seed predation and if predation varies due to environmental factors was unknown. Californian studies on bush lupine (*Lupinus arboreus*) showed that mice seed predation decreased seedling recruitment, seed bank size, and adult lupine numbers (Kaufmann and Maron 2006, Maron and Kaufmann 2006). By examining the population abundance of *P. leucopus* and *P. maniculatus* in relation to their distribution and amount of seed predation, we could assess what effect they might have on the lupine population.

The ecosystems in the Oak Openings Region occur as a mosaic, where many of the habitats are patchy and dominated by edges. Edge effect is described as the changes occurring on the edge because of its presence. The population dynamics of a plant experiencing an edge effect from rodent seed predation has been shown to be influenced by vegetation structure (Kollmann and Buschor 2002). More structural complexity at the edge from increased shrub and herbaceous plants provides more cover and food availability than the interior (Gehlhausen et al. 2000, Kollmann and Buschor 2002). This edge habitat can lead mice to forage up to 10 m in the adjacent habitat (Wolf and Batzli 2004), which could lead mice to lupine habitat. In this study, edge will be defined as in Kollmann and Bushor (2002), and will be considered as a 20 m wide margin that separates oak savanna and woodland.

Protected areas of oak savanna in the Oak Openings Region are being managed through prescribed burning and mowing to restore their natural disturbance regimes, which helps mitigate the impact of human fire suppression and maintain their early successional state. For lupine, research has shown that burning reduces more leaf litter than mowing, and that lupine responds favorably to burning with increased leaf and seed production, seed survival and seedling survival (Grigore and Tramer 1996). For the Oak Openings Preserve Metropark the guidelines are to burn prairies once every two years, savannas once every three years, and oak woodlands once every four to five years (L. Sprow, Oak Openings Preserve Metropark, personal communication). Mowing is also used to reduce shrub and saplings in the early-successional habitat, especially in areas where burning cannot be done. Consideration for the protected butterflies of the area is also taken into account by dividing butterfly habitat up into thirds and rotating every year with 1/3 of the lupine stems burned, 1/3 mowed, and 1/3 left as Karner refugia (USFWS 2003).

The results of management may affect foraging behavior in mice since it has been shown that increased amount of leaf litter decreases mice foraging success (Reed et al. 2005), seedling recruitment (Pavlovic and Grundel in press), and decreases lupine size (Pickens 2006; Pickens and Root 2008). Jacksy (1997) did not find an effect of prescribed burning on *P. leucopus* numbers in the Oak Openings Preserve Metropark, but the study did not examine if changes occurred in foraging behavior. Our study assessed if the management of this habitat mosaic may be influencing mouse distribution and amount of lupine seed predation in oak savanna. We hypothesized that the type of management practices occurring can influence if the seeds are predated upon and by how much. Those areas that are never managed could have the highest amount of seed predation due to an increase in vegetation cover for mice. Maron and Simms (1997) found that bush lupine in grasslands tended to be limited from competition with the grasses. Therefore, allowing succession to take place may severely diminish the lupine population through mice predation and plant competition.

In this study, we focused on questions related to mice seed predation. What is the estimated population density of *P. leucopus* and *P. maniculatus,* and *L. perennis* in the Oak Openings Metropark relative to the oak savanna/woodland edge? What is the estimated predation rate on *L. perennis* seeds by mice? Does seed predation vary over time or space? We also wanted to identify specific indicators of seed predation. Are there spatial indicators of areas with seed predation? Do environmental variables (e.g., leaf litter depth, vegetation height/density, edge, cover, etc.) affect mice seed predation? Does land management affect seed predation? Answers to these questions will enhance our understanding of processes occurring in this unique ecosystem.

METHODS

Study Sites

We estimated the population abundances and distribution of mice, lupine, and the extent of seed predation on six different lupine populations from April to September 2008. Sites were all located in the Oak Openings Preserve Metropark (41” 32-34’N x 83” 50-51’W), which is the largest of the Metroparks of the Toledo area located near

Whitehouse, Ohio (Figure 7). These sites were chosen based on areas of historic, persistent populations of lupine, and then limited to populations that were in oak savanna and adjacent to woodlands (Table 1). Selected sites were at least 0.70 km from each other to reduce the probability that mice populations and management practices would overlap. Site management history was categorized by year of each action and management type (i.e., prescribed burning and mowing), and total management, which included other types (herbicide, pesticide, clearing, and tree girdling/cutting).

Vegetation Surveys

We gathered data for our vegetation survey from 1-m^2 quadrats that were placed every 20 m along parallel transects running North-South through the oak savanna and along the edge of each site (Figure 8). Transects were 20 m apart from each other and kept 20 m away from roads, trails, and water-bodies to minimize other edge effects. Transects covered the oak savanna and crossed over the edge and into the adjacent woodland for live trapping. We recorded the distance from the forest edge at which lupine was no longer found. Percent vegetation-type, canopy cover, vegetation height / density, number of flowering lupine stems, and leaf litter depth were recorded from each 1-m^2 quadrat. These measurements were done once each during the spring and summer (May 13 and June 18) for each site. Percent vegetation-type was categorized for each quadrat into bare ground, leaf litter, sapling/shrubs, graminoids (grass), crypto-biotic crust (soil crust containing moss/lichens/algae), ferns, other angiosperms, and lupine. Photos were taken of each quadrats ground cover in order assess percent vegetation-type in the lab. Each photo had a 10 by 10 grid applied to it in Adobe Photoshop (Adobe Systems Incorporated, San Jose, California, USA), we then counted the number of squares a vegetation-type was found in and converted that into a percentage. Canopy cover was estimated visually from the center of the quadrat. Vegetation height (dm) was measured by placing the Robel pole next to the tallest vegetation in the quadrat (Robel et al. 1970). Vegetation density was measured from the North and East cardinal direction by standing 3 m away from the Robel pole placed at the center of the quadrat and recording the visible height (dm) seen on the pole when viewing it from a height of 1.5 m. The two Robel pole measurements were then averaged. Leaf litter depth was measured in centimeters and averaged from two random points in the quadrat. Percentage of dead wood in the site was estimated visually. Lupine population abundance of each site was estimated by the Oak Openings Preserve staff by counting the number of flowering adult lupine stems in each population.

GIS Analyses

Geographical Information System (GIS) was used to map out the locations of all seed trays and tracking tubes. Locations were found using a (Garmin eTrex) handheld GPS unit, which had an accuracy of 5-10 m. Each location was queried to find landscape variables extracted from satellite data using ArcMap 9.2 (ESRI, Redlands, California, USA). A LANDSAT image (July 7, 2008, Path 20, Row 31) was pan sharpened using color-space transformation to convert the true color images between the red/blue/green and hue/lightness/saturation images so that the spatial resolution of the images was increased to 10 m pixels. From these spatial layers, we extracted estimated NDVI, altitude, and distance from horse trails, distance from water, and distance from roads. Percent land cover type within a 50 m buffer of each site was calculated using a supervised classification raster layer containing 16 land cover types and created using 3

LANDSAT images (Nov. 11, 2005, March 3, 2006, June 23, 2006, Path 20, Row 31) (Scheeter and Root in prep.). The 16 classes of land cover types for this layer were: swamp forests/woodlands, floodplain forests/woodlands, upland deciduous forest/woodlands, upland coniferous forest/woodlands, upland savannas, wet shrubland, wet prairie, mesic prairie, dry prairie, sand barrens, Eurasian meadows, perennial ponds, urban/asphalt, residential, turf/pasture, and croplands (Schetter and Root in prep.).

Mouse Distribution Surveys

Tracking tubes at each site were utilized to analyze mouse distribution, presence and to provide a second abundance estimate. The tracking papers from the tubes were used to count the number of times the tube was entered, where the mouse was located, and which direction it was going. The tubes were set out in March 2008 and left empty a month before data collection to allow mice to acclimate to their presence. The tracking tubes were set up in grids 20 meters apart along the vegetation transect lines, overlapping the lupine population and the woodland edge to identify their distribution (Figure 8). Along each transect line the tubes were placed alternately laying one East-West and the next North-South. Tubes were placed on level ground and held in place by pushing an 18-gauge wire U-hook over it and into the ground.

The tubes were replicated as in Nams and Gillis (2003), and were 3.81 cm diameter PVC piping cut into 36 cm long tubes with a slit cut at the bottom of the tube 3 cm in from each end to allow for drainage (Figure 9). The tracking paper was inkjet printer paper cut into 28 x 7 cm rectangles with 6 x 6 cm wax paper squares glued to each end using a glue stick or all-purpose glue (Figure 9). Each tracking paper had ink applied to the wax paper with a 2.5 cm wide paintbrush. The ink was made from fluorescent powder and mineral oil in a 1:3 gram ratio. Tracking paper was changed once every 4 days. To get the tracking paper to the field already painted we separated them with cardboard and carried them in a plastic container. Those papers with tracks were marked with the tube number and the date. We counted the tracks and identified direction of travel by illuminating the paper with a UV light in the lab.

Seed Predation

To estimate seed predation eight seed trays were set out on the ground at each site, 4 along the woodland edge and 4 within the oak savanna. Seed trays were placed at random spots at least 20 m apart along the transect lines, and were 1-3 m away from the tracking tubes. The seed trays were made with sand put in a flat 25.4 cm aluminum tray with 1 cm high edges that were held in the ground with 18-gauge wire U-hook. The trays were covered completely with a cylinder made of insect screening (15.24H x 22.86 cm diameter) except for 4 evenly spaced 2.5 x 2.5 cm square openings cut out along the bottom edge to allow only small mammals to enter (Figure 10). Tray screens were held in place with at least 4 12-gauge wire U-hooks. Lupine seeds were added to the trays in May, and recounted every 4-8 days (if weather permitted) until mid-August. One black sunflower seed was also added to the tray to assess if the tray had been entered. If it was eaten or removed, we assumed the tray to be entered by a mouse. Sand was sifted through a seine when sand was dry and when sand was wet seeds were hand counted. The number of missing seeds was counted and then we replaced the same number of seeds. If a seed had germinated it was replaced as well. Fifteen lupine seeds of random seed coat colors were added to each tray; the number of seeds mimicked the density used by Maron and Simms (1997), who utilized 30 bush lupine seeds in a 929 cm^2 enclosure.

Previously collected lupine seeds from Northwest Ohio were used until seed collection was performed that year on July 20th. The new seeds were placed 10 per seed tray because of limited supply. Therefore, during analysis number of seeds eaten per trial was calculated as proportion of seeds eaten in order to combine trays with 15 seeds and 10 seeds present.

Statistical Analysis

Our data were not normally distributed so we performed a Kruskal-Wallas one-way ANOVA on Ranks (KW test) (NCSS, Kaysville, UT, USA) on site, time, and location of the amount of seed predation over the collection period. Location was designated as those trays either at the edge or in the open oak savanna portion of the site. This allowed us to see if there were significant differences in seed predation between sites, over time, and between the edge and oak savanna. We also performed KW tests with seed predation as the response variable and management practices as the explanatory variable. Management practices were categorized into (a) prescribed burns or mowings done in the past 5 years, (b) in the past 10 years, and (c) total number of management practices of any kind that was on record. Finally we used the KW test to see if there was a difference in seed predation when using the old seeds versus the new seeds collected that year.

We ran a nonparametric two-way ANOVA, the Cochran-Mantel-Haenszel (CMH) Statistic, on site and time controlling for seed predation. Data from seed trays were used in the analyses if trays were not disturbed and the sunflower seed had been eaten or removed. In order to see if seed predation was correlated with mice tracks we ran a Spearman Correlation in the software SAS (SAS Institute Inc., Cary, NC, USA), with percent seed predation and number of tracks, and with percent seed predation averaged per site by date and summed number of tracks per site by date. We also ran average seed predation over time in a Spearman Correlation to see if there were any dates correlated. We also ran a Spearman Correlation with weather conditions and seed predation. For weather variables we included average daily temperature, high temperature, and low temperature which were averaged for the days involved in each seed tray trial. We included the temperature range which was taken from the high and low temperature averages, and precipitation which was summed over each seed tray trial. For seed predation variables we included the seed predation averaged over all sites and across time, the weighted summed proportion of seeds removed for each date, and the max seed predation for each date.

We used the Schnabel Method (Krebs 1999) on our tracking tube data because it can estimate abundances over more than one mark and recapture period and assumes a closed population with no migration/immigration, births or deaths in order to estimate the abundance of mice each month. In order to have capture and recapture data for tracking tubes each tube was treated as an individual because we assumed that only one individual mouse was using one individual tube. Therefore, the first time the tube had tracks was the initial capture and any other dates tracks were found were considered recaptures.

We ran a forward stepwise logistic regression using SAS software to assess if presence of seed predation was affected by any of our explanatory variables and to develop a parsimonious model. It was performed on presence of seed predation as the response variable, and included data from each seed tray location, i.e., at the quadrat scale. We examined the average amount of vegetation type between May and June from vegetation surveys, presence or absence of mice next to the tray, and other variables extracted from satellite data using ArcMap 9.2. These data included NDVI, altitude, and distance from horse trails, distance from water, and distance from roads, entered for each quadrat in the logistic regression. We used the Spearman Rank Correlation to eliminate variables highly correlated (> 0.70) with each other from the logistic regression. AICc, P-value, and the estimated coefficient were used to find the most predictive explanatory variable(s) for each logistic regression.

We ran a second forward stepwise logistic regression utilizing data we averaged over transect lines in order to look at a larger scale than our quadrat data, since we do not know at what scale seed predation is being affected. The average amount of each vegetation type per transect was used from the vegetation survey data. For tracking tube data we used the percentage of tubes used per transect and weighted the number of tracks since some transect lines were longer than others.

In order to look at the site scale we ran a forward stepwise logistic regression utilizing data we had from each site, including the number of management events per site and amount of land cover type per site. Amount of each land cover type was found using ArcMap 9.2 by counting the number of pixels for each land cover within the mice distribution buffer. This buffer was a 50 m radius around the tracking tubes to account for mice home range size of 0.2 ha (2,000 m^2) (Animal Diversity Web 2009).

We entered the locations of each seed tray into ArcMap 9.2, from our handheld GPS unit. By changing the symbology of each point to reflect the average amount of seed predation it received over time, we were able to represent any major differences in seed predation. Some of these spots were visibly larger than others so we used the spatial statistics toolbox we performed a Getis-Ord G_i* statistic on the predation at the seed tray locations. This test indicated where clusters of high and low values of predation were located, and can tell us if our any of our seed trays were the center of a high or low cluster area. This test is defined as:

$$\sum G_i^*(d) = \sum W_{ij}\,(d)\,X_j / X_j \qquad \text{Equation 1}$$

$G_i^*(d)$ is the statistic for point i where with distance d from i, $W_{ij}(d)$ is the spatial weight matrix at distance d in dimensions i and j, and X_j is the average seed predation over time. It sums the values of the target point with its neighboring points and divided it by the sum of all the features (Mitchell 2005). It then calculated a z score to indicate where significant clusters were present by labeling each point with the z score, and for a confidence level of 95% if it varies more than 1.96 away from zero it is a significant z score value (Mitchell 2005). We defined neighbors with an inverse distance weight over the entire study area, which meant that the further one point was from another the less it would be considered a neighbor. We then ran a forward stepwise logistic regression with the presence of a seed tray hot spot as the response variable and the same explanatory variables from the second logistic regression.

RESULTS

Vegetation Surveys

Lupine stem counts conducted by the Oak Openings Preserve in 2008 (Table 1) showed a wide range (100-6,800) of population sizes. The area of our sites ranged from 4,040 – 10,330 m^2, and area of edge with seed trays ranged from 245 – 1,587 m^2 (Table 1). Tracking tube areas ranged from 2,687 – 10,330 m^2 (Table 1). Vegetation density for May ranged from 0 – 0.16667 dm, and June's density ranged from 0.278 – 1.557 dm

(Table 1). The amount of bare ground, saplings/shrubs, leaf litter, crypto-biotic crust, ferns, graminoids, other angiosperms, lupine, and canopy cover sampled per quadrat was averaged per month over all sites (Figure 11a). There was variation between months most notably in bare ground (May 42.6%, June 24%), leaf litter (May 33.4%, June 10.8%), and saplings/shrubs (May 3%, June 23%) (Figure 11a). In May, vegetation cover varied between sites, especially saplings/shrubs, crypto-biotic crust, and ferns (Figure 11b). In June vegetation cover, bare ground, and saplings/shrubs were variable between sites (Figure 11c).

Mice Distribution Survey

Tracking tubes allowed us to assess where the mice occur naturally, estimate abundance, and identify which direction they were moving (Shepherd and Greaves 1984; Mabee 1998). Number of tracks per site per month increased as time went on (Figure 12), except for tubes in Bike Trail and Mary’s Savanna in August. The Schnabel Method total abundance estimates from May to August were 4 (S.E. = 0.25), 22 (S.E. = 0.023), 45 (S.E. = 0.003), and 56 (S.E. 0.01) mice (Figure 13). We found the density was 20 mice per hectare tracked when using the total abundance estimate of 56. The abundance for each site over the field season using the Schnabel method was Monclova 10 (S.E. = 0.02), Reed Road 8 (S.E. = 0.03), Crash 11 (S.E. = 0.02), Bike Trail 12 (S.E. = 0.02), Tansel Dunes 3 (S.E. = 0.34), and Mary’s Savanna 12 (S.E. 0.02). Mice tracks were seen in tubes in both the oak savanna and the edge, showing no preference for one habitat over the other. With our N-S and E-W running tubes we did not detect any preference in direction of movement.

