ASSESSING THE EFFECTS OF WHITE-TAILED DEER (ODOCOILEUS VIRGINIANUS) ON THE OAK SAVANNA

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ABSTRACT

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The Oak Openings Region of northwest Ohio is a unique and complex collection of ecosystems. The heterogeneity of the area is extreme, and permeates all scales. Oak savanna, one of the habitats within the mosaic, is vital for the federally endangered Karner Blue Butterfly (*Lycaeides melissa samuelis*).

We sought to shed light on the interactions between the savanna habitat, wild blue lupine (*Lupinus perennis*) and white-tailed deer (*Odocoileus virginianus*). To this end we measured browsing on oak seedlings and lupine leaves within $1m^2$ quadrats at six sites within three different natural areas. We compared trends in lupine and oak abundance and browsing pressure over space, time and at the site scale as well as the quadrat scale using logistic regression and a spatially explicit test for clustering. The results indicated that there were complex interactions at both scales that were not adequately captured by the variables measured. In the logistic regressions of quadrat scale browsing on both lupine and oaks, browsing on one predicted variation in browsing on the other. Interesting correlations were found at the site scale between management actions such as burning and mowing and proportion of the site classified as closed canopy. Examination at a single scale would have excluded part of the picture present in these natural areas. Results from the spatial clustering test suggest different spatial trends in distribution of lupine. Spatial statistics added much to our understanding of trends in the data that were invisible to other measures.

We also performed weekly road-based surveys within the largest natural area, Oak Openings Preserve Metropark, to estimate relative deer abundance. Deer abundance observations were analyzed using forward stepwise logistic regression. The results of our forward stepwise logistic regression model indicated that length of streams within a zone was an important variable for predicting overall deer abundance in a zone. This suggests that the deer may be moving throughout the park exploiting patchy resources.

Scale effects were evident in trends for browsing and distributions of lupine and oaks, and both were affected by the heterogeneous nature of the area. Both spatial and temporal effects were evident in deer utilization of the park. This study deepened our understanding of complex interactions between deer, oak, and lupine within the globally rare, early successional oak savanna. Our methods to study these interactions were easy to replicate, initiate, extend and monitor.

Dedicated to those who have gone before.

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I wish to thank all the organizations which allowed me to use their property for this study and the people who facilitated the process of obtaining permits. This study was carried out in Oak Openings Preserve Metropark by permission of the Metroparks of the Toledo Area through Karen Menard, Kitty Todd Nature Preserve with the permission of The Nature Conservancy through Gary Haase and at Meilke Road Savanna with the permission of the Ohio Department of Natural Resources through Jennifer Windus.

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Introduction

Why Conserve

To save, you must first understand what you're trying to save. If we do not know what is in an area we could lose valuable natural resources and interesting species and assemblages without even recognizing them. This would be a tragedy anywhere, but we have in Northwest Ohio one of the "last great places on Earth" as designated by the Nature Conservancy (Green Ribbon Initiative 2008). It is a complex and varied system which hosts many species of interest and concern. Alongside the rare and threatened species are a host of common species, all facing common threats to the area. Why, then study such a common animal as deer? While deer are prevalent and common, they are not well studied here. Our goal was to begin to fill in that gap in information in an open habitat characteristic of the region, the oak savanna.

Oak Openings Region

The Oak Openings region spans parts of the Midwest, with extensions into northwest Ohio and Michigan. Historically in the Midwest it covered between 11 and 13 million hectares of which 0.02% remains as of 1986 (Nuzzo 1986). It contains a complex mosaic of habitats, some of which are globally rare, such as the wet prairie and oak savanna (Grundel et al. 1998, Nuzzo 1986). This interweaving of different habitats results in an area rich in biodiversity as these habitats host one third of the plant species of concern for the state of Ohio (ODNR 2009b).

A major threat to this unique association of habitats is fragmentation (Fig 1). Agricultural expansion to the South and urban sprawl from the North threatens to squeeze the largest pieces of natural areas between them (Abella et al. 2007). Our study focused on the oak savanna habitat. It is an early successional habitat characterized by sparse oak trees and a distinct lack of woody understory (Grundel et al. 1998, Green Ribbon 2004b, Grundel and Pavlovic 2007). Oak savannas can vary greatly in canopy cover, one study recorded sites with 5 to 80 % canopy cover as oak savannas (Grundel and Pavlovic 2007, Faber-Langendoen 2001).

Historically fire kept the landscape of the Toledo area as a shifting mosaic of dunes, oak savanna and oak woodland as well as the wet habitats (Abella et al. 2007). Fire suppression led to succession to oak woodland and many places that could be oak savannas are still oak woodland today (Abella et al. 2007). Currently oak savanna is managed for in the Metroparks of the Toledo Area by a combination of burning and mowing practices (Green Ribbon 2004b). There are other organizations also involved in conservation of land within the Oak Openings region; some of the larger ones are The Nature Conservancy (TNC) and the Ohio Division of Natural Resources (ODNR). Each organization has their own approach to management and goals for their pieces of land, but they all value oak savanna for possible sites for reintroduction of the Karner Blue butterfly.

The Karner

The Karner Blue Butterfly (*Lycaeides melissa samuelis*) has been federally endangered since 1992 (UFWS 2003). The endangered status of this species is one of the major reasons for local interest in the oak savanna habitat. It is one of a number of small butterflies sporting blue color that occur in the Oak Openings region and has a wingspan of a scant inch. During the summer it produces two broods in the oak savannas, one hatches from overwintering eggs into adults during that summer and lays the eggs that will hatch as the second brood which lays eggs that overwinter. Larvae feed exclusively on wild lupine (*Lupinus perennis*) though adults depend on a variety of plant species for nectar. In 1998 Karners were reintroduced to the region following previous extirpation in 1988 (Chan and Packard 2006). The initial site was at Kitty Todd Nature Preserve and later in Oak Openings Metropark (OOMP) in Lou Campbell Prairie. Efforts at both sites focus on habitat quality and sufficient populations of wild lupine for larvae.

Lupine

Wild lupine (*Lupinus perennis*) is a species frequently associated with the open, grassy savannas. Lupine is a species of interest in the Oak Openings region since it is a larval food source for several butterfly species, including the federally endangered Karner Blue Butterfly (Grundel et al. 1998, Green Ribbon 2004b, Grundel and Pavlovic 2007). This is the reason behind monitoring wild lupine in our study. It is a perennial with a central stem that bears small blue flowers from late May to the middle of June, though this can be changed by wet or dry conditions by a few weeks. Lupine sprouts in early spring and sets seed through dehiscing in midsummer. When browsed lupines produce toxic secondary compounds as defense against herbivores (Wink 1983), rendering them unpalatable. Lupine is also a nitrogen fixer, as are most in the genus, which can impact soil nitrogen content (McNeil Cushman 2005). This makes lupine a critical resource for the entire community, not just the Karner.

Oaks

Oak savannas vary widely in canopy cover (5-80 %) but can also be distinguished from oak woodlands based on associated species such as wild blue lupine and big bluestem or characteristic sandy soil (Faber-Langendoen 2001). A secondary layer of subcanopy may be present and include oaks or other species such as sassafras (Faber-Langendoen 2001). Common oak species for the area include black oak (*Quercus velutina*), northern pin oak (*Quercus ellipsoidalis*) and white oak (*Quercus alba*) sassafras (Faber-Langendoen 2001). The mature trees provide food and shelter for many species of herbivores. A common herbivore in the area is the white-tailed deer (*Odocoileus virginianus).* Studies have shown that deer keep areas more open by browsing tree seedlings (Casabon and Pothier 2008, Tremblay et al. 2007) and that browsing intensity differs spatially (Conover and Kania 1995). In the Oak Openings Region, succession from oak savanna to oak woodland is generally defined by canopy cover (Nuzzo 1986, Faber-Langendoen 2001). Therefore browsing on oaks may keep savannas open longer, which would be beneficial under current management practices.