Seed Predation

At the smallest scale, which is the comparison of the 8 seed trays of each site, we found there was no difference in mean percent predation between the seed trays at any one site on each date data was collected when using the KW test. When we looked at mean seed predation for each site over time using the KW test, there was no difference between seed trays located within a site ($P > 0.05$). Using the KW test we found that seed predation did not significantly differ between edge seed trays and oak savanna seed trays within each site ($P > 0.05$). We found seed predation varied along the edge over time and in the oak savanna (OS) over time significantly at the Monclova site (edge $P = 0.015$, OS $P = 0.037$), and only within Bike Trails oak savanna over time ($P = 0.023$). With our Spearman Correlation we found that there was no significant correlation with percent seed predation and number of tracks ($P = 0.49$, $\rho = 0.05$). We also found that seed predation had an insignificant, negative correlation with the date ($P = 0.22$, $\rho = -0.09$). When we used the KW test we found that there was no difference in seed predation when using the old seeds versus the new seeds ($P > 0.05$).

When we averaged the seed predation within sites it was significantly correlated with the summed number of tracks within sites for each date of data collection ($P = 0.004$, $\rho = 0.388$). When comparing seed trays between sites in our KW test, we found no significant difference ($P > 0.05$). Edge seed predation compared between sites was significantly different ($P = 0.016$), and oak savanna seed predation compared between sites was significantly different ($P = 0.042$).

On average, 22 % of the lupine seeds from all sites were eaten or removed from seed trays over the sampling period. When we looked at seed predation for each date separately using the KW test, we found no significant difference in means between seed trays on any one day across sites. When we included the percent seed predation for all trays using the KW test, the differences in seed removal were significant over time (Figure 14) ($P < 0.0001$). Seed predation was not significantly affected by site and time interactions according to the CMH statistic (Table 5) ($P = 0.80$). With our Spearman Correlation between weather and seed predation variables, we found that average seed predation across all sites and over time was not significantly correlated with any weather variables, and that all correlations were negative and > 0.38. The summed proportion of seeds removed for each date was significant in being negatively correlated with the temperature range ($P = 0.03$, $\rho = -0.64$). In other words, the average seed predation levels changed significantly over the course of the study.

Seed predation was not significantly different when we compared all edge seed trays to all oak savanna seed trays ($P > 0.05$). We found that the seed predation was significantly different along the edge over time ($P = 0.002$) (Figure 15A), and in the oak savanna ($P = 0.0003$) (Figure 15B) over time. Our results show that there is no difference in predation between edge and oak savanna seed trays, but there was a difference in seed predation rates between the edge over time and between the oak savannas over time, and when predation in similar habitat was compared across sites.

Across all sites, seed predation averages over time were significantly different depending on the amount of prescribed burns over the last 10 years ($P = 0.034$) (Table 6) using the KW test, but not affected by prescribed burns only during 2008 or over the last 5 years. Seed predation averages were significantly different ($P = 0.0001$) depending on the total number of burns over the last 19 years across all sites (Table 6). Predation increased with prescribed burns, but predation did not show a linear relationship with the number of prescribed burns. Seed predation averages across all sites were significantly reduced with an increase in the number of mowing events they were associated with over the last 5 years ($P = 0.025$), and significantly increased with the total number of management events they were associated with ($P = 0.0003$) over the last 19 years (Table 6). This indicates that there was an increase in seed predation rates that occurred with increased management events, and mice may not have encountered or favored lupine at those sites that had no management.

The forward stepwise logistic regression performed on seed tray at the quadrat level across sites found that crypto-biotic crust coverage was the only significant variable to influence seed predation presence ($P < 0.0001$, CE = 0.15) at this scale. The forward stepwise logistic regressions based on averages within transect lines did not find any significant explanatory variables ($P > 0.05$) from our vegetation, tracking tube, live trapping, and GIS data. We did not find any significant explanatory variables for seed predation at the site level ($P > 0.05$) from our vegetation, live trapping, management, and GIS data. With our data we identified one key predictor of seed predation, which was cryptobiotic crust.

When we visually represented the average amount of seed predation at each seed tray there were a number of trays with large predation averages. At Mary's Savanna seed trays 41, 42, 43, 44 and 46 were in the largest category (52-83%) (Figure 16), and at Bike trail seed tray 27 and 31 were in the largest category (Figure 18). We found from the Getis-Ordinal G_i* test there were 4 clusters of high values that were significant at the 95% confidence level ($z > 1.96$). We found that the seed trays that represented a high cluster value were seed trays 42, 43, and 46 at Mary's Savanna (Figure 17), and seed tray

31 at Bike Trail (Figure 19). When we ran the forward stepwise regression with hot spots as the response variable we had no significant explanatory variables ($P > 0.05$) from any of the data we had used in other logistic regressions.

DISCUSSION

Vegetation Surveys

We found that crypto-biotic crust coverage was an indicator of seed predation at the seed tray, i.e., quadrat, level. A wide variety of other studies have shown that *Peromyscus* prefer higher vegetation cover in general (Rosenzweig and Winakur 1969, Dueser and Shugart 1979, Morris 1991, Bowers and Dooley 1993). In a similar study, *Peromyscus* removed more *Ceanothus* seeds under plant canopies especially under unbrowsed plants (Deveney and Fox 2006). Many other studies have shown vegetation cover to be important in mice seed predation (Hulme 1990, Manson and Stiles 1998, Osterfeld et al. 1997, Kollmann and Buschor 2002). Vegetation cover may be more important to mice only in other habitat types and thus not show up in our logistic regression on seed predation in the oak savanna. The smaller scale of the seed tray level resulting in a crypto-biotic crust predictor may be explained in that it provided an easier surface for the mice to find seeds in and an area that may have reduced predation since crypto-biotic crust is darker than the bare soil and quieter than leaf litter to move through (Reed et al. 2005). Crypto-biotic crust may also benefit the mice by either providing hydration from the dew on the moss or an area where fungi may be found for food. It is possible that mice will have retained landscape information under bright conditions and moved into crypto-biotic crust areas under darker conditions to reduce predation (Zollner and Lima 1999). Other studies have found that more bush lupine seeds were removed in dune areas than grasslands, which are areas of reduced cover (Maron and Simms 1997, Maron and Kauffman 2006, Kauffman and Maron 2006). Increased lupine abundances did not correspond to increases in seed predation, which indicates that mice may be using the "fixed time rule" where the probability of lupine being consumed is independent of the amount of lupine found in the foraging patch (Morris and Davidson 2000). In other words, predation was not linked directly to lupine availability. Our scale at which we placed our seed trays may have masked other effects, since seed trays spread out in our site may give us a response at the mice population level which may not correlate with cover of lupine. Overall, it is possible for these two different vegetation variables, crypto-biotic crust and lupine, to be influencing mice seed predation at different scales.

Mice Distribution Surveys

Tracking tubes were used to ascertain the location of these species. Baited traps in oak savannas could have been entered by edge dwelling individuals simply for the bait reward, and not necessarily represent its typical location. Non-baited tracking tubes allowed us to assess where the mice occur naturally and which direction they were moving, and were less affected by inclement weather (Shepherd and Greaves 1984, Mabee 1998). With our N-S and E-W running tubes we found no preference in direction of movement. This suggests that there was no mice movement specifically associated with our focal edge of each site.

Seed Predation

We found no significant correlation with seed predation and the tracks from the nearest tracking tube, but we did find a significant correlation when we averaged the seed predation within sites and summed the number of tracks within the site for each date.

This suggests that even though a mouse is at a specific tracking tube near a seed tray it was not necessarily going to remove seeds from it. It also indicates that sites with more mice tracks are more likely to have seed predation. We cannot tell if this is because there are more mice around or only a few mice taking regular trips through those openings. If it is only a few mice taking many trips this may indicate that familiarity makes it more likely that a mouse will stop to forage. Overall, tracks are correlated with seed predation on a site scale, and this gives us the scale at which these interactions occur.

Our summer average for our seed predation rate was 22%, but our averages varied through out time from 0 – 58% (Figure 14). Other studies in mice seed predation show similar results where predation can be variable but have an impact on the plant population dynamics (Hulme 1994, Maron and Simms 1997, Kollmann and Buschor 2002, Cote et al. 2003, Deveny and Fox 2006). The high variation in our lupine population abundances makes protecting and monitoring the smaller populations of more importance, such as Crash or Tansel Dunes, since seed predation can reduce their population size the most (Table 1). There is a noticeable jump in the amount of seed predation at the end of July as seen in Figure 14, which seems to be correlated with the natural timing of seed production in Lupine. Lupine usually dehisce their seeds in July once it is dry enough for the seed coat to open. This jump in seed predation happens on the sample date after seeds from that year were put out into the seed trays instead of last year's seeds, suggesting a novelty effect, with the predation rates decreasing again starting in August (Figure 14). This time of the year may also reflect an annual fluctuation of seed predation correlating with increased mice numbers, although this study was only conducted over one field season and we cannot be confident in that assumption. Seed predation could also have a lag effect and not show a significant impact on Lupine reproduction until the next year. Even this small average amount of seed predation may have an impact on the success of lupine in an area, because it adds to the other threats of reduced habitat, fragmentation, and inbreeding load (Michaels et al. 2008).

We found no significant difference in seed predation amounts between the edges versus oak savannas at individual sites, but did see a difference when comparing edge seed predation across time and between sites as well as a difference for oak savanna predation across time and between sites. There was a difference in seed predation between sites, whether trays were grouped together or split into edge/oak savanna trays. Factors influencing edge seed predation may operate at a different scale than our study measured. Seed predation could be dependent on the spatial distribution of the lupine, if the seed is not evenly distributed from the savanna to the edge; conspecific seeds' density dependence can conceal edge effects on rodent seed predation (Chauvet and Forget 2005). This would especially be the case if the mice in our study were using the same foraging rate independent of the amount of lupine. Based on the quit harvesting rate equation, if the increase in cost of foraging is more than the increase in lupine density there is no benefit for mice to forage longer in the area (Mitchell et al. 1990, Davidson and Morris 2001). The variability within and between sites probably influences our ability to detect significant edge effects as well. These factors may be concealing or preventing a detectable edge effect on rodent seed predation within sites.

Prescribed burning may make it easier for mice to locate the seeds because of reduced leaf litter (Grigore and Tramer 1996, Reed et al. 2005, Plenzler 2008). Our results support this; we found an increase in predation at sites with more prescribed fires, although there is an apparent time lag between burning and increased predation because in both the 10 yr. and 19 yr. test predation doesn't increase significantly within 5 years. Our results also show less seed predation in sites with no management, which corresponds to previous findings that areas with no management have lupine of decreased quality and more leaf litter (Reed et al. 2005, Pickens and Root 2008, Plenzler 2008). Therefore, mice may not have encountered or favored lupine at those sites that had no management. Overall, lupine will still be in areas managed to keep oak savannas at their mid-successional state and, although our study shows an increase in seed predation as a result, prescribed fires allow for increased lupine vegetative growth and seed set (Grigore and Tramer 1996). Even though prescribed fire management increased seed predation, mice populations should not have to be managed because there are a number of other factors that generally regulate these populations such as harsh winters, male dispersal, disease, and predation (Krohne and Burgin 1987, Wilder and Meikle 2004, Wilder et al. 2005, Vandegrift et al. 2008).

Mowing was shown to have a significant negative influence on mean seed predation rates in our study. Mowing allows for continual leaf litter coverage and ground vegetation decreases the likelihood of mice foraging out in the open because of predation pressures and foraging difficulty (Roche et al. 1999, Reed et al. 2005). The amount of leaf litter did not affect the amount of seed predation directly in our study, however, suggesting that there was not enough litter built up in the areas or at the time of our sampling. Mowing has been shown to help increase lupine cover and clump density, but reduced mean height and percent of flowering stems which are important characteristics to Karner blue butterflies (Forrester et al. 2005). Therefore, mowing without any prescribed fire treatments has its costs and benefits.

Spatial clustering in interactions has been examined in a number of other studies using the Getis-Ord *Gi** clustering statistic. For example, this approach has been used to focus on the location of bear-human conflict areas, kangaroo and olive fly locations (Baruch-Mordo et al. 2008, Pople et al. 2007, Kounatidis et al. 2008). Significant clusters of predation at seed trays within two of our sites (Mary's Savanna and Bike Trail) suggests that there was something different about these from our other sites. Both Mary's Savanna and Bike Trail did have a larger lupine population than the other sites except for Monclova. Monclova could have had no hot spots because some of its data had to be thrown out from seed tray interference with large mammals. None of the variables we examined were significant explanatory variables in our logistic regression, suggesting that these clusters were influenced by factors we did not measure such as distance to focal edge or fragment size, or entered such as sites lupine population size. These clusters also may result simply based upon random mice movements, responses to other organisms, or distance from their nests. One possible explanation would be that the scales that we examined were too small and having a bigger area with more locations would help reveal effects of clustering. A high amount of zeros can skew the *Gi** distribution, and without a large number of neighbors normality cannot be reached, which had happened in our study with the distribution of tracks and seed predation being non-normal (Ord and Getis 1995). Sokal et al. (1998) indicates that non-normality in the Getis-Ord *Gi** results should focus on outliers and non-stationarity than cluster significance. Therefore, our clusters should be seen more as outliers and its significance interpreted with caution. While we do have areas of higher seed predation we currently do not know what is causing this but hypothesize that it may be due to lupine population size.

Since we surveyed over a single growing season, we were not able to assess annual variations in lupine seed predation, so we cannot determine if our peaks in seed removal were based on random movement or on annual variation. However, others have shown that mice respond to pulse resource foods such as acorns (Wolff 1996, Schradin and Pillay 2006, Marcello et al. 2008). By using a seed tray design that limited the entry to small creatures (2.5 cm^2), however, we were able to exclude predation by larger mammals and birds. The design did not exclude ants though. We observed ants in the seed trays but they were not able to move seeds by themselves or cooperatively, so we do not believe they were responsible for any seed removal in our experiment. One of the benefits of our seed tray design is that, because of its small size it did not draw attention from park visitors, although it could be dismantled by other large mammals. The tray design also allowed for a more natural setting for the seeds, and did not disturb the surrounding vegetation as larger enclosures could. This form of seed tray could be a useful new tool to capture only mice seed predation.

We found mice seed predation on wild lupine was not high during the entire spring and summer seasons (only 22% on average). With our data, we identified key predictors of seed predation which was crypto-biotic crust. Overall, our results show that there is no difference in seed predation rates between the edge and oak savannas, and an increase in seed predation rates occurs with increased management events. These data have highlighted some of the critical factors that affect the interactions between white-footed mice and wild lupine.

Management implications

Our findings on how management affects lupine seed predation and previous research on how prescribed burns affect mice populations suggests that a mix of prescribed fires and mowing is the best management technique to balance wild lupine seed predation and growth. Prescribed burnings have been shown to increased lupine growth and not negatively affect mice population numbers (Grigore and Tramer 1996, Jacksey 1997). Our research shows that prescribed burns tend to increase the amount of seed predation, and that mowing tended to decrease the amount of seed predation over time. In order to maintain seed predation at a tolerable level, a mix of both management techniques could be applied. While mowing will permit litter to remain, litter can also aid lupine seedlings in areas with little canopy cover (Grigore and Tramer 1996, Pavlovic and Gleason in press). To assess if the current management protocol is beneficial, measuring vegetation height with the Robel pole could be performed (Robel et al. 1970). This approach is one way to assess if a site is at a vegetation height that would benefit from a prescribed burn or mowing. Previous research in the area has shown a positive benefit for lupine nutritional quality when density was between 0-2.5 dm (Pickens 2008); this suggests that mowing when the density is under 3 dm and burning when the density is 3-4 dm would be beneficial. Although there are many other factors that determine if a prescribed burn will be performed, this approach would allow managers to assess site priority when the goal is to increase legume species, especially wild lupine. This in turn will help the federally endangered Karner Blue butterfly expand its range naturally, since it has been shown to re-enter areas after prescribed burns (Kwilosz and Knutson 1999). The current management strategy for Karner sites mimics our suggestion because it requires each site to have 1/3 lupine stems mowed, 1/3 burned, and 1/3 left for refugia annually (Kwilosz and Knutson 1999), however this rotation is based on time and not on vegetation density. Future research should focus on the resulting lupine population dynamics from management in order to recommend modifications to this strict management rotation on Karner sites. Overall, this study increased our understanding of the interactions between white-footed mice and lupine populations, and provided data that can be used for wild lupine management.

CHAPTER II. *PEROMYSCUS* POPULATION DYNAMICS AND DISTRIBUTION IN AND AROUND MIDWEST OAK SAVANNAS

INTRODUCTION

The Oak Openings Region of Northwest Ohio has many different ecosystems intermixed in a mosaic of small to large habitat patches which have been diminished by human settlement and fire suppression. Currently oak savannas are only found on 0.02 % of the landscape in the Midwest Region of the United States (Nuzzo 1985). Oak Savannas can be described as an area of scattered oak dominated canopy cover (5-80%) on well-drained, sandy soils created from glacial outwash, and have an understory consisting of graminoids and shrubs with indicator species such as little blue stem and wild blue lupine (Faber-Langendoen 2001). This region’s landscape diversity is important to many species in the area.

Mice (*Peromyscus spp.*) abundance has been shown to be variable over time and space (King 1968). In a review by Vessey (1987) weather, shelter, and food were the possible factors affecting mice populations. The acorn masts from oaks have been shown to influence mice population fluctuations, while mice caches of acorns have possibly assisted in seed dispersal (Wolff 1996, Iida 2006). White-footed mice are a host for ticks that carry Lyme disease, and tick attachment to mice is more successful when mice densities are high (Ostfeld et al. 1996). They also have an important role as a critical food resource in this region for many predators (Errington 1932, Knable 1970, Swengel and Swengel 1992). Knowledge of mice population dynamics helps us better understand the fluctuations occurring in this ecosystem.