Deer Characteristics

White-tailed deer are generalist herbivores that can be very plastic in diet and behavior (Halls 1984, Cash and Fulbright 2005, Pellerin et al. 2006) by altering temporal activity schedules and subsisting on a wide variety of plant species. According to the literature, deer are generally crepuscular, favoring dawn and dusk for feeding but this may change in response to predation or anthropogenic factors (Halls 1984, Dumont at al. 2000). The reproductive capability of a doe varies according to condition but females may produce up to three fawns per year, after the first year. The births center around May to early June and fawns are even more elusive than adults. Deer have been known to severely reduce the abundance of favored browse species (Kirschbaum and Anacker 2005) and, when population pressure is intense even unpalatable plant species suffer (Sekura et al. 2005, Pellerin et al. 2006, Cash and Fullbright 2005). This may be important to our study, even though we are not assessing browsing within a forest, but rather the progression of succession of oaks in the early successional oak savanna. Kie and Bowyer (1999) found little evidence of different dietary niches for male and female white-tailed deer in their study, regardless of the population density. Both sexes browse a variety of grasses and forbs (Kie and Bowyer 1999), subsisting on woody material in lean times (Coulombe, Cote and Huot 2008) and supplementing their diet with a variety of fruits and very rarely, animal matter such as eggs (Ellis-Felege et al 2008). There is temporal variation in the diet of white-tailed deer as the species available to consume change with the seasons (Coulombe, Cote and Huot 2008).

White-tailed deer (*Odocoileus virginianus*) and the associated subspecies have colonized a range that extends from Mexico to Canada and all but the southwestern portions of the US where the mule deer is a competitor (Heffelfinger 2006). They exist in habitats ranging from plains and prairie in Texas to the forests of Maine and they even come into suburban developments which can lead to conflict with humans (Kilpatrick et al. 2003). Home ranges vary by sex with males generally covering more area than females (Halls 1984). Deer may be seasonally migratory or non-migratory in the US depending on environmental conditions, especially availability of browse and shelter during the winter months (Dumont et al 2000). In the Oak Openings Region of Ohio there is no documentation of migratory behavior in the local deer populations. When dispersing from their natal herds deer can travel fairly far, which places them at risk from encounters with cars and other anthropogenic hazards. One study found that juvenile males may travel between 9 km for a spring dispersing yearling and 5 km for one that disperses in fall (Long et al 2008) before establishing a new home range. It should be noted that the maximum dispersal distances for spring and fall recorded by Long and colleagues (2008) were both over 40 km.

Impacts of Overabundant Herbivores

Herbivores can cause changes in species assemblages (Halls 1984, Stromayer and Warren 1997, Kie and Bowyer 1999, Dumont et al. 2000, Bugmann and Weisberg 2003, Rooney and Waller 2003, Gordon et al. 2004, Kraft et al. 2004, Cash and Fulbright 2005, Kirschbaum and Anacker 2005, McGraw and Furedi 2005, Sekura et al. 2005, Pellerin et al. 2006, Tremblay et al. 2007, Washburn and Seamans 2007). Grazing or browsing pressure and the selectivity of certain species of large herbivores, whether domesticated or wild can shift which species of plants can survive and thrive in a variety of environments around the world (Bugman and Weisberg 2003, Cash and Fulbright 2005,). This can be for a variety of reasons ranging from direct pressure of browsing or herbivory (Halls 1984, Bugman and Weisberg 2003, Rooney and Waller 2003, Kraft et al. 2004, Cash and Fulbright 2005, Kirschbaum and Anacker 2005, McGraw and Furedi 2005, Tremblay et al. 2007) to physical effects such as trampling (Halls 1984, Rooney and Waller 2003, Pellerin et al. 2006) or indirect effects such as spread of non-native plants (Williams and Ward 2006, 2008). Nevertheless, this means that very different plant communities can result from introduction or increased abundance of an herbivore. This project focuses on the potential impacts of one herbivore common to the United States, white-tailed deer, on a rare, transitional habitat found in northwestern Ohio, oak savanna.

Deer in particular are a concern in parts of the United States due to growing populations and worry over increases in deer vehicle collisions, as well as the ever present threat of chronic wasting disease and vector borne illnesses such as Lyme disease (Stout et al. 1993, Jones et al. 1998, Belant and Seamans 2000, Kilpatrick and LaBonte 2003, Brinkman et al. 2004, Tonkovich et al. 2004). White-tailed deer are very well studied and modeled from the perspective of hunting and damage to commercial crops (Halls 1984, Conover and Kania 1995, Mower et al. 1997, Belant and Seamans 2000, Brinkman et al. 2004, Felix et al. 2004, Gordon et al. 2004, Grund and Woolf 2004, Cooper et al. 2006, Felix et al. 2006, Stewart et al. 2006, Belant and Seamans 2007). Most studies focus on the forest habitat (Rose and Harder 1985, Mech et al. 1987, Stromayer and Warren 1997, Jones et al. 1998, Dumont et al. 2000, Bugman and Weisberg 2003, Rooney and Waller 2003, Felix et al. 2004, Kraft et al. 2004, Kirschbaum and Anacker 2005, Mandujano 2005, McGraw and Furedi 2005, Belant and Seamans 2007, Tremblay et al. 2007) and agricultural landscapes (Conover and Kania 1995, Mower et al. 1997, Brinkman et al. 2004, Stewart et al. 2006). There are a few studies in other, more open habitat types such as prairies or grasslands (Sorensen and Taylor 1995, Kie and Bowyer 1997, Cooper et al. 2006, Smith et al. 2007, Washburn and Seamans 2007). Comparatively few studies have been done in habitat mosaics like the Oak Openings region of northwest Ohio, which is the focus of our study. Others who have studied deer in similarly diverse habitats found that complex and unexpected interactions can result (Johnson et al 2005).

Local Deer Data

In Ohio deer are the dominant mammalian herbivore, state mammal and a good source of revenue through the sale of hunting licenses. Since 1943 there have been regulated deer harvests in the state with only five years warranting a closure of the season (ODNR 2007). At the state level, harvest from hunters has shown an increasing trend since 1966. Currently across Ohio harvest from the yearly deer hunting season is on the rise with a record 252,017 harvested in the 2008-09 season (ODNR 2009) and in Lucas county, location of the Oak Openings region; deer vehicle collisions have also shown an increasing year to year trend with 414 reported in 2006 (ODNR 2007). In the 2006 season there were 561 deer harvested in Lucas County which is an increase over the 421 from the previous year, but pales in comparison to Coshocton County in the middle-eastern part of Ohio, which is on the top five counties by any mode of deer harvest, with 5,426 deer harvested in 2006 (ODNR 2007). The statewide harvest data and country level data are valuable, but too broad scale to capture the impacts of local populations. Specifically within OOMP there is only anecdotal data about the deer population abundance and impacts and no spatial quantification of deer browsing has been done in any of the study sites.

Goals

In light of the aforementioned trends, this study addressed the need for a deeper understanding of the potential impacts of this increasing herbivore abundance on the vulnerable oak savanna. The goal of our study was to assess the impacts of deer browsing on the lupine and oaks found at the sites. We also wanted to know how the distribution of the lupine and oaks varied over space and time as well as the browsing pressure from deer.

If deer were prevalent enough in the oak savannas, we expected to find widespread browsing on oaks and lupine due to population pressure. At intermediate levels the deer should browse more on heavily on oaks than lupine since oaks are more widespread, considered fairly palatable to deer (Kramer et al. 2008) and would be less likely to have irritating secondary compounds in their stems than lupine would in its leaves (Wink 1983). Though oaks have tannins, which are used as a defense against herbivory, a study found that white-tailed deer were more deterred by thorns on tannin producing shrubs than the chemical compounds (Cash and Fulbright 2005). Also, defenses such as tannins and alkaloids are inducible, or triggered as a result of past herbivory, so not all of population may exhibit them (Wink 1983). Therefore seedlings should be more palatable than older plants (Cash and Fulbright 2005).