The ecosystems in the Oak Openings Region occur as a mosaic, where many of the habitats are patchy and dominated by edges. Edge effect is described as the changes occurring on the edge because of its presence. More structural complexity at the edge from increased shrub and herbaceous plants provides more cover and food availability than the interior (Gehlhausen et al. 2000, Kollmann and Buschor 2002). This edge habitat can lead mice to forage up to 10 m in the adjacent habitat (Wolf and Batzli 2004), which could lead mice to oak savanna habitat. In this study, edge will be defined as Kollmann and Buschor (2002) have stated, and will be considered as a 20 m wide margin that separates oak savanna and woodland.

Protected areas of oak savanna in the Oak Openings Region are being managed through prescribed burning and mowing to restore their natural disturbance regimes, which helps mitigate the impact of human fire suppression and maintain their early successional state. For the Oak Openings Preserve Metropark the guidelines are to burn prairies once every two years, savannas once every three years, and oak woodlands once every four to five years (L. Sprow, Oak Openings Preserve Metropark, personal communication). Mowing is also used to reduce shrub and saplings in the early-successional habitat, especially in areas where burning cannot not be done. Jacksy (1997) did not find an effect of prescribed burning on *Peromyscus leucopus* numbers in the Oak Openings Preserve Metropark, but the study did not examine if changes occurred in survival and recapture probabilities or in oak savanna habitat.

Current rodent population dynamics and their distribution are unknown for the Oak Openings Region. Previous research on mice in Northwest Ohio has been mostly on woodland population demographics and behavior (Cummings and Vessey 1994, Jacksy

1997, Jacquot and Vessey 1998, Lewellen and Vessey 1999, 1998). Other ecological research on mice has covered a wide range of factors including give up densities, species interactions, and distribution (King 1968, Adler 1985, Brown et al. 1988). Distribution can also be examined using spatial cluster analysis (Root et al. 2005, Baruch-Mordo et al. 2008, Pople et al. 2007). By examining the population abundance of *P. leucopus* and *P. maniculatus* in relation to their distribution, we can gain insight on their local population dynamics in the heterogeneous landscape of the Oak Openings Region.

In this study we were looking to answer three basic questions:

- What are the population dynamics of mice found in and around the edge of oak savannas?
- Which environmental variables (e.g., leaf litter depth, vegetation height, edge, cover, and management practices) affect mice distribution?
- What is the spatial distribution of *Peromyscus spp.*?

METHODS

Study Sites

We estimated the population abundances and distribution of mice, lupine, and the extent of seed predation on six different lupine populations from April to September 2008. Sites were all located in the Oak Openings Preserve Metropark (41” 32-34’N x 83” 50-51’W), which is the largest of the Metroparks of the Toledo area located near Whitehouse, Ohio (Figure 7). These sites were chosen based on areas of historic, persistent populations of lupine, and then limited to populations that were in oak savanna and adjacent to woodlands (Table 1). Selected sites were at least 0.70 km from each other to reduce the probability that mice populations and management practices would overlap. Site management history was categorized by year of each action and management type (i.e., prescribed burning and mowing), and total management, which included other types (herbicide, pesticide, clearing, and tree girdling/cutting).

Vegetation Surveys

We gathered data for our vegetation survey from 1-m^2 quadrats that were placed every 20 m along parallel transects running North-South through the oak savanna and along the edge of each site (Figure 8). Transects were 20 m apart from each other and kept 20 m away from roads, trails, and water-bodies to minimize other edge effects. Transects covered the oak savanna and crossed over the edge and into the adjacent woodland for live trapping. We recorded the distance from the forest edge at which lupine was no longer found. Percent vegetation-type, canopy cover, vegetation height / density, number of flowering lupine stems, and leaf litter depth were recorded from each 1-m^2 quadrat. These measurements were done once each during the spring and summer (May 13 and June 18) for each site. Percent vegetation-type was categorized for each quadrat into bare ground, leaf litter, sapling/shrubs, graminoids (grass), crypto-biotic crust (soil crust containing moss/lichens/algae), ferns, other angiosperms, and lupine. Photos were taken of each quadrats ground cover in order assess percent vegetation-type in the lab. Each photo had a 10 by 10 grid applied to it in Adobe Photoshop (Adobe Systems Incorporated, San Jose, California, USA), we then counted the number of squares a vegetation-type was found in and calculated that into a percentage. Canopy cover was estimated visually from the center of the quadrat. Vegetation height (dm) was measured by placing the Robel pole next to the tallest vegetation in the quadrat (Robel et al. 1970). Vegetation density was measured from the North and East cardinal direction by standing 3 m away from the Robel pole placed at the center of the quadrat and recording the visible height (dm) seen on the pole when viewing it from a height of 1.5 m. The two Robel pole measurements were then averaged. Leaf litter depth was measured in centimeters and averaged from two random points in the quadrat. Percentage of dead wood in the site was estimated visually. Lupine population abundance of each site was estimated by the Oak Openings Preserve staff by counting the number of flowering adult lupine stems in each population.

GIS Analyses

Geographical Information System (GIS) was used to map out the locations of all tracking tubes and live traps. Locations were found using a (Garmin eTrex) handheld GPS unit, which had an accuracy of 5-10 m. Each location was queried to find landscape variables extracted from satellite data using ArcMap 9.2 (ESRI, Redlands, California, USA). A LANDSAT image (July 7, 2008, Path 20, Row 31) was pan sharpened using color-space transformation to convert the true color images between the red/blue/green and hue/lightness/saturation images so that the spatial resolution of the images was increased to 10 m pixels. From these spatial layers, we extracted estimated NDVI, altitude, and distance from horse trails, distance from water, and distance from roads. Percent land cover type within a 50 m buffer of each site was calculated using a supervised classification raster layer containing 16 land cover types and created using 3 LANDSAT images (Nov. 11, 2005, March 3, 2006, June 23, 2006, Path 20, Row 31) (Scheeter and Root in prep.). The 16 classes of land cover types for this layer were: swamp forests/woodlands, floodplain forests/woodlands, upland deciduous forest/woodlands, upland coniferous forest/woodlands, upland savannas, wet shrubland, wet prairie, mesic prairie, dry prairie, sand barrens, Eurasian meadows, perennial ponds, urban/asphalt, residential, turf/pasture, and croplands (Schetter and Root in prep.).

Live Trapping

In order to estimate the population abundance of mice in each area we set out small Sherman live traps (7.62 x 8.89 x 22.86 cm) (3 x 3.5 x 9") in grids. They were set up monthly on the three nights surrounding the new moon between May and September 2008. This approach is used because mice are less active under full moon periods (Bowers and Dooley 1993) and more active on moonless and cloudy nights (Vickery and Bider 1981). If temperatures were below 0°C (32° F) at night trapping did not commence. Seven by three trapping grids at 20 meters apart were set up at 4 of the 6 sites; two were not sampled since they did not have a definitive savanna-woodland edge. Live trapping grids overlapped 3 transect lines at each site, with the 7 traps set up evenly over each habitat type (3 in the savanna, 1 at the edge, 3 in the woodland) (Figure 8). Traps were set out in the field at least 3 days before trapping to allow acclimation, left out in the field for the 3 nights of trapping, and then retrieved each month. Set up in the evening included opening the trap door and inserting a tablespoon of oats mixed with peanut butter, and a small amount of cotton filling when temperatures were below 4.5°C (40° F.). All traps were checked the next morning starting just before dawn. The following data was recorded for each mouse captured: species, sex, age by pelage color, mass (g), reproductive status, ear tag number, and trap number. New captures were ear tagged, and all mice were released where they were captured. Species were identified by tail to body length comparison, with *P. leucopus* having a tail longer than its body length and *P. maniculatus* having a tail shorter than its body length.

Mouse Distribution Surveys

Tracking tubes at each site were utilized to analyze mouse distribution, presence and to provide a second abundance estimate. The tracking papers from the tubes were used to count the number of times the tube was entered, where the mouse was located, and which direction it was going. The tubes were set out in March 2008 and left empty a month before data collection to allow mice to acclimate to their presence. The tracking tubes were set up in grids 20 meters apart along the vegetation transect lines, overlapping the lupine population and the woodland edge to identify their distribution (Figure 8). Along each transect line the tubes were placed alternately laying one East-West and the next North-South. Tubes were placed on level ground and held in place by pushing an 18-gauge wire U-hook over it and into the ground.

The tubes were replicated as in Nams and Gillis (2003), and were 3.81 cm diameter PVC piping cut into 36 cm long tubes with a slit cut at the bottom of the tube 3 cm in from each end to allow for drainage (Figure 9). The tracking paper was inkjet printer paper cut into 28 x 7 cm rectangles with 6 x 6 cm wax paper squares glued to each end using a glue stick or all-purpose glue (Figure 9). Each tracking paper had ink applied to the wax paper with a 2.5 cm wide paintbrush. The ink was made from fluorescent powder and mineral oil in a 1:3 gram ratio. Tracking paper was changed once every 4 days. To get the tracking paper to the field already painted we separated them with cardboard and carried them in a plastic container. Those papers with tracks were marked with the tube number and the date. We counted the tracks by illuminating the paper with a UV light in the lab.

Statistical Analysis

We estimated average monthly population abundances using the Lincoln-Peterson index on live trapping data for the most basic estimates. The Schnabel method was also used on live trap and tracking tube data. The Schnabel method is different from the Lincoln-Peterson index because it can estimate abundances over more than one mark and recapture period, although they both assume a closed population with no migration/immigration, births or deaths (Krebs 1999). In order to have capture and recapture data for tracking tubes each tube was treated as an individual because we assumed that only one individual mouse was using one individual tube. Therefore, the first time the tube had tracks was the initial capture and any other dates tracks were found were considered recaptures. In order to obtain survival, recapture, and abundance estimates we used program MARK (Gary C. White, Colorado State University, Fort Collins, CO, USA) with our capture-recapture data. We used the basic closed capture model in MARK to compare to our population estimates when using the Lincoln-Peterson Index and Schnabel method. Our one mouse per tracking tube assumption allowed us to format the .inp file as it is done for live trapping data in order to enter it into MARK.

We used program RELEASE in MARK, to assess the goodness-of-fit of our data to the Cormack-Jolly-Seber (CJS) model (Cooch and White 2008). RELEASE tests the CJS assumptions that all marked captures have the same recapture and survival probabilities (Cooch and White 2008). If over dispersion (i.e., a significant goodness-of-fit test) occurred the variance inflation factor ($\hat{c}$) was corrected. The CJS model was used to assess the probability of survival (Phi or Φ) and recapture (p) of the population as a whole and with sex-based variation assuming an open population with emigration/immigration, births, and deaths. We estimated survival and recapture probabilities with live trap and tracking tube data in MARK and ran them under the CJS and closed population models to compare estimates. We based model selection upon the corrected Akaike's Information Criterion (AICc; Akaike 1981), corrected in MARK using the goodness of fit analysis. If models had an AICc difference of < 2 we considered them equally likely, and when possible we ran a likelihood ratio test (LRT) on the similar models within a set of models to see if there was a significant difference in the estimable parameters between them. In order to compare two similar models one was categorized as general and the other as a nested model. We then averaged our model sets for each type of model ran (CJS, closed population), to account for model uncertainty. We report the unconditional standard error for these averages; the unconditional standard error accounts for the specific model variation and the variation from model uncertainty (Cooch and White 2008).

In order to assess the relevant variables that influenced mice distribution we ran multiple forward stepwise logistic regressions completed at the individual quadrat levels, transect and site level using SAS software (SAS Institute Inc., Cary, NC, USA), since we do not know at what scale mice presence is being affected. The logistic regression at the quadrat level had mouse live trap presence or track presence as the response variable. Our explanatory variables were the average amount per quadrat of each vegetation type between May and June from vegetation surveys (tracking tubes only), distance from focal edge, amount of vegetation covering the live trap/tracking tube, and other variables extracted from satellite data using ArcMap 9.2 (ESRI, Redlands, California, USA). These data included NDVI, altitude, distance from horse trails, distance from water, and distance from roads, entered for each quadrat line in the logistic regression. We used the Spearman Rank Correlation to eliminate variables that were highly correlated (< 0.70) with each other from the logistic regressions. We used AICc, P-value, and the estimated coefficient to find the most predictive explanatory variable(s) for each logistic regression.

At the transect level, we used mice track presence per transect or mice presence in live traps per transect as the response variables. We averaged explanatory variable data over each transect line to look at a larger scale than our quadrat scale. The average amount of each vegetation type per transect was used from the vegetation survey data. For our live trap regression, tracking tube data was the weighted percentage of tubes used per transect since some transect lines were longer than others. For our tracking tube regression, live trapping data was the summed number of individuals caught per transect.

Number of management events per site and amount of each land cover type per site was also entered into the logistic regression at the site level. The average amount of each vegetation type per site was used from the vegetation survey data. Amount of each land cover type was found using ArcMap 9.2 by counting the number of pixels for each land cover within the mice distribution buffer. This buffer was a 50 m radius around the tracking tubes to account for mice home range size of 0.2 ha (2,000 m^2) (Animal Diversity Web 2009). We also used distance from nearest residential area and percentage of dead wood at each site.

We entered the locations of each seed tray into ArcMap 9.2 from our handheld GPS unit. By changing the symbology of each point to reflect the summed amount of tracks or live captures it received over time we were able to represent visually any major differences in mice distribution. Some of these spots were visibly larger than others and so we used the spatial statistics toolbox and performed a Getis-Ord G_i^* statistic on the seed tray locations. This test indicated where clusters of high and low values were located, and can tell us if our any of our tracking tubes were the center of a high or low cluster. This test is defined as:

$$\sum G_i^*(d) = \sum W_{ij}(d) X_j / X_j \qquad \text{Equation 1}$$

$G_i^*(d)$ is the statistic for point i where with distance d from i, $W_{ij}(d)$ is the spatial weight matrix at distance d in dimensions i and j, and X_j is the sum of the number of tracks found at a tube over the field season or the number of times a mouse was captured in a live trap. If a point was representing both a tracking tube and a live trap, we weighed it with the highest sum (between the two) of either the tracking tube or the live trap. This statistic sums the values of the target point with its neighboring points and divided it by the sum of all the features (Mitchell 2005). It then calculated a z score to indicate where significant clusters were present by labeling each point with the z score, and for a confidence level of 95% if it varies more than 1.96 away from zero it is a significant z score value (Mitchell 2005). We defined neighbors with an inverse distance weight over the entire study area, which meant that the further one point was from another the less it would be considered a neighbor. We then made the points binary with statistically significant points of high cluster values being 1 and all others being zero. We ran a forward stepwise regression with the presence of a high cluster values (hot spots) as the response variable using the same explanatory variables as in our quadrat level logistic regression.

RESULTS

Vegetation Surveys

See Chapter 1.

Live Trapping

The sampling sites ranged in size and varied over time in terms of the amount of vegetation cover that occurred, including the amount of lupine, see Table 1. In 18 trap nights we caught 70 mice, all of which were *Peromyscus leucopus*. Similarly, the amount of mice captured varied considerably over time and across sites. From May until the end of September the average monthly abundances were 0, 2, 11, 46, 68, and 50, respectively, when using the Lincoln-Peterson Index (Figure 20). Using the largest abundance estimate (68) the number of mice per hectare trapped was estimated as 25. When using the Schnabel method for each month we found the population abundances from May to October were 0, 14.5, 24, 12, and 18, respectively (Figure 21). The total abundance from May through October was 75 mice, with an estimated density of 27 mice per hectare trapped. The abundance for each site over the field season using the Schnabel method was Monclova 25, Reed Road 21, Crash 24, and Bike Trail 11 mice, with corresponding densities of 42, 30, 36, and 14 mice per hectare trapped, respectively. The number of mice caught in the woodland, at the edge, or in the oak savanna did not differ significantly. The sex ratio was 1:4; male to female, proportion of males was 0.20 and 0.80 for females. These two methods for estimation provided similar results revealing an abundant population of mice across these sites.

In general, our survival estimates for mice were high and increased over time. We found from the closed population run in MARK that both models p(t)c(.)N(.) and p(t)c(.)N(t) had the lowest AICc value of 240.0965. The capture probability for animals that had previously been caught (c) was 0.16 (95% CI = 0.127 – 0.199), N = 75, and the capture probability (p) for those not previously caught varied from 0 – 0.615. Using LRT we did not detect significant differences between the two similar models. The capture probability (p) varied for each model because of time, and therefore the model's survival and recapture probability averages varied for each trapping session (capture = 0 – 0.615, recapture = 0.1598 – 0.1599) (Table 2). The closed population model's average abundance N = 75.0 (95% CI = 74.999 – 75.000) with and unconditional standard error (SE*) of 0.00004 was similar to the abundance estimates found under the Lincoln-Peterson Index and Schnabel method.

We used estimates from the most supported model and for the CJS entire population run the model was Φ(.)p(.) (AICc = 332.580), which resulted in a total survival probability (Phi or Φ) of 0.870 (95% CI = 0.784 - 0.926) and a recapture probability of 0.269 (95% CI = 0.198 - 0.353). This model fit the data according to RELEASE in MARK. When we averaged the created models there was no difference in the probabilities of survival and recapture or their 95% CI from the model Φ(.)p(.) when rounding to the third decimal place. The unconditional standard error for the survival probability was 0.0354 and 0.0396 for recapture probability. In comparison, the recapture probability of this CJS model is higher than that of the closed population model.

The CJS model that included sex-based variation had three possible models that fit the data: Φ(.) p(.),Φ(g) p(.), and, Φ(.)p(g) (Table 3). The differences between the models were not significant based on LRT. All three models fit the data according to RELEASE in MARK. The survival and recapture probabilities were similar regardless of the model; males having a lower, but not significantly different, probability than the females (Table 3). We looked at the model averages for the male and female mice probabilities of survival and recapture and each parameter was the same up to three decimal places. Males had an average survival probability of 0.855 (95% CI = 0.719 – 0.931), and an unconditional SE (SE*) of 0.053, and females had an average survival probability of 0.877 (95% CI = 0.784 – 0.933, SE* = 0.037). We found the average recapture probability for males was 0.263 (95% CI = 0.175 – 0.374, SE* = 0.051), and for females the average was 0.281 (95% CI = 0.203 – 0.376, SE* = 0.044). These models allow us to separate sexes, but both sexes have similar probabilities compared to the CJS entire population model with overlapping confidence intervals.

The forward stepwise logistic regression we ran with the presence of mice at each live trap at the quadrat scale and transect scale had no explanatory variables ($P > 0.05$). We were unable to perform a logistic regression at the site level due to a lack of data.

Mice Distribution

Number of tracks detected per site per month increased as time went on (Figure 12), except for tubes in Bike Trail and Mary's Savanna in August. This was similar to the increase in mice abundance over time we found with live trapping over the same period. The Schnabel Method abundance estimates from May to August were 4 (S.E. = 0.25), 22 (S.E. = 0.023), 45 (S.E. = 0.003), and 56 (S.E. 0.01) mice (Figure 13). We found the density was 20 mice per hectare tracked when using the total abundance estimate of 56. The abundance for each site over the field season using the Schnabel method was Monclova 10 (S.E. = 0.02), Reed Road 8 (S.E. = 0.03), Crash 11 (S.E. = 0.02), Bike Trail 12 (S.E. = 0.02), Tansel Dunes 3 (S.E. = 0.34), and Mary's Savanna 12

(S.E. 0.02). Mice tracks were seen in tubes in both the oak savanna and the edge. There was not detectable preference in direction of movement based on a comparison of the N-S and E-W running tubes.

Tracking tubes, similar to the live trapping, predicted high survival rates for mice at these sites over the sampling period. When we ran program MARK with the tracking tube data in the closed population model, the most parsimonious models were p(t)c(.)N(.) and p(t)c(.)N(t) (AICc = 365.265), which were the same models chosen for the live trapping closed capture models (Table 4). The capture probability for those that had previously been caught (c) was 0.28 (95% CI = 0.234 – 0.327), N = 61, and the capture probability (p) for those not previously caught varied from 0 – 0.70. We could not run the LRT for these two similar models. The capture (p) and recapture probability (c) varied for each model because of the time parameter, and therefore these probability averages varied for each trapping session ($p = 0 – 0.699$, $c = 0.277 – 0.280$). The model average for abundance was N = 173.192 (95% CI = 13,721 – 14,067, SE* = 7,089). These models provided parameter estimates that were similar to the closed capture model performed with live trapping data (Table 4).

With our tracking tube data the CJS model in MARK that was most parsimonious was Φ(.)p(.) (AICc = 411.914), which was the same model selected for the live trapping CJS model (Table 4). The probability of survival was 0.934 (95% CI = 0.863 – 0.969), and the probability of recapture was 0.354 (95% CI = 0.284 – 0.432) for model Φ(.)p(.). When we performed model averaging, the survival probability was 0.9338 (95% CI = 0.863 – 0.969, SE* = 0.0253). The probability of recapture was 0.354 (95% CI = 0.28 – 0.43, SE* = 0.04). Our data did not fit the model according to RELEASE in MARK (P =

0.0343). There may be differences in juvenile versus adult survival, which cannot be separated with tracking tube data. These results were similar to those found using live trapping data, although incomparable due to the data's lack of fit to the model.

The forward stepwise logistic regression we ran predicted that mice track presence at the quadrat level was slightly positively influenced by bare ground (June) ($P = 0.0002$, CE = 0.004), and distance from water ($P = 0.0032$, CE = 0.003), and negatively influenced by vegetation covering the tracking tubes ($P = 0.0115$, CE = -0.963). Mice track presence at the transect level was slightly positively influenced by an increase in crypto-biotic crust ($P = 0.012$, CE = 4.387). At the site level our logistic regression had no significant explanatory variables ($P > 0.05$). This suggests that the tracking tubes could be an aid in movement over bare ground and in areas where they are not found under vegetation cover.

When we visualized the summed amount of tracks or live captures we found a few points that were in the largest category (13-23). At Monclova tracking tubes 13, 14, 15 were in the largest category (Figure 22); the same was for tracking tubes 17 and 26 at Reed road (Figure 24), Mary's Savanna's tracking tubes 112 and 113 (Figure 16), and Crash's tracking tube 38 and 41 (Figure 26). For the Getis-Ordinal G_i* test we found that there were several locations with significant high clusters at the 95% confidence level ($z > 1.96$). Our high cluster areas (i.e. hot spots) were located at: Monclova tracking tubes 13, 14, and 15 (Figure 23), at Reed road tracking tube 17 and 26 (Figure 25), at Crash it was live traps 38 and 41 (Figure 27), and at Mary's Savanna it was at tracking tube 113 (Figure 17). We found no significant hot spot locations at our Tansel Dunes or Bike Trail sites (Figure 19). When we ran the forward stepwise logistic regression for hot spot presence there were no significant explanatory variables ($P > 0.05$) from the data we had entered into the other logistic regressions.

DISCUSSION

There appeared to be a relatively robust population of white-footed mice for 2008 in these oak savannas bordered by a woodland edge without having any competition from deer mice. Survival rates were quite high and the numbers increased, as expected, over the growing season. The travel of mice through the sites appeared to be affected primarily by structural elements such as the type of cover and landscape present. From this research we have learned more about the population dynamics of mice in the Oak Openings Region of Northwest Ohio.

Live Trapping

P. leucopus was the only mouse species found in our study area. *P. maniculatus* has been found in neighboring Wood County agriculture fields (Jacquot and Vessey 1998; Lewellen and Vessey 1999), but may not have been found at the park due to habitat and food preferences (Wolff et al. 1983, Adler 1985, Dooley and Dueser 1996, Kamler and Pennock 2004) or other unknown factors. Mice abundances changed over time, generally increasing until August for the Lincoln-Peterson Index and varying more so with the Schnabel method. Number of mice captured and therefore abundance estimates also varied by site. It is likely that these differences across sites were caused by the vegetative heterogeneity of each site, although variations in *Peromyscus* densities over time and space are typical (Vessey 1987, Kaufman and Kaufman 1989). There are a number of factors that cause variation in these populations such as male dispersal, disease, predation, and food resources and extreme weather events influencing their rate of population growth (King 1968, Krohne and Burgin 1987, Lewellen and Vessey 1999, 1998, Wilder and Meikle 2004, Vandegrift et al. 2008). Our densities varied between sites from 14 - 42 mice per ha, which is comparable to other capture-recapture density estimates, but our sex ratio was skewed with a higher proportion of females (Hanley and Barnard 1999). With four times more females than males trapped this indicates that our sites could be breeding areas, especially since many of the females caught were pregnant. This might also indicate a female trap bias or a skewed sex ratio. Our abundance estimates indicate that while there is variation among sites the mouse population at Oak Openings Preserve was relatively stable in 2008.

There was no difference found in the number of mice trapped or tracked between the woodland, edge, and oak savanna. *P. leucopus* was found inhabiting the woodlands, oak savanna areas and the edge where vegetation cover was present. This trend was found not only with live traps but with nest boxes placed on the ground and in the trees in a preliminary study. This differed from our expectations since *P. leucopus* is generally found in woodland settings (Whitaker 1996). Ground nest boxes in the savanna were inhabited by reproducing females or juveniles. This indicates that mice were utilizing the savanna area not only for foraging and dispersal, but for reproductive purposes as well, suggesting that the mice are using all areas similarly. We may have seen no difference because we did not trap far enough into the interior of each habitat type. Other studies in Ohio have shown that mice have higher densities in smaller than larger fragments and on the edge versus the interior, and that mice are present in both woodland and surrounding agricultural areas (Cummings and Vessey 1994, Lewellen and Vessey 1998, Wilder et al. 2005, Anderson and Meikle 2006). These studies have all taken place in a woodland/agriculture matrix though and may not be directly comparable. Others have found *P. leucopus* abundance at the tallgrass prairie/forest interface increased as woody cover increased from 0-62%, and abundance decreased as woody cover increased to 100% (Matlack et al. 2008). This may possibly explain what we observed at the edge between the oak savanna and oak woodland in the Oak Openings Preserve Metropark.

Our closed capture model had similar results similar to those found in the CJS models, which gave us a range of values for recapture probabilities (0.16 – 0.269) with the closed capture model having a more conservative value. The finding that the LRT did not show any significant differences between models compared from the entire population and sex based CJS, indicates that the most likely model was one with constant survival and recapture probabilities, as illustrated by the lowest AICc value for $\Phi(.)p(.)$. Reed and Slade (2006) found similar adult *Peromyscus* survival rates over time from 0.6 – 0.8 with variation between months, even though he used a multi-state model on multiple years of data. Small mammal population dynamics can be quite variable as the higher variation in the survival of female woodrats over 7 years (0.4 – 0.9) found by Lee and Tietje (2005) illustrates. Our estimated survival probabilities were robust for the year we sampled, but variation is probable over time. It is reassuring however, that the management activities (e.g., prescribed burning and mowing) that occurred in some of these oak savanna sites, does not appear to have reduced the survival rates of the resident mouse population.

Lee and Teitje (2005) showed no change in woodrat abundance after a prescribed burn, which is similar to the results of Jacksy (1997) for mice in the Oak Openings Preserve. Management did not appear to influence abundance or distribution in the short term of our study with its lack of significance in our logistic regression and Spearman correlation (*P* > 0.05). However, there may be delayed effects following management activities that our single season study could not capture; Lee and Teitje (2005) found that woodrats had a reduced number of juveniles per female adult the spring following a prescribed burn. Examining female reproductive success in the future could give us better insight into the longer-term effects of land management on mice populations. Overall, humans seem to have an indirect effect on mice presence and monitoring of them should continue to make sure our effects do not impact them negatively.

Mice Distribution

As with our live trapping, abundance estimates also changed over time for tracking tube usage. Tracking tubes have also been suggested as a way to estimate abundance comparable to live trapping (Glennon et al. 2002). In this study, we were able to compare abundance estimates using tracking tubes versus live traps. The results of the closed capture model for tracking tube use was only slightly higher than the estimate made using live trapping data. When we ran the CJS model with tracking tube data we were unable to make the data fit to the model. This occurred even after we adjusted the $\hat{c}$ value, but only for the 3SR test, which suggests that there are biological reasons why the survival of the mice was not the same. This may be due to differences in juvenile and adult survival, which we cannot detect with tracks. We found, as others have, that tracking tubes were more cost effective, could be checked any time during the day, caused no harm to the focal species, held up to wind, rain, and dry spells, and were faster to process than live trapping (Wiewel et al. 2007). It has been shown that tracking tubes are less sensitive to changes than live traps, although those studies that compare abundances find tracking tube estimates similar and correlated to live trapping estimates (Drennan et al. 1998, Glennon et al. 2002, Wiewel et al. 2007). Therefore, tracking tubes may be useful for comparing location and diversity of local fauna, and estimating abundances assuming a closed population.

Our logistic regression suggests that track presence was predicted by the amount of crypto-biotic crust at the transect level, and by bare ground (June), distance from water, and vegetation covering the tracking tubes at the quadrat level. Mice seem to be using the tracking tubes for aid in movement over crypto-biotic crust and areas where vegetation did not cover the tracking tubes. In one study, *Peromyscus* spp. were found in both undisturbed and timber harvested woodlands, although those in the harvested area weighed more and were caught more often in areas with lower leaf litter, less grass, and more rocks and bare ground (Kaminski et al. 2007). Mice may be using the tracking tubes for shelter as they travel through a more open area when they are not as likely to linger and forage. Perhaps this is because tubes are easily seen from normal perception distances under lower light levels since the tubes were white (Zollner and Lima 1999). Crypto-biotic crust may also benefit the mice by either providing hydration from the dew on the moss or an area where fungi may be found for food. Usage could also be influenced by male dispersal, increased population numbers, or used for cover (King 1968). The mice did not prefer to use tubes in certain habitats or directions; they seem to be moving randomly. We did not detect a notable edge effect on movement patterns during the course of our study. Mice are generalists and seem to be willing to be in any area as long as there are food resources and protection from predators at their ground level.

There were no significant explanatory variables in our hot spot logistic regression, suggesting that these clusters are probably influenced by factors we did not measure. Other related studies using the Getis-Ord *Gi** clustering statistic have been focusing on the location of bear-human conflict areas, kangaroo and olive fly locations (Baruch-Mordo et al. 2008, Pople et al. 2007, Kounatidis et al. 2008). We had clusters of activity located at only a few tracking tubes of each site except for Tansel Dunes which had none. On a simply observational basis these tracking tubes had more vegetative cover than other spots in the sites, but because they were only a few from the many areas sampled there may be too much variation within each site to detect a clear explanatory variable. One possible explanation would be that the scales that we examined were too small and having a bigger survey area with more locations would help reveal effects of clustering. These clusters of activity also may be the result of random mice movements or related to the distance from their nests. Although a high amount of zeros can skew the *Gi** distribution, and without a large number of neighbors normality cannot be reached (Ord and Getis 1995), Sokal et al. (1998) indicates that non-normality in the Getis-Ord *Gi** results should focus on outliers and non-stationarity than cluster significance. Therefore, our clusters should be seen more as outliers and the significance interpreted with caution. While we do have areas with higher usage of tracking tubes we currently do not know what is causing this but hypothesize that it may be due to lack of cover for the mice.

Conclusions

We found that mice distribution throughout our sites was not limited to just one habitat type, but found in woodland, edge, and oak savannas. Only a few areas were indicated as hot spots but there was no correlation of them to any of our explanatory variables. The survival and recapture probability estimates with tracking tubes were similar to those found using live trapping data, although the CJS model did not fit the data. Mouse presence at a tracking tube was predicted by the amount of bare ground, vegetation density, and distance from water, and mice presence in live traps was predicted by amount of trail and which gives us an idea that the mice were not only using them in their usual high vegetation density path, but also taking advantage of their use in open areas. Edge was not an important factor in changing the distribution of mice perhaps because oak savannas have similar food and structural resources as oak woodlands from the perspective of a mouse. It is important to study this species in multiple habitats; it being a generalist there is always the possibility of its activities occurring in places other than woodlands.

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Tables

1: Study site information comparing: Lupine stems, entire perimeter (m), entire area (m^2), tracking tube (TT) perimeter and area, live trapping (LT) area (ha), edge area with seed trays (m^2), vegetation density (dm, May and June), vegetation height (dm, May and June), litter depth (cm, June), and management events.

Site	**Monclova**	**Reed**	**Crash**	**BikeTrail**	**Tansel**	**Marys**
Lupine Stems	1536	996	363	6800	100	1173
Entire Perimeter (m)	355	445	340	600	420	415
Entire Area (m^2)	6,450	8,540	7,015	8,340	4, 040	10,330
TT Perimeter (m)	246	245	242	393	420	415
TT Area (m^2)	3,800	3,413	3,580	2,687	4040	10,330
LT Area (ha)	0.589	0.710	0.658	0.771	N/A	N/A
Edge w/ Seedtrays (m^2)	680	480	585	545	245	1,587
Veg. Density May (dm)	0	0.1	0	0.137	0.167	0
Veg. Height May (dm)	3.0625	3.034	4.428	3.65	2.556	4.971
Veg. Density June (dm)	1.125	1.467	0.928	1.013	0.278	1.557
Veg. Height June (dm)	4.813	4.4	4.357	5.55	3.5	5.471
Litter Depth June (cm)	0	2.22	1.822	2.175	1.014	0.571
Burns (5 yrs)	3	0	2	2	0	3
Burns (10 yrs)	5	0	0	4	0	5
Burns (19 yrs)	8	0	2	5	0	9
Mowings (5 yrs)	3	1	0	0	0	0
Total MGMT (19 yrs)	14	7	3	9	0	22

2: Closed capture model averages for each monthly live trapping session over the course of the study, from May to October 2008. Shown are capture probability (p) , its standard error and 95% confidence interval and the recapture probability (c) with its standard error and 95% confidence interval depending on session (date).