Methods

Sites and Parks

Study sites were situated within local parks and green spaces in the Oak Openings Region of northwestern Ohio, USA. Sites for this study were considered oak savanna if they had 5-80% canopy cover (Faber-Langendoen 2001). Potential sites had been identified the winter before this study commenced by scouting open areas which had contained lupine in the previous season. Six sites were chosen based on the following criteria: had oak savanna, presence of lupine, presence of deer sign and young oaks. Three of these sites were in Oak Openings Preserve Metropark (OOMP), which is operated by Metroparks of the Toledo Area. These sites were Crash (CR), Reed Road (RR), and Mary's Savanna (MS). Oak Openings Metropark is located in Lucas County (lat. 41.5579 N, long. -83.3531 W) and covers approximately 1,500 ha, making it the largest of the Metroparks. Two sites were on land owned by the Nature Conservancy at Kitty Todd Nature Preserve; these were designated Wahl Tract (WT) and Cactus Hill (CH). Kitty Todd Nature Preserve is located at (lat. 41.699 N, long. -83.7886 W). The final site was at Meilke Road Savanna (MR), owned by the Ohio Department of Natural Resources located at (lat. 41.6411 N, long. -83.7667 W). Figure 2 shows the spatial distribution of all six study sites within the Oak Openings Region. Permits were obtained from each of the respective agencies to work on their property for the duration of the study, which ran from late May to early August 2008. We also obtained management histories for each of our sites including management actions such as burning, mowing and tree thinning (Gary Haase pers comm., LaRae Sprow pers comm. Jennifer Windus, pers comm.). The management histories were used to generate the variables:; number of last five years with management activities and total number of years with management actions for each site, which were used in later analyses. We chose the time span of the most recent five years to compare across all sites since it was the longest time frame that they have all been under management for and recent enough to impact current conditions at the sites.

Site Setup

Flags were set up at two opposing ends of each site to mark parallel transect lines 5m apart in North- South direction. There were two sizes of sites in this study, large and small. Large sites (CH, CR, MS) covered more than 0.10 ha and had 14-18 quadrats within them and these quadrats were spaced 20m apart along the transect lines, small sites (MR, RR, WT) covered less than 0.10 ha and had 10-11 quadrats spaced 10m apart along the transects. Figure 3 shows one of the sites and the quadrat locations. Each quadrat was 1 m^2 and marked with 1"circular, numbered metal tags at each corner for identification purposes. The location of each site was entered into a portable GPS unit, Garmin eTrex Vista HcX by making a track around the site. Also, the location of each quadrat was marked with a waypoint identifying site and quadrat number within the site such as CR01, which would be the first quadrat at Crash, to yield unique designations for all 81 quadrats in our study. The quadrat setup and data collection is shown in Figure 4. Wahl Tract and Cactus Hill also had white flag tape marking the quadrats to aid in locating them on subsequent visits as these sites had dense underbrush. Sites within OOMP (CR, RR, MS) were sampled every 6-8 days from May 27th until August 12th 2008. Sites at Kitty Todd Nature Preserve (CH and WT) and Meilke Road Savanna (MR) were sampled every 6-8 days from June 17th through August 13th. Crash and Meilke Road were the only two non-rectangular sites due to the dispersion of lupine within the site and orientation of the oak savanna opening. After the last census of the quadrats, the tags marking the corners of the quadrats were retrieved and the flags marking the boundaries of the sites were removed.

Survey Techniques for Lupine and Oaks

Each site was visited once a week from May 27th to August 13th, 2008 and all the quadrats within were checked for lupine, oak seedlings and evidence of deer browsing. Locally, browsing could have been the result of three main herbivores in the system, deer, rabbits or insects. Insect damage usually consisted of ragged punctures in the leaves of the plants or pinpoint holes in the stems. Rabbit herbivory was within one inch of the ground and characterized by a sharp slice when in woody tissue. Deer browsing manifested as a blunt force rip or tear of the plant material that was at least 15cm off the ground. To facilitate the observation of changes from week to week, each quadrat was photographed from two opposing angles using a FujiFilm FinePix A900 digital camera. Within each quadrat the number of oak seedlings was recorded and deer damage was estimated by counting how many stems showed evidence of browsing. Also in each quadrat we counted the number of leaves of lupine as an estimate of vegetative biomass and recorded the number showing signs of deer browsing (Fig 4). When measuring browsing only new browsing was counted, older browsing could be distinguished from new by level of desiccation of the plant tissues. Oaks were not identified to species but were distinguished by leaf morphology. If there was insufficient leaf for identification that specimen was not counted as an oak. From the data we generated many variables at the quadrat and site scale. Subsets of these were used in analyses to predict browsing at the site and quadrat level.