Session	**Capture (p)**	**95% CI**	**SE***	**Recapture (c)**	**95% CI**	**SE***
1	0.0133333	0.001875 to 0.0885983	0.0132441	0.1598743	0.1267382 to 0.1996929	0.018568
2	0.027027	0.0067693 to 0.1017006	0.018851	0.1598743	0.1267382 to 0.1996929	0.018568
3	0	0	0	0.1598743	0.1267382 to 0.1996929	0.018568
4	0	0	0	0.1598743	0.1267382 to 0.1996929	0.018568
5	0.0416667	0.0135005 to 0.1213671	0.0235498	0.1598995	0.1267783 to 0.1996949	0.018558
6	0.0289855	0.0072606 to 0.1086036	0.0201966	0.1598932	0.1268269 to 0.1996099	0.018524
7	0.0447761	0.0145129 to 0.1298318	0.0252661	0.1599018	0.1268411 to 0.1996098	0.01852
8	0.21875	0.1340501 to 0.3361904	0.0516748	0.1599106	0.1268516 to 0.1996155	0.018519
9	0.12	0.0549190 to 0.2424214	0.0459565	0.1598987	0.1269017 to 0.1995150	0.018481
10	0.0454545	0.0113956 to 0.1643818	0.0314022	0.1599156	0.1268233 to 0.1996681	0.01854
11	0.1666666	0.0815887 to 0.3104702	0.0575054	0.1598857	0.1268587 to 0.1995459	0.0185
12	0.2	0.0984519 to 0.3640002	0.0676123	0.1599065	0.1268961 to 0.1995416	0.018489
13	0.1428571	0.0546668 to 0.3244844	0.06613	0.1598951	0.1269083 to 0.1994969	0.018475
14	0.4583335	0.2748779 to 0.6538275	0.1017071	0.1598987	0.1269161 to 0.1994942	0.018472
15	0.6153846	0.3435828 to 0.8302465	0.134932	0.1598938	0.1269086 to 0.1994932	0.018474

3: Resulting models for monthly live trap data under CJS sex-based variation. Survival (Φ) probability and recapture (p) probability either stayed constant (.) or vary by group/sex (g). Shown are the Aikaike Information Criterion corrected for small sample size (AICc), the number of parameters, deviance, and survival and recapture estimates with their 95% confidence intervals for each model.

Model	AICc	Parameters	Deviance	Survival	95% CI	Recapture	95% CI
Φ(.)p(.)	330.9690	2	231.96	0.87	0.784-0.925	0.027	0.04-0.358
Φ(g)p(.)	331.9952	3	230.88	M=0.82 F=0.889	M=0.666-0.913 F=0.792-0.944	0.278	0.205-0.364
Φ(.)p(g)	332.1739	3	231.06	0.873	0.788-0.927	M=0.231 F=0.296	M=0.14-0.355 F=0.21-0.399

4: Comparisons of the models run with tracking tube and live trapping data, with similar results (with their 95% confidence intervals) between open population (CJS) and closed population (closed capture) models. models run for tracking tubes and live traps. Survival probability (Φ) and recapture probability (p) either remained constant (.) or varied over time (t). In closed capture models recapture probability is c, and capture probability for new individuals is p.

	Tracking Tubes		**Live Trapping**	
CJS	Φ(.)p(.)		Φ(.)p(.)	
		95% CI		95% CI
Survival	0.934	0.863 – 0.969	0.87	0.784 - 0.926
Recapture	0.345	0.284 – 0.432	0.269	0.198 - 0.353
Closed capture	p(t)c(.)N(.) / p(t)c(.)N(t)		p(t)c(.)N(.) / p(t)c(.)N(t)	
		95% CI		95% CI
Recapture	0.28	0.234 – 0.327	0.16	0.127 – 0.199
Abundance (N)	61		75	

5: The average percentage of seeds removed per site for each date of data collection across all study sites.

Average % Seeds Removed per Site for each Date

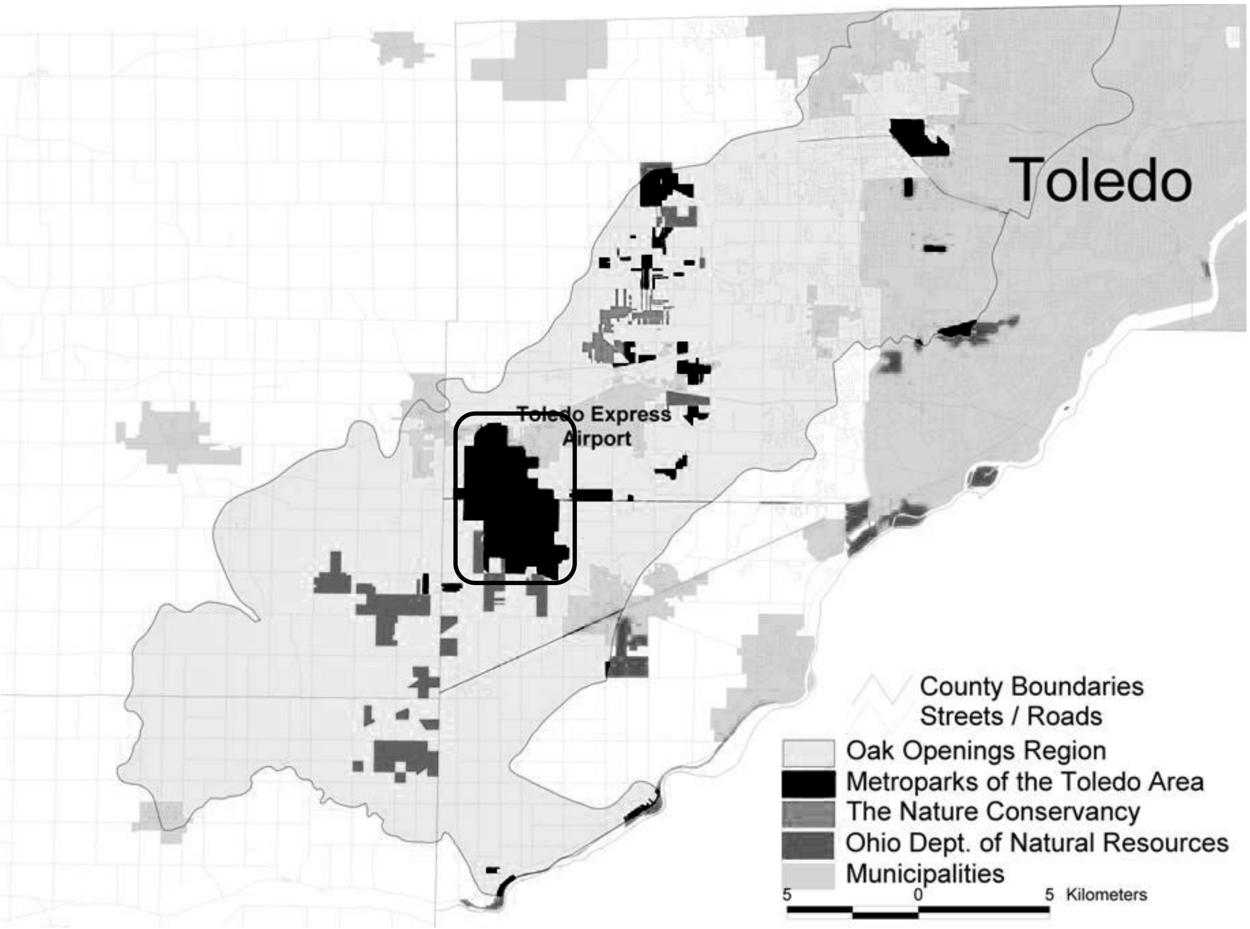
	6/6/2008	6/14/2008	6/22/2008	6/30/2008	7/22/2008	7/26/2008	7/31/2008	8/6/2008	8/10/2008	8/15/2008	8/20/2008
Monclova	0	19.6667	1.1714	30.2	24.3334	0	0	22.5	13.75	1.25	5
Reed	3.25	5.5	4.875	9	14.75	7.5	12.5	1.25	12.5	2.8571	20
Crash	1.625	6.375	4.125	18.125	22.875	10	0	2.8571	28.5714	18.3334	2
Biketrail	5	11.6	8.4286	13	48	75	6.6667	4	38	26	26
Tansel	10	11.1429	0	5.42857	10.6667	1.6667	0	3.75	3.75	3.75	10
Marys	0	3.875	0.75	26.2857	51.375	65	13.3334	28	5	2.5	2.5

6: Comparison of Kruskal-Wallas test on seed predation versus management activities. For each test the sites, number of management events, mean % seed removal, and P-value is given.

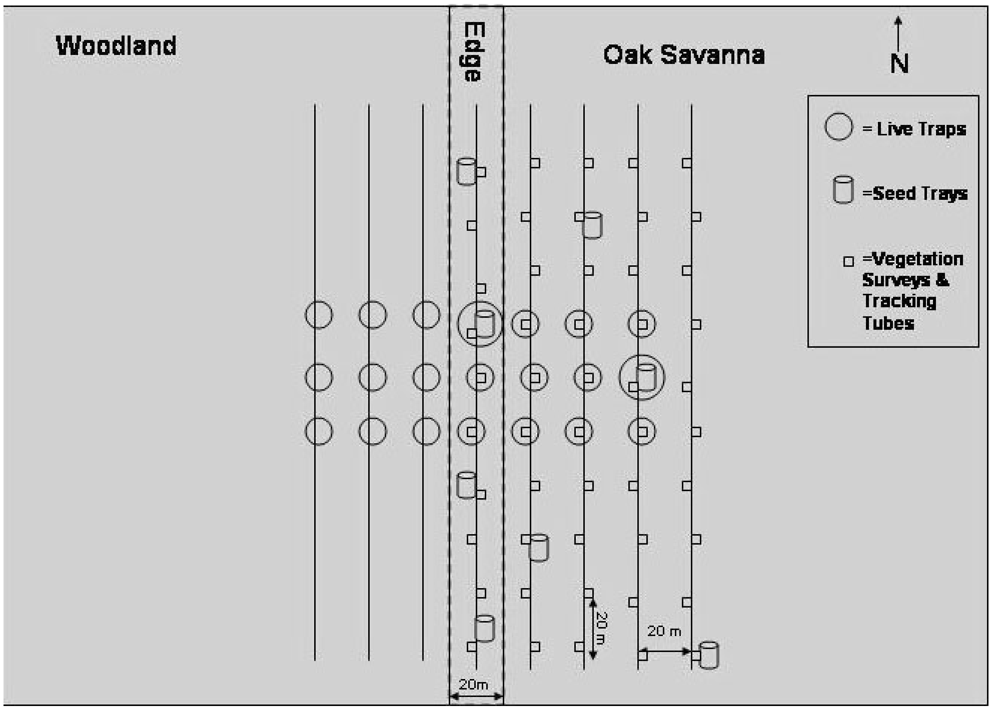
Management	Site	# Events	Mean % Seed Removed	P
Burn 10 yr.				0.034
	Reed Rd., Crash, Tansel	0	13	
	Bike Trail	4	26	
	Monclova, Marys	5	24	
Burn 19 yr.				0.0001
	Reed Rd., Tansel	0	13	
	Crash	2	13	
	Bike Trail	5	26	
	Monclova	8	14	
	Marys	9	42	
Mowing 5 yr.				0.025
	Crash, Bike Trail, Tansel, Marys	0	25	
	Reed Rd.	1	13	
	Monclova	3	14	
Total Management 19 yr.				0.0003
	Tansel	0	0.09	
	Crash	3	13	
	Reed Rd.	7	13	
	Bike Trail	9	26	
	Monclova	14	14	
	Marys	22	42	

Figures

7. Map of study sites in the natural areas in Northwest Ohio with Oak Openings Preserve Metropark with inlay of the location of the park in Ohio circled. Major protected areas are identified by owner.



8. Study site layout with transect grid, live traps (circles), seed trays (cylinders), vegetation survey and tracking tube areas (squares) identified. Distances given in meters (m).

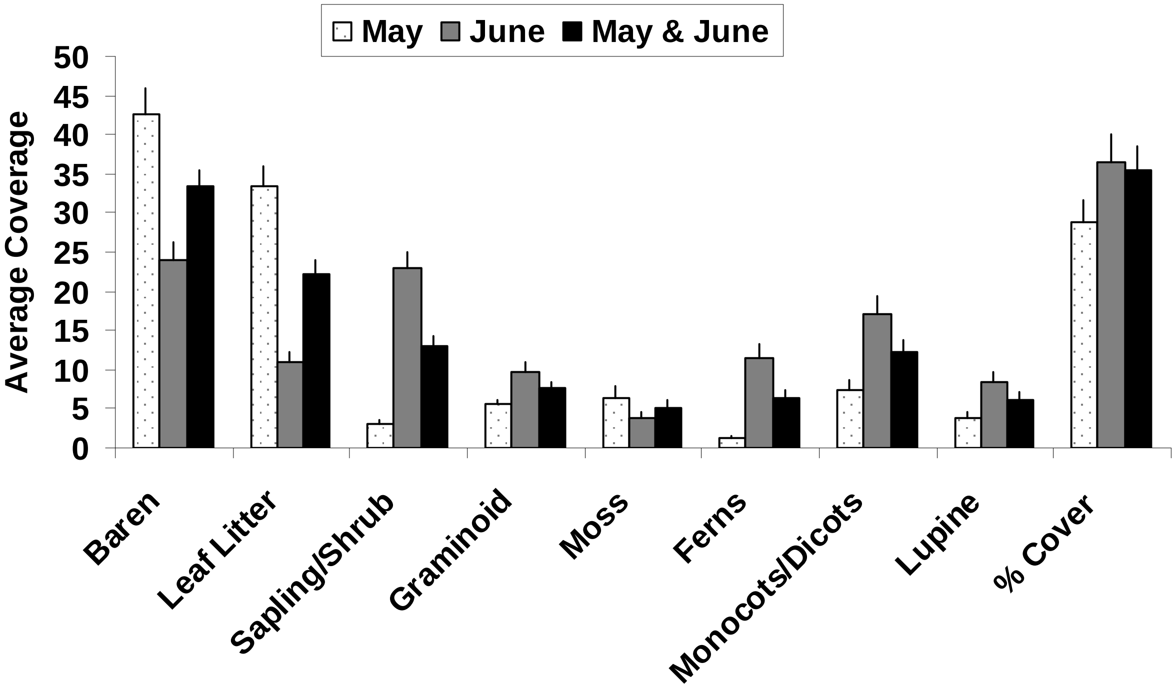


9. Photo of a tracking tube and schematic of the tracking tube paper that was placed inside the tube to detect mice tracks. The dark rectangles at each end of the inserted paper indicates the locations of the ink.

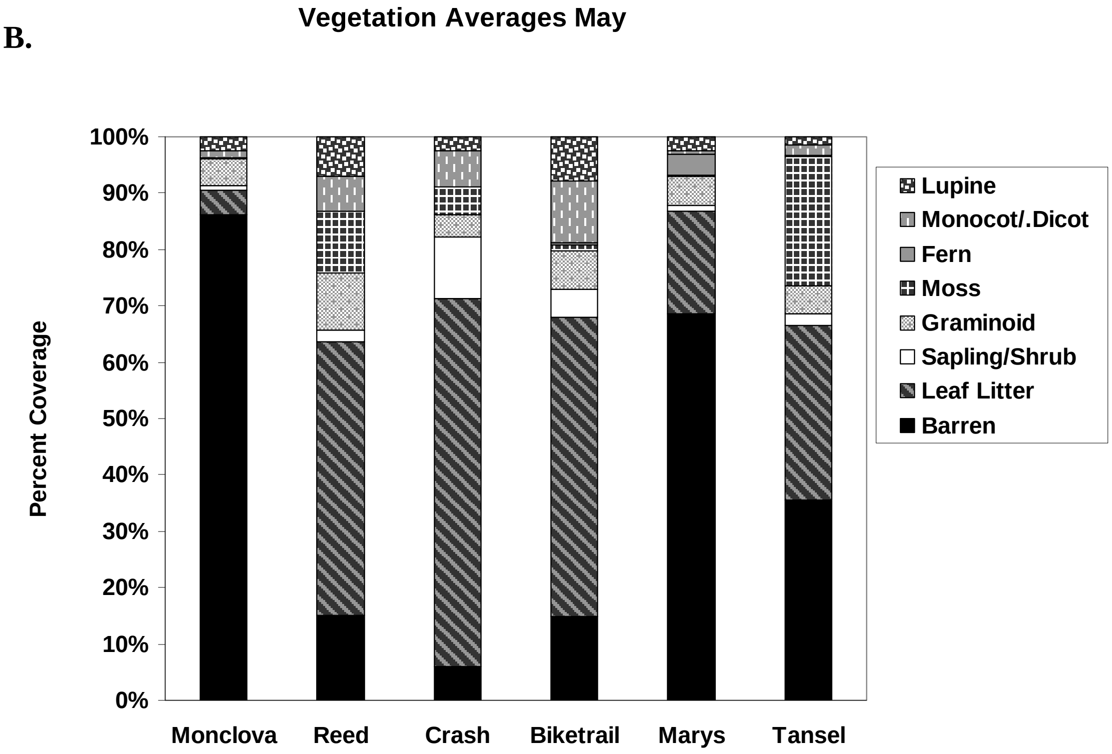
10. Photo of a seed tray used to detect levels of mice seed predation. Seeds were place in the tray and checked weekly for predation. The mesh screening had four equally spaced doors that allowed small mammal entry.

11. Vegetation survey averages for all study sites in (A) Each category in May, June, and May/June average. (B) Variation between study sites in the percent coverage of each type of vegetation found for May. (C) Variation between study sites in the percent coverage of each type of vegetation found for June.

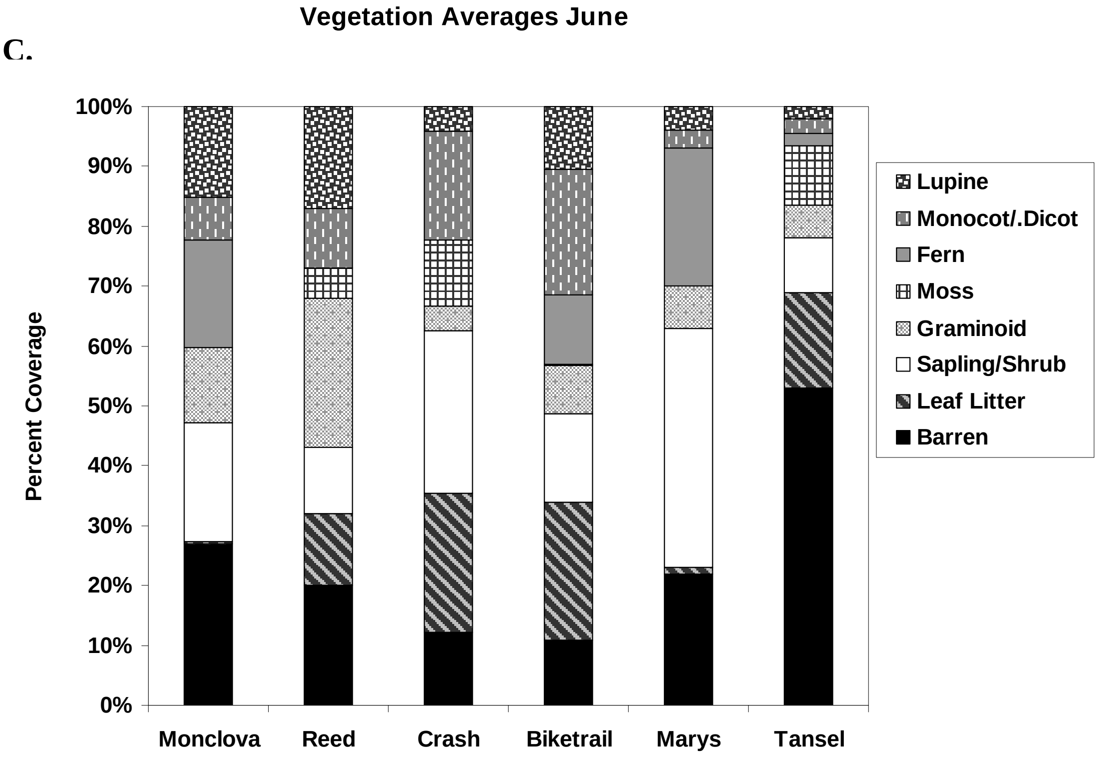
A.



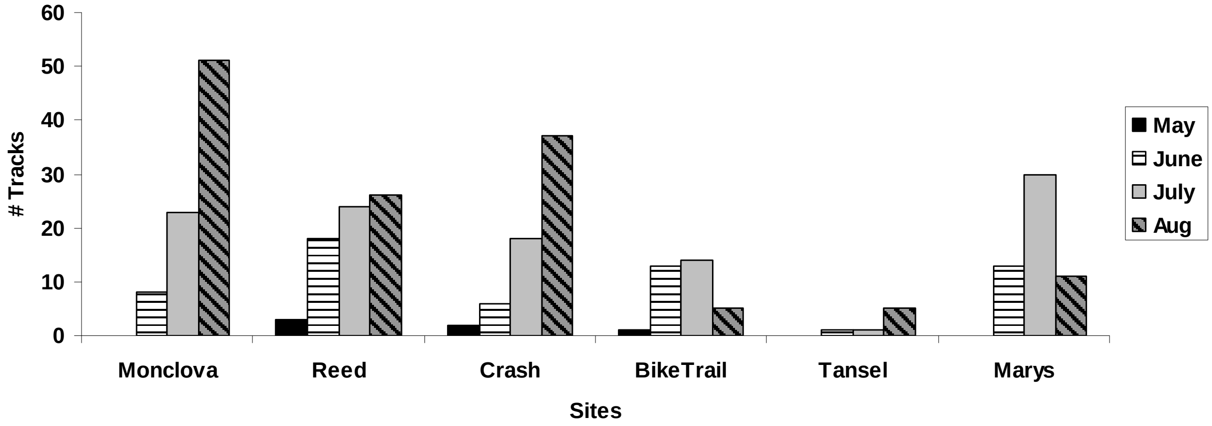
B.


Vegetation Averages May
Percent Coverage
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Monclova
Reed
Crash
Biketrail
Marys
Tansel
Lupine
Monocot/.Dicot
Fern
Moss
Graminoid
Sapling/Shrub
Leaf Litter
Barren

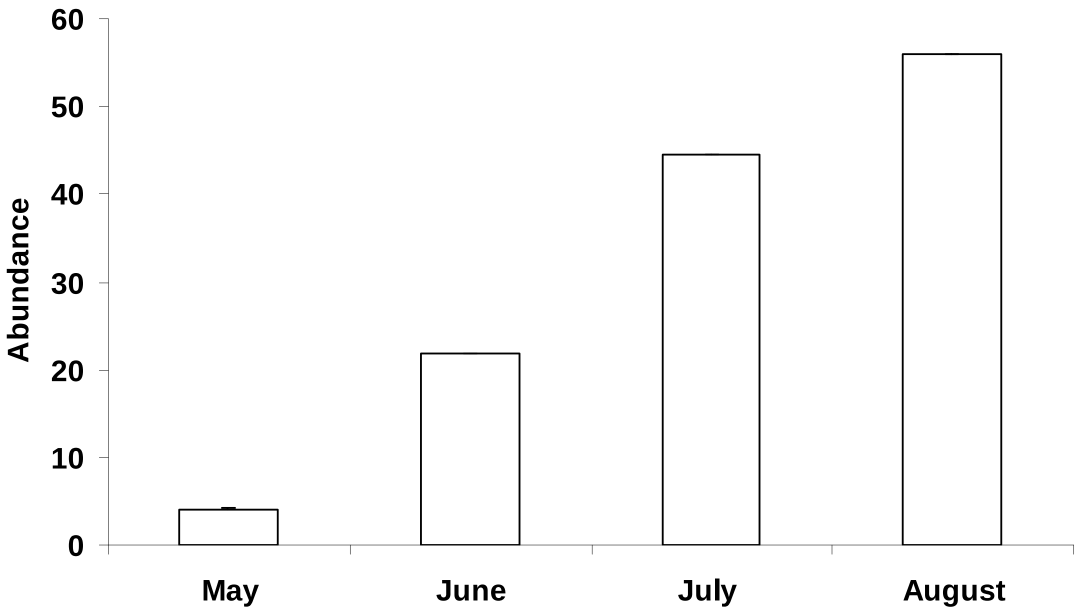
C.


Vegetation Averages June
Percent Coverage
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Monclova
Reed
Crash
Biketrail
Marys
Tansel
Lupine
Monocot/.Dicot
Fern
Moss
Graminoid
Sapling/Shrub
Leaf Litter
Barren

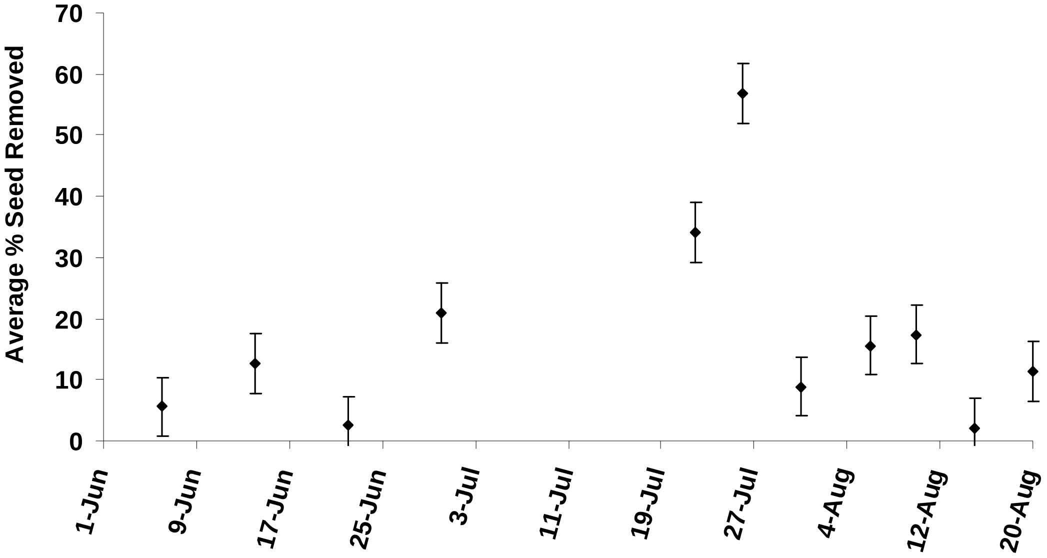
12. The number of tracking tube entries per study site per month, each individual mouse track within a given tube was counted and those with more than 3 individual tracks were counted as 4 tracks.



13. The Schnabel method abundance estimates of the total number of mice per month from weekly tracking tube data. Standard error bars are small and may not be visible.

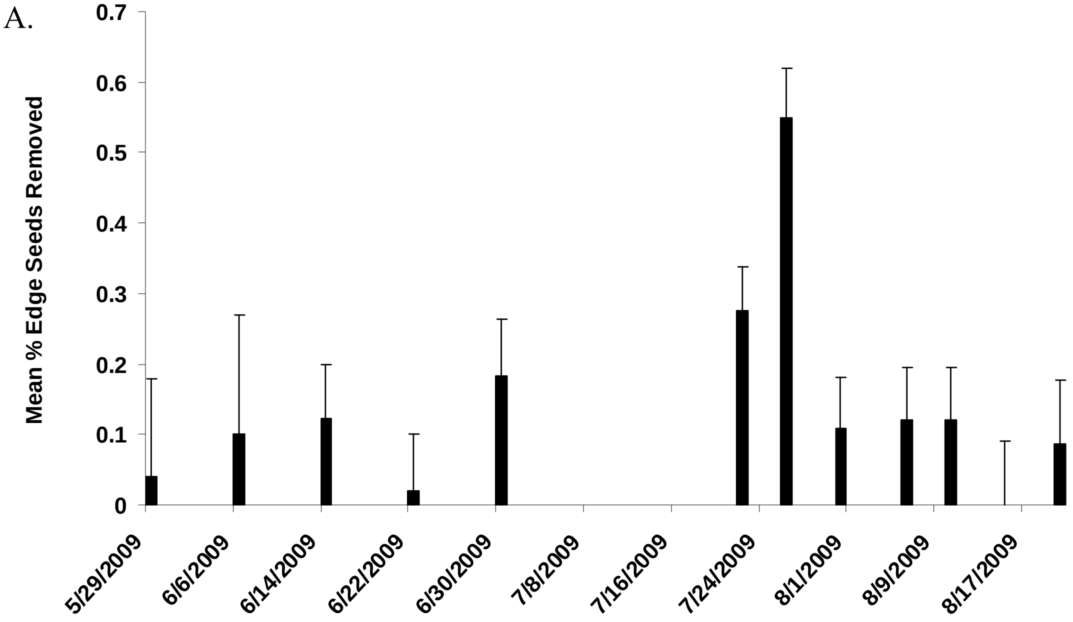


14. Average percentage of seeds removed per week across all sites (e.g., level of seed predation) was significantly different over time (P < 0.0001); shown with standard error bars.

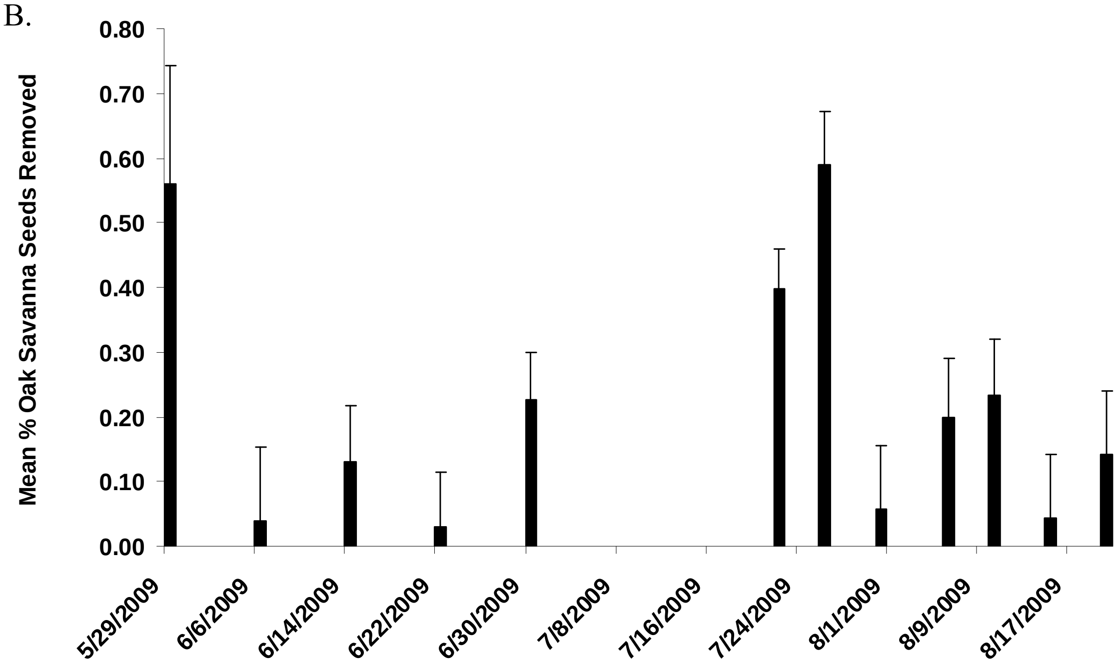


15. Seed predation over time split between edge and oak savanna seed trays and shown as the average percentage of seeds removed. (A) Seed predation at the woodland/savanna edge was significantly different over time; standard error bars are shown. (B) Seed predation in the oak savanna was also significantly different over time; standard error bars are shown.

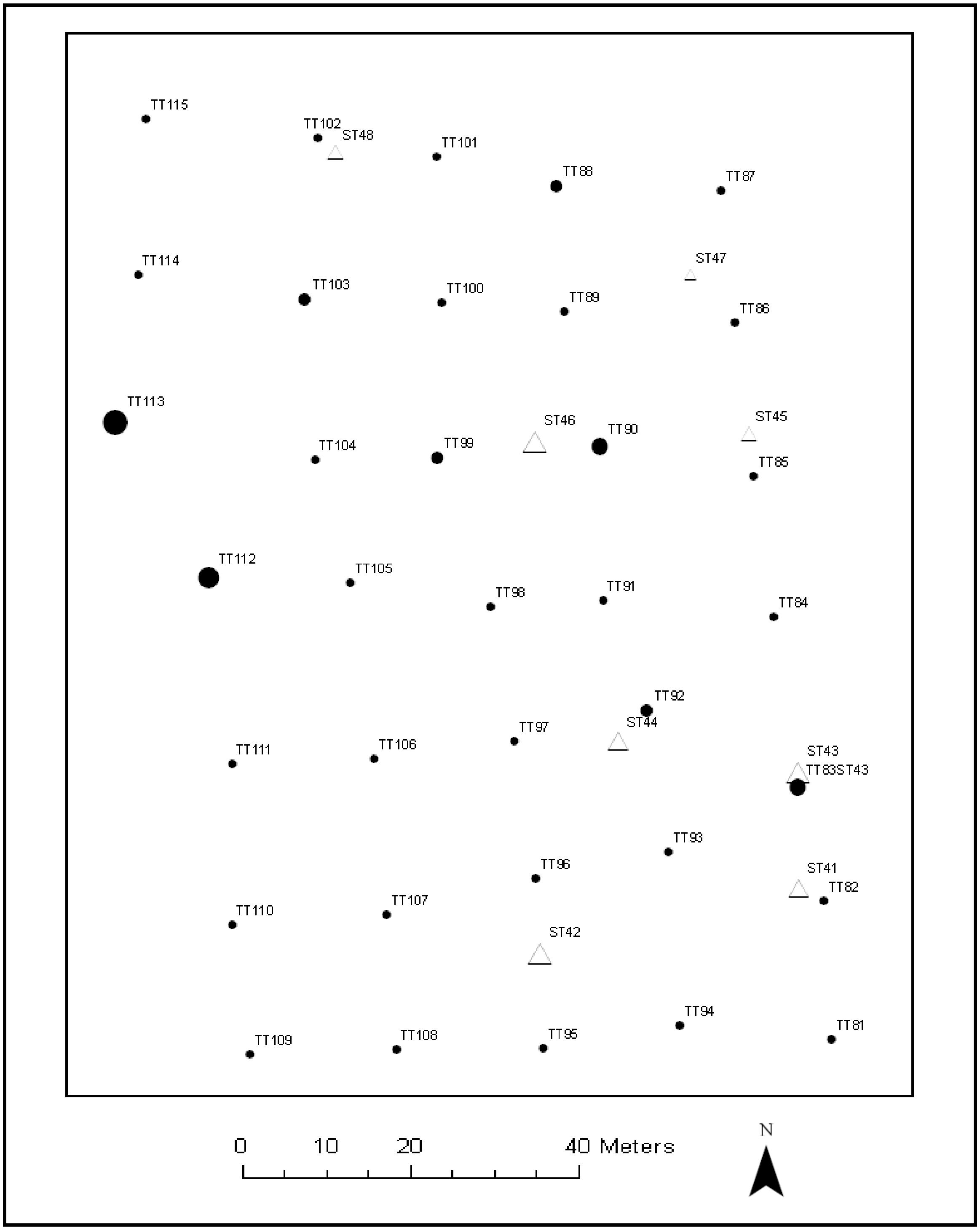
A.