Trail Data

Near the end of the field season in August a thorough search was conducted within each site for deer trails. All trails that were found were mapped in the GPS unit using the 'Tracks' function, which created a line feature of the trail walked. A trail was considered a deer trail if deer feces, tracks or browse marks were found within it or it stemmed from a large oval of flattened cover known as a deer bed.

Sand Pans

Sand pans were also utilized on sunny days between May 25th and July 25th to compare deer activity in a site to activity outside of the site in an adjacent, more densely wooded area. The pans were plastic 16 in diameter and 1.5 in deep (Fig 5) marked with the numbers one through ten and the designation ‘Woods’ or ‘Site’ to aid in retrieval. During each use ten sand pans would be filled with sand from a nearby horse trail and spread over the area of the site, never closer to another sand pan than 5 m and not inside a quadrat of that site. The other ten sand pans would be placed in a roughly equal sized, wooded area adjacent to the site. Pictures were then taken of each sand pan and the coordinates entered into the GPS unit. After 24 hours we would return to the site, photograph each pan, and return the sand to the nearest horse trail. Due to the necessity of the sand remaining dry to retain evidence of activity by any animals during the time when the pans were out, rain at any point would invalidate that group of sand pans. Also, since the source of sand was a horse trail network, the days leading up to using the sand pans also needed to be dry as well.

Data Analysis Methods

We used ArcGIS version 9.2 by ESRI (2007) to plot and analyze the spatial aspects of the data. Variables derived from map layers were: distance from water, roads, and trails. We also explored if quadrats containing varying densities of lupine or oaks are clumped together. Trail, tracks and waypoints were uploaded from the GPS unit into ArcMap and projected using the GCS_WGS_1984 projection. Two layers were drawn from TIGER2000 line files for streams and roads in the area and used the GCS_WGS_1984 projection. We also used a land use and land cover layer derived from three LANDSAT 7 images (Nov 11, 2005, March 3, 2006 and June 23, 2006, all Path 20, Row 31) of Lucas County, Ohio with the coordinate system UTM_NAD_1983_zone17 (Shetter and Root in prep). The land cover for this map was developed using supervised classification. The various possible classifications of land cover were: grass/turf, residential/mixed use, dense urban/asphalt, croplands, ponds, conifers, cool season grasslands, oak savannas, shrub/scrub wetland, wet prairies, oak swamp and flatwoods, xeric oak woodlands and forests, mesic oak woodlands and forests, floodplain forests and unassociated wet woods, sand barrens and dunes and prairies; mesic and xeric. This classification was condensed for this study. Grass/turf, residential/mixed use and dense urban/ asphalt were combined to form the non-vegetated class. Conifers, oak swamp and flatwoods, xeric oak woodlands and forests, mesic oak woodlands and forests, floodplain forests and unassociated wet woods were combined to form the closed canopy class in our study. Cool season grasslands, shrub/scrub wetland, wet prairies, sand barrens and dunes, and mesic and xeric prairies made up the open canopy class. We kept the oak savanna class the same. In summary, our land cover classifications were: closed canopy, open canopy, non-vegetated, and oak savanna. We used an aerial photograph of Lucas County as the background for our maps for help with orientation (projection NAD_1983_StatePlane_Ohio_North_FIPS_3401(Feet)). All layers were reprojected using the UTM_NAD_1983_zone17 N projection to allow analysis using the NDVI raster. This means that the data points we collected during field season were in a different global coordinate system than the aerial photograph and other map layers. Our data were point and line type, while the aerial photograph and NDVI layer were both grids (made up of pixels). We used these layers to derive landscape features to use as variables in later analyses. The 'near' function in ArcToolbox allowed us to calculate distance to nearest road for each individual quadrat. These numbers were averaged to yield the site variable mean distance to nearest road. We created polygons for the boundaries of each site and calculated area, percent area sampled and perimeter. By overlaying our abbreviated land cover classification layer we could determine the proportion of the site for each land cover.

The program JMP v 8.0 by SAS Institute (2009) was used for statistical tests, mainly Shapiro-Wilk tests for normality, Spearman correlation and to run forward stepwise logistic regressions. Before entering variables into the stepwise forward logistic regression we assessed the normality of a larger set of variables and found most to be not normal. We also used Spearman's test for correlation to explore our variables and eliminate one of each pair that were highly correlated, i.e., greater than 0.7. We ran five different forward stepwise logistic regressions to capture both the site scale and the quadrat scale and find important variables to help explain the occurrence of browsing on either lupine or oaks. We used forward stepwise logistic regressions to avoid violating assumptions of normality in the data set, because of the binary nature of our response variables, and to yield the least complicated model by only adding in variables as needed. There were four quadrat scale forward stepwise logistic regressions, one examining factors affecting the presence or absence of lupine, one for the presence or absence of oaks, one to elucidate factors affecting the presence or absence of browsing on lupine and one for presence or absence of browsing on oaks. We also examined factors affecting prediction of browsing events at the site level. To be included in any regression model a variable had to be significant at the 0.05 level.

Preliminary data analysis suggested spatial trends so we sought to explore this in more detail. One of the options to help analyze data using spatial statistics is the Getis-Ord Gi* test for spatial clustering (Mitchell 2005), represented by the equation:

$$G_i^*(d) = \frac{\sum_j w_{ij}(d) x_j}{\sum_j x_j} .$$

This test uses distance of features from each other as weights to look for spatial clustering of a specific attribute of the feature. We used this test to look for spatial clustering in the distribution of oaks, distribution of lupine, browsing on oaks and browsing on lupine as separate entities. This means that each of the quadrats was weighted by how many stems of oaks were observed, how many leaves of lupine and proportion of each that was browsed. We used inverse distance weighted as the weighting to use for the quadrat points to influence each other with a distance of zero. This means that all points were considered in the analysis. The equation used by ArcMap converts the output to a z-score. When using the 95% confidence interval a significant z-score is larger than ± 1.96. A high positive z-score indicated an area where high values of a variable were spatially clustered; hereafter we will refer to such clustering as a 'hot spot', the equivalent negative value would be called a 'cold spot'.

Results

Sites

Each site was unique in our study. Table 1 highlights some features that helped to distinguish the sites from each other. The sites varied greatly in area, ranging from the largest (0.34 ha) CR to the smallest (0.04 ha) MR and RR. They also varied in proportion of site classified as open canopy, closed canopy, non-natural, or oak savanna using the abbreviated land cover classification scheme. Sites ranged from completely open canopy classified sites (CH and WT) to a nearly half and half split of two land covers (CR, MR and RR) to a mix of the oak savanna and closed canopy (MS). For a pictorial view of this heterogeneity refer to Figure 6. The sites also varied in spatial relation of the site center to roads ranging from RR which was only 40 m from a road to MS which was more than 400 m away from any roads. Since the sites were owned by different organizations with varying management frequencies and goals, the sites have substantially different management histories. Burning and mowing, the two most common management strategies for altering vegetation composition in the area, varied greatly between sites, even those within the same park. All sites, except for CR received some form of management within the last five years. Other forms of management applied were: tree thinning, girdling or limb lopping, application of herbicides and seeding of selected species.

To answer the question of which factors affect the number of browsing events (days in which there was browsing at a site, a categorical variable) at the site scale we used stepwise forward logistic regression After disposing of highly correlated variables (cutoff at 0.7), there were seven left to potentially predict number of browsing events of any type. These variables were: mean distance to nearest road, number of years with management actions, number of burns, number of mows, and number of years out of the last five that have had management actions, maximum number of lupine leaves observed at the site and mean maximum number of oak stems at the site. This forward stepwise logistic regression ran into an error and yielded no predictor variables, likely due to the small sample size.