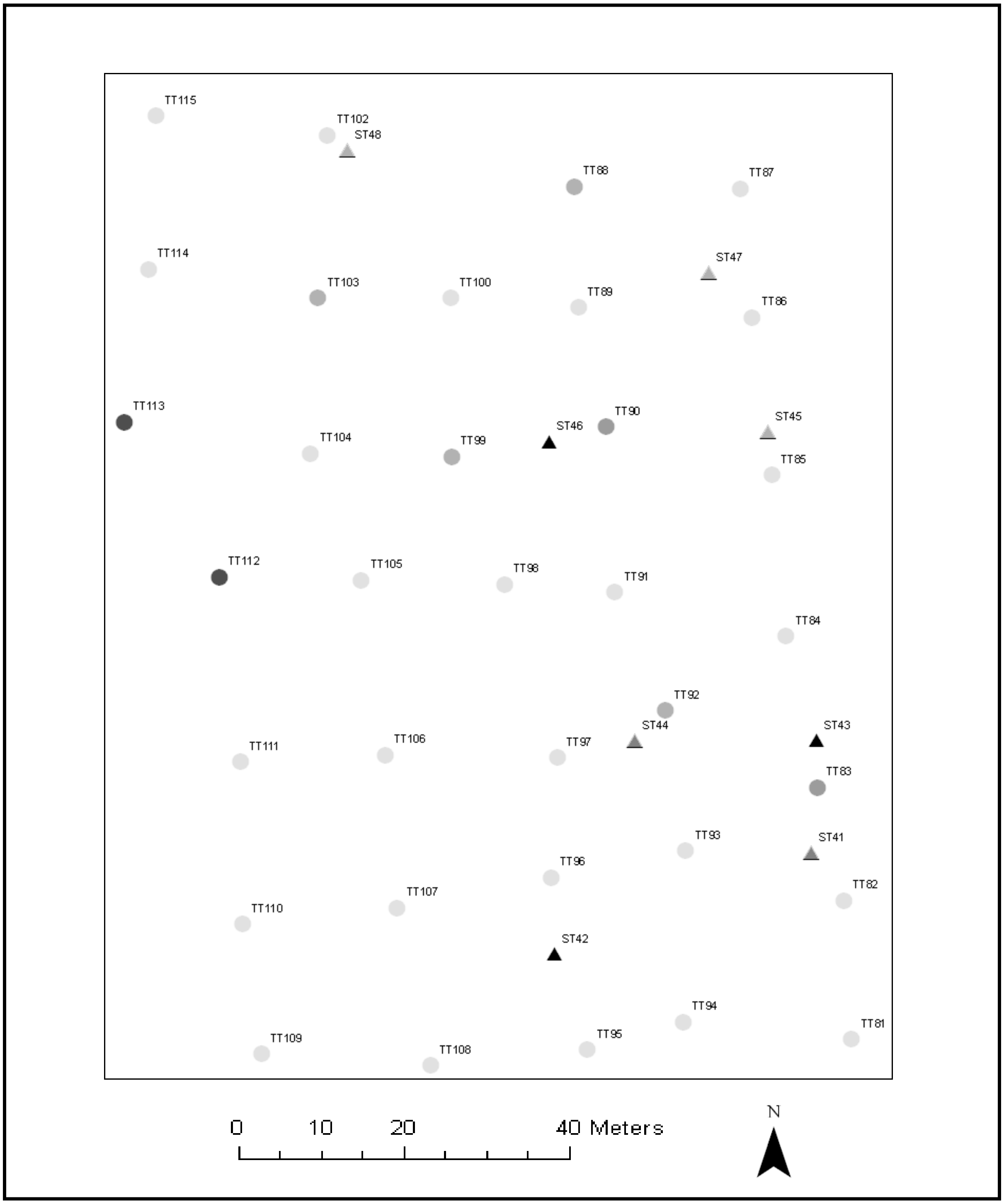
B.


Mean % Oak Savanna Seeds Removed
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
5/29/2009
6/6/2009
6/14/2009
6/22/2009
6/30/2009
7/8/2009
7/16/2009
7/24/2009
8/1/2009
8/9/2009
8/17/2009

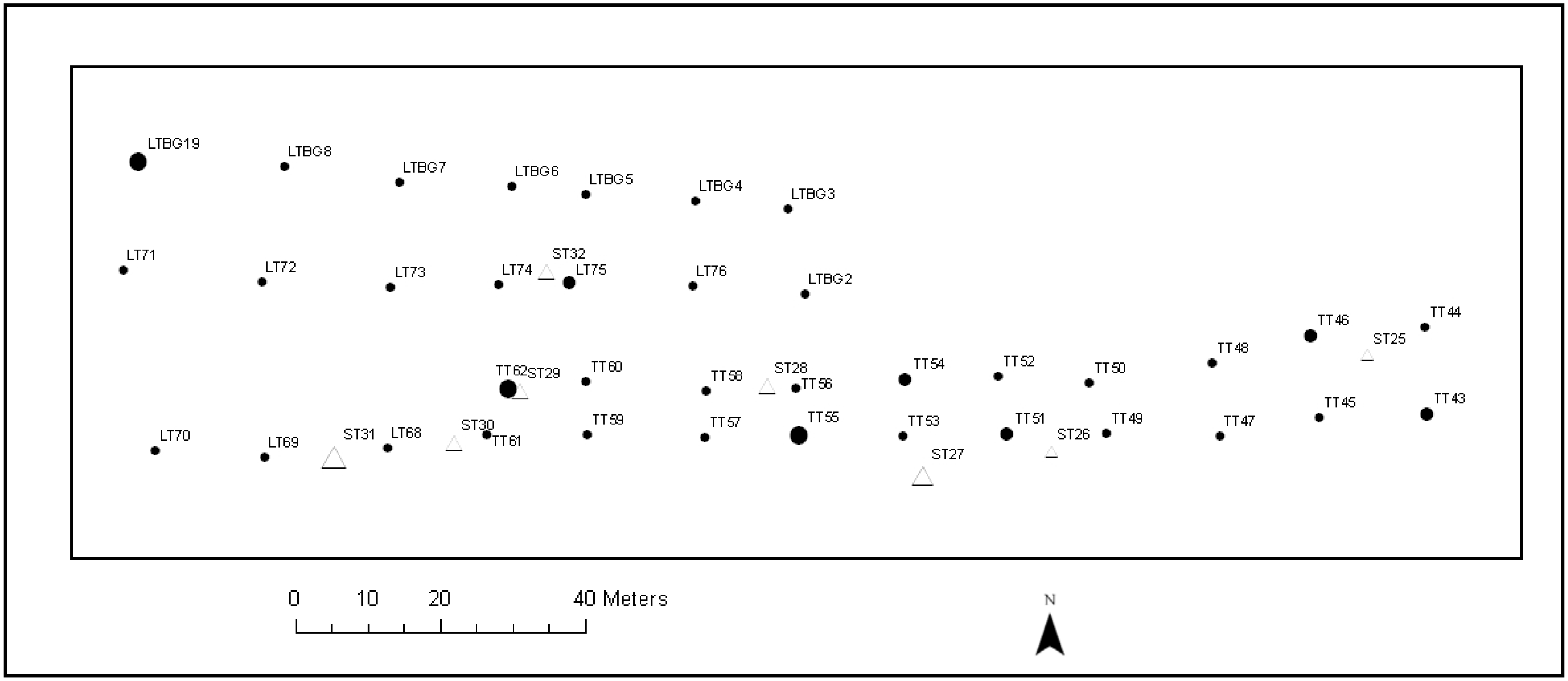
16. Mary’s Savanna weighted seed trays (triangles) and tracking tubes/live traps (circles) with the average amount of seed predation over time and summed number of tracks or live captures, larger symbols mean a higher number. Each symbol represents a unique sampling unit, either a seed tray or tracking tube, in each approximate location within the site.



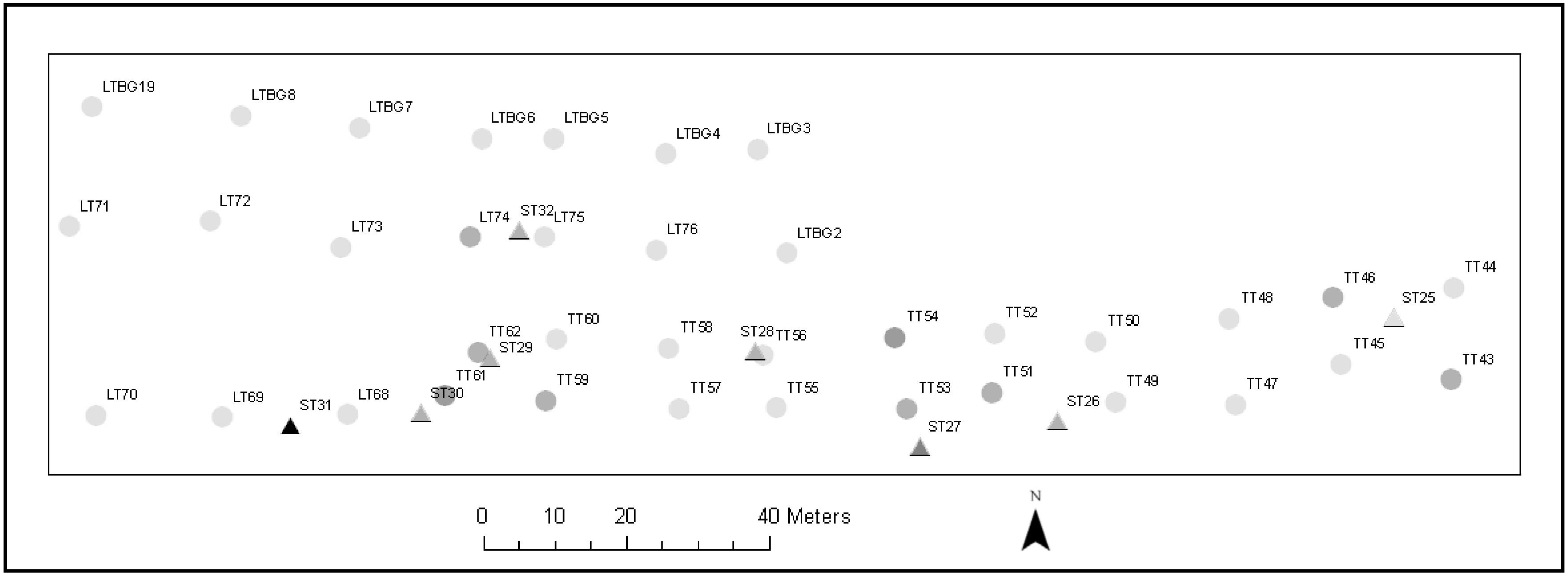
17. Mary's Savanna seed trays (triangles) and tracking tubes/live traps (circles) hot spots, weighted with the z-score from the Getis-Ord Gi* test, black indicates significant clusters of seed predation or mouse traffic. Each symbol represents a unique sampling unit, either a seed tray or tracking tube, in each approximate location within the site.



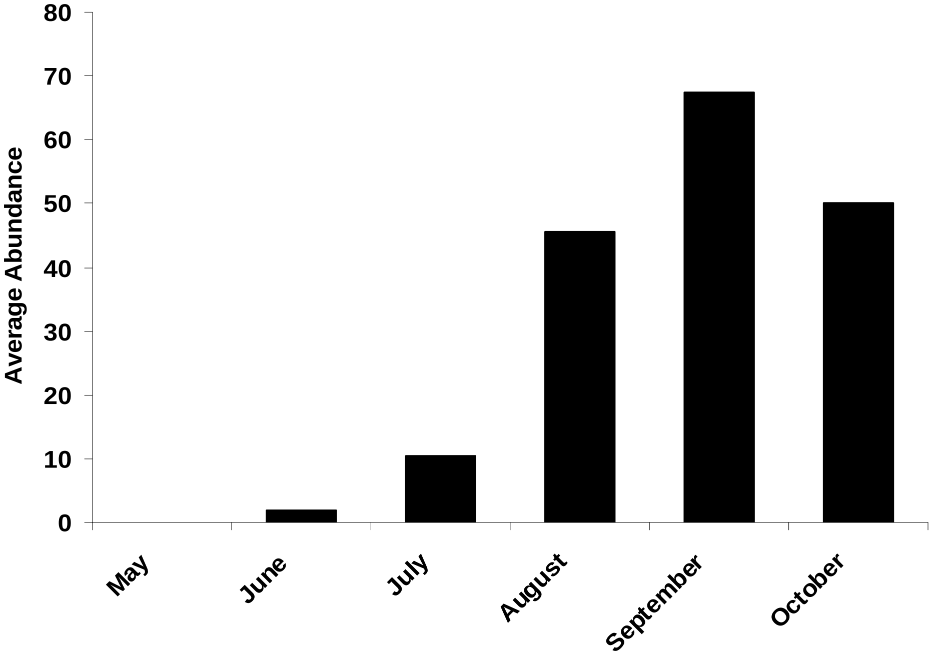
18. Bike trail weighed seed trays (triangles) and tracking tubes/live traps (circles) with the average seed predation over time and the summed number of tracks or live captures, larger symbols mean a higher number. Each symbol represents a unique sampling unit, either a seed tray or tracking tube, in each approximate location within the site.



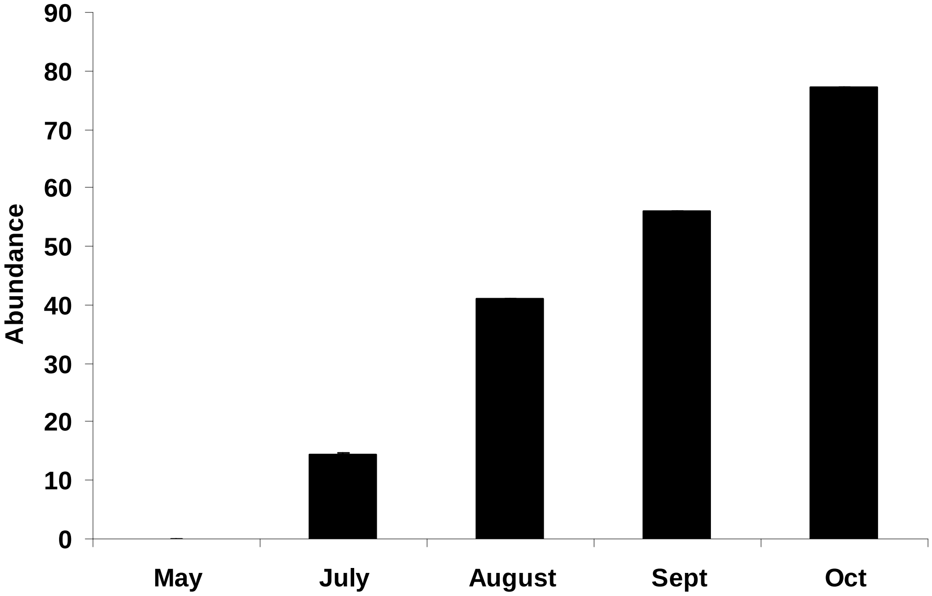
19. Bike trail site seed trays (triangles) and tracking tubes/live traps (circles) hot spots**,** weighted with the z-score from the Getis-Ord Gi* test, black indicates significant clusters of seed predation or mouse traffic. Each symbol represents a unique sampling unit, either a seed tray or tracking tube, in each approximate location within the site.



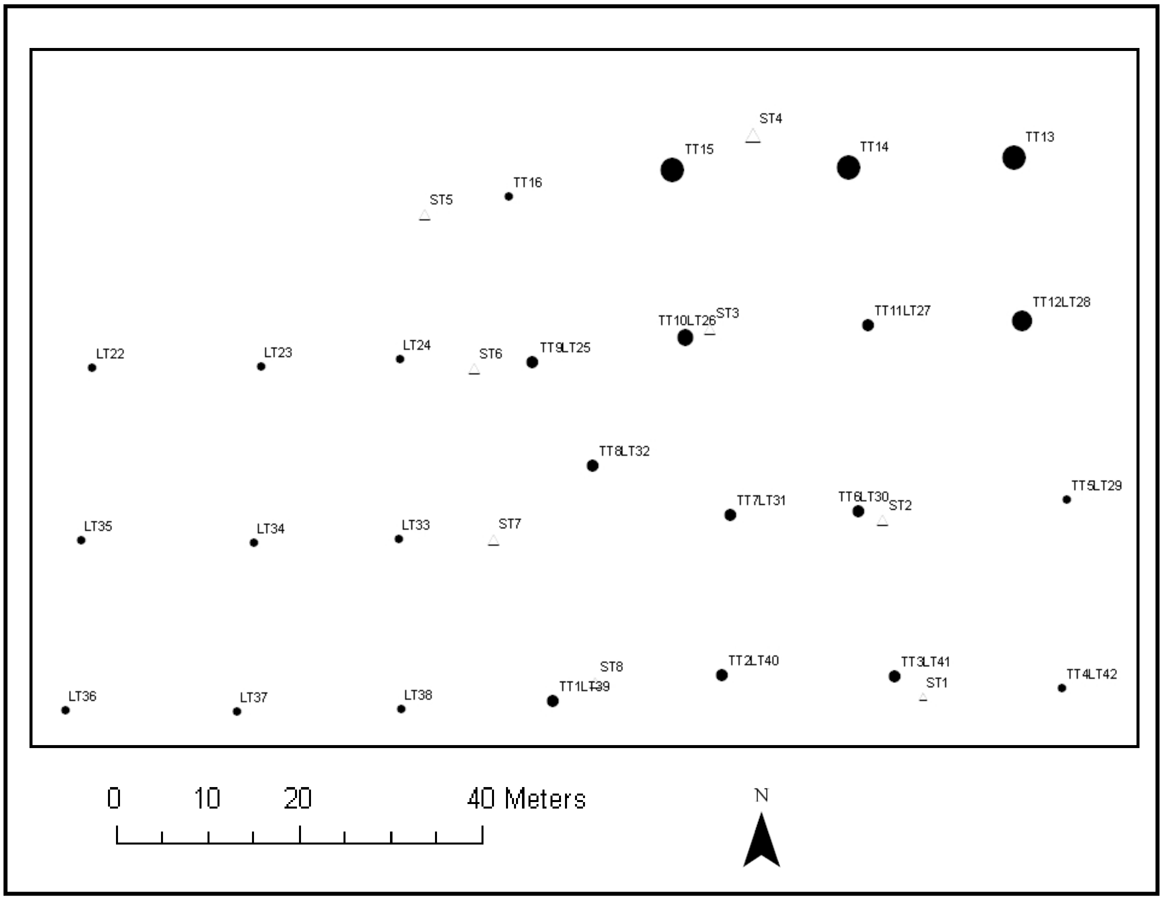
20. Monthly Lincoln-Peterson Index average mouse abundance estimates from monthly live trapping data.



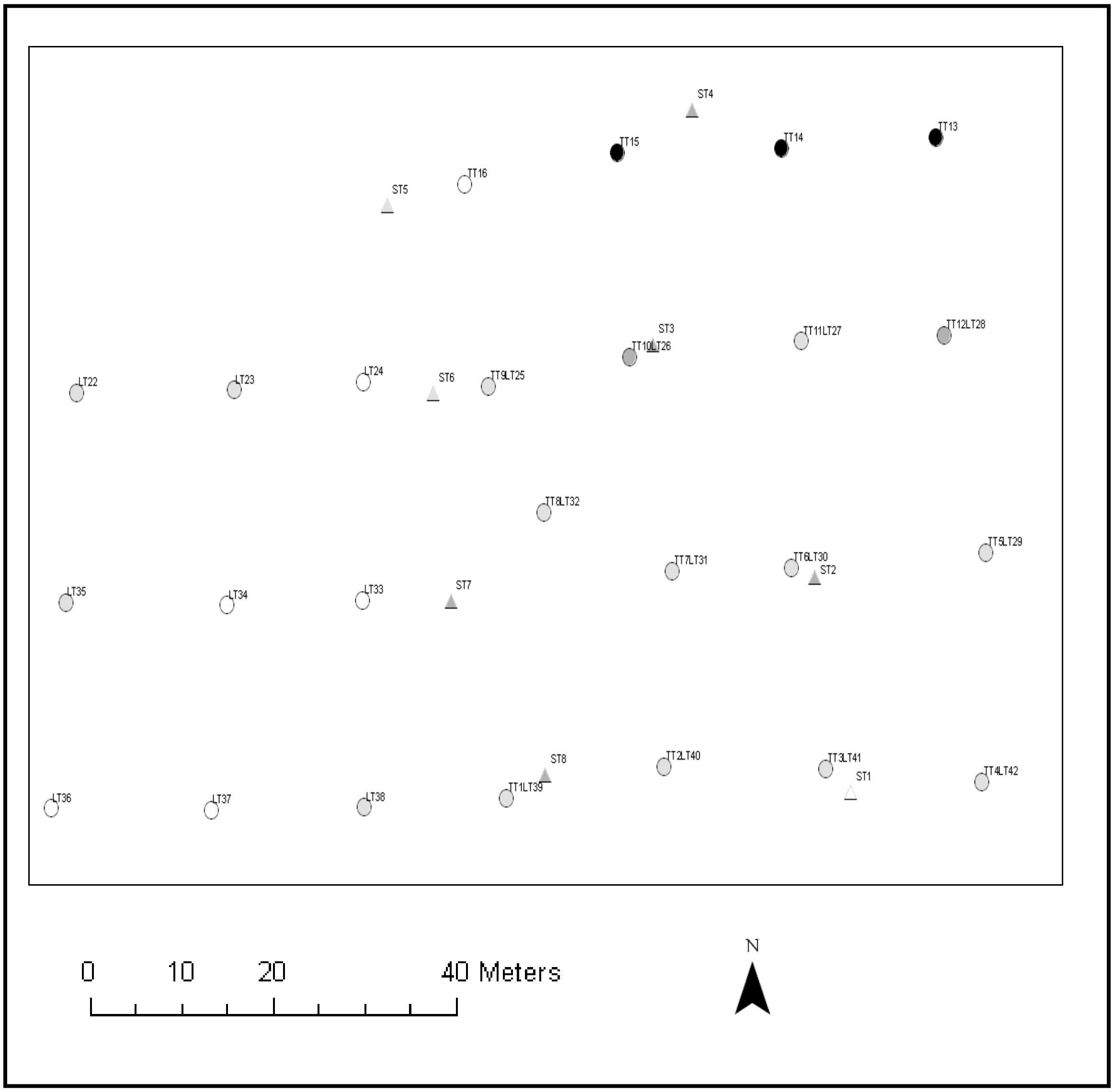
21: The Schnabel monthly average mouse abundance estimates based on monthly live trap data, standard error bars are present but not visible.



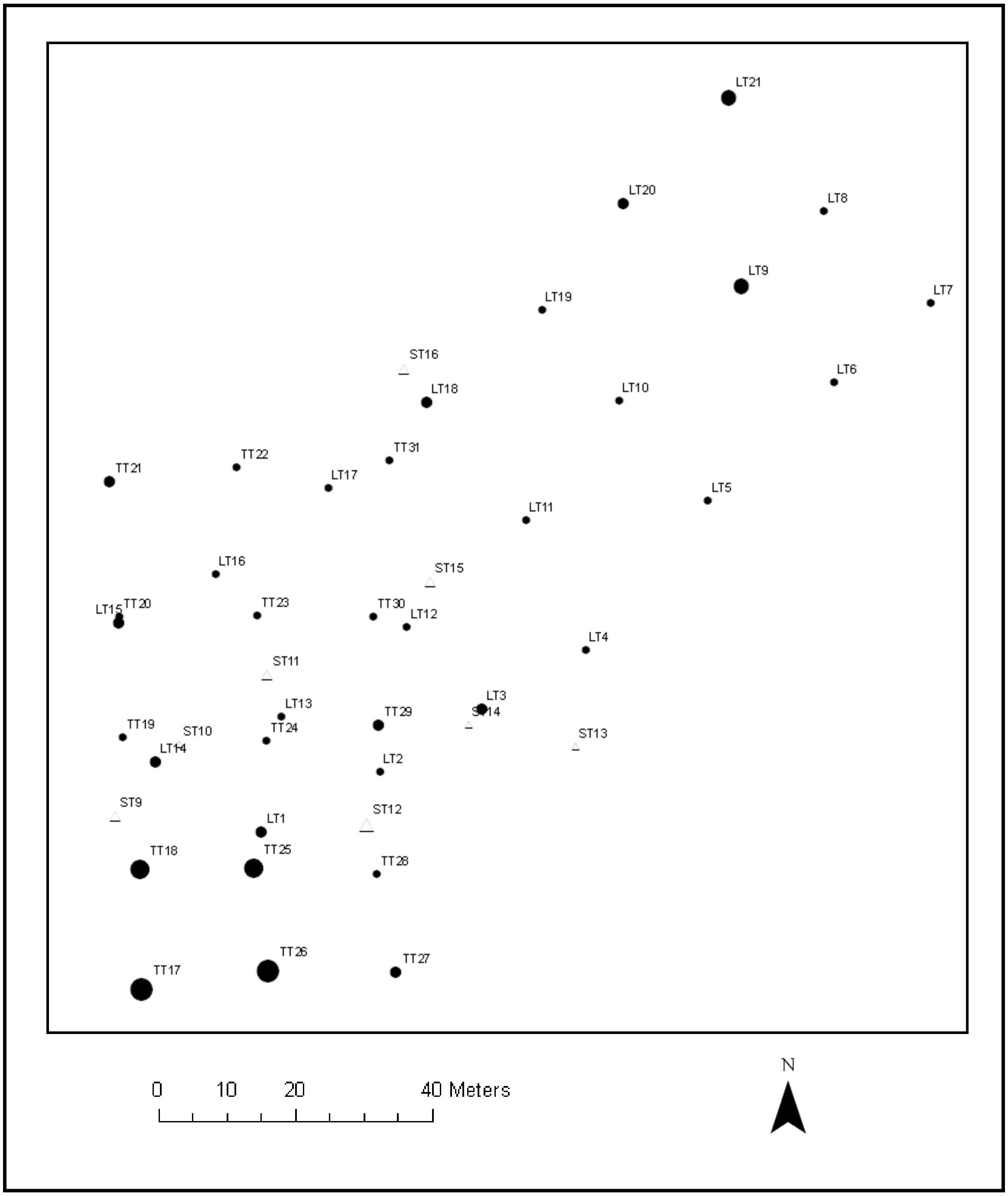
22. Monclova weighted seed trays (triangles) and tracking tubes/live traps (circles) with the average amount of seed predation over time or the summed number of tracks or live captures over time, larger symbols mean a higher number. Each symbol represents a unique sampling unit, either a seed tray or tracking tube, in each approximate location within the site.



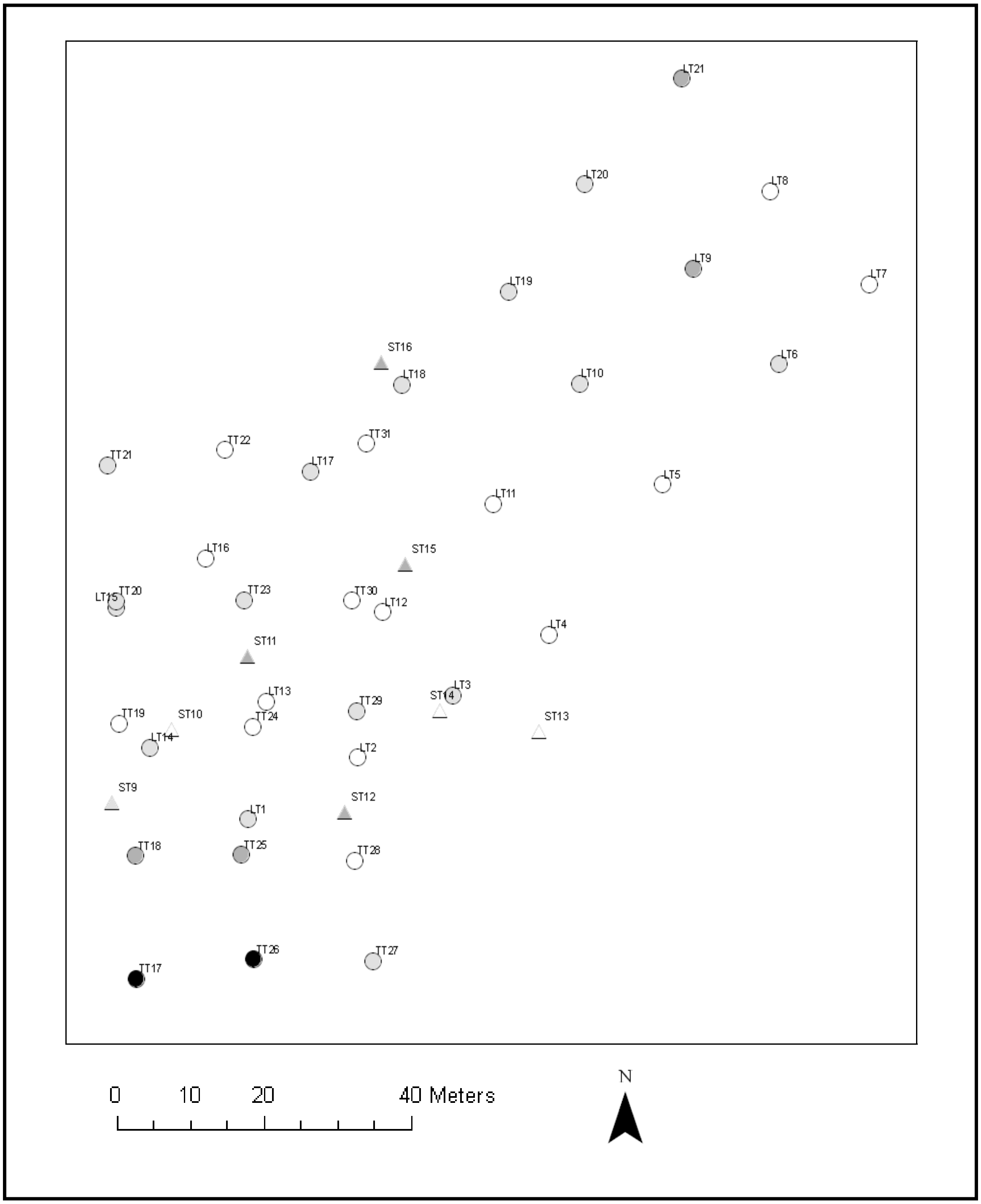
23. Monclova site seed trays (triangles) and tracking tubes/live traps (circles) hot spots weighted with the z-score from the Getis-Ord Gi* test, black indicates significant clusters of seed predation or mouse traffic. Each symbol represents a unique sampling unit, either a seed tray or tracking tube, in each approximate location within the site.



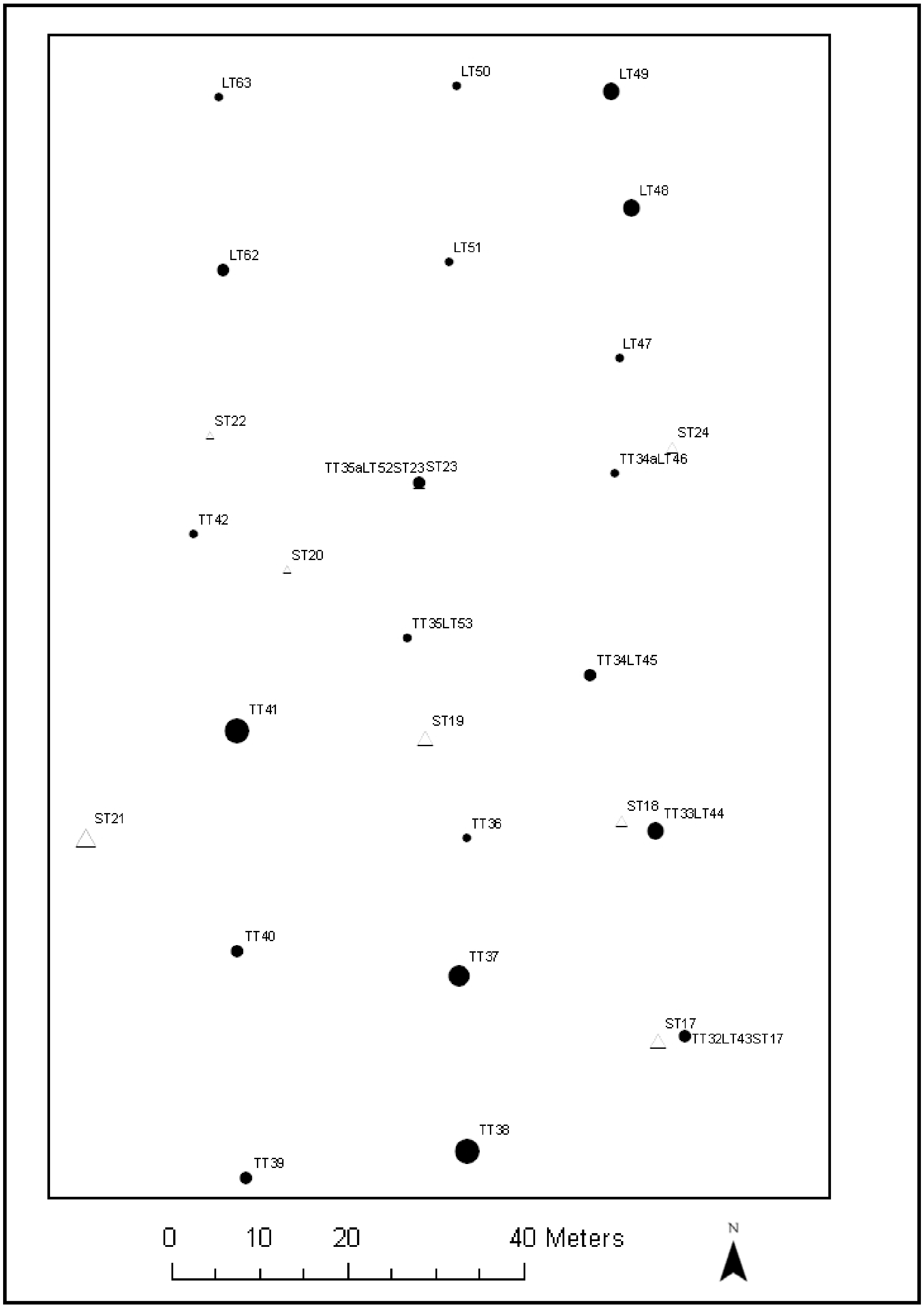
24. Reed road weighted seed trays (triangles) and tracking tubes/live traps (circles) weighted with the average amount of seed predation over time or the summed number of tracks or live captures over time, larger symbols mean a higher number. Each symbol represents a unique sampling unit, either a seed tray or tracking tube, in each approximate location within the site.



25. Reed road site seed trays (triangles) and tracking tubes/live traps (circles) hot spots weighted with the z-score from the Getis-Ord Gi* test, black indicates significant clusters of seed predation or mouse traffic. Each symbol represents a unique sampling unit, either a seed tray or tracking tube, in each approximate location within the site.



26. Crash weighted seed trays (triangles) and tracking tubes/live traps (circles) weighed with the average amount of seed predation over time or the summed number of tracks or live captures over time, larger symbols mean a higher number. Each symbol represents a unique sampling unit, either a seed tray or tracking tube, in each approximate location within the site.



27. Crash site seed trays (triangles) and tracking tubes/live traps (circles) hot spots weighted with the z-score from the Getis-Ord Gi* test, black indicates significant clusters of seed predation or mouse traffic. Each symbol represents a unique sampling unit, either a seed tray or tracking tube, in each approximate location within the site.