However, there were some interesting correlations among the potential explanatory variables. At the site scale the number of browsing events on oak was highly, but not quite significantly correlated with the number of browsing events on lupine (R^2=0.76 p=0.080) The number of burns in the history of a site was significantly and highly positively correlated with the proportion of the site classified as closed canopy (R^2=0.82 $p<0.05$). In other words, an increased number of burns was associated with and increase in the proportion of closed canopy at a site. Number of mowing events in the history of the site was significantly negatively correlated with proportion of the site classified as closed canopy (ρ=-0.87 $p<0.05$) Increased number of mowing events was associated with a decrease in the proportion of closed canopy at a site.

Lupine Trends

Throughout the field season the general trend in mean abundance of lupine leaves was a declining one. Peak abundance was observed in the first week that each site was studied, though a few quadrats showed slightly higher leaf counts in the second week (Figure 7). There was great variability between sites, even those within the same park (CR, MS, RR in OOMP) and (CH, WT) which, along with the variability within a site, made trends difficult to discern (Figure 8). Average browsing pressure (number of leaves browsed) appeared to differ by site within a week, but there were few instances of browsing (Figure 9). Table 2 summarizes the sites in terms of lupine characteristics. The sites differed greatly in patchiness of the distribution of lupine as shown by the average proportion of quadrats containing lupine, which ranged from only 0.2 in CR to 0.59 in RR. Maximum lupine leaves at the site illustrates how much abundance of lupine leaves varied between sites with CH only ever reaching 456 leaves total across the entire site and RR recording 1696 leaves in one week, though RR was the smaller site with fewer quadrats. Cumulative browsing appeared to differ between sites at first glance. But the highest level of browsing on lupine leaves is in CR with 3.1% leaves browsed out of the total possible, which was very small considering that this was the cumulative browsing over 12 weeks.

We utilized forward stepwise logistic regression models to test the effects of multiple variables in explaining the variation seen at different scales. The potential explanatory variables (after removal of those that were highly correlated) were: distance to nearest road, distance to nearest source of water, presence or absence of lupine, presence or absence of oaks, presence or absence of browsing on lupine leaves and presence or absence of browsing on oak stems. Our model for predicting the presence or absence of lupine used the distance to nearest road, distance to nearest source of water, presence or absence of oaks and presence or absence of browsing on oaks. None of these variables were significant enough to be included in the model. It is worth noting that presence or absence of lupine was not strongly or significantly correlated with presence or absence of oaks (R^2=0.11 p=0.3234). This suggested that the spatial distributions of oaks and lupine were independent of each other.

Another forward stepwise logistic regression model examined factors affecting the presence or absence of browsing on lupine. The variables used in this regression were: distance to nearest road, distance to nearest water source, presence or absence of oaks, presence or absence of lupine and presence or absence of browsing on oaks. Of these variables presence or absence of lupine and presence or absence of browsing on oaks were included in the model (R^2 = 0.4354). This was our strongest model. In other words, browsing on lupine was positively associated with presence of lupine and browsing on oaks. Table 3 summarizes the results of our regressions for lupine and oaks and details coefficients for significant variables.

To test for spatial clustering of the distributions of lupine and browsing on lupine we used the Getis-Ord Gi* test. The results for spatial clustering of mean lupine distribution revealed hot spots in quadrats MS08, MS08, RR04 and RR05.This means that these quadrats and those near them were more likely to have high abundances of lupine leaves at any point in time.

Oak Trends

There were no consistent trends in abundance of oak stems over time (Figure 10). Large standard error showed that over time the mean abundance of oak stems over all sites hovered between 50 and 80 stems throughout our study period. The mean number of oak stems per quadrat also remained fairly consistent over time (Figure 11). Browsing pressure appeared to differ between sites and weeks it when graphed (Figure 12). Table 4 summarizes the sites by characteristics of the oak populations in them. The average proportion of quadrats that contained oaks ranged from 0.11 in CH to 0.9 in RR, with three of the sites (CR, MR, and MS) between 0.75 and 0.64. The maximum number of oak stems in one week showed that some sites varied greatly in number of oak stems while other remained more stable. The most dynamic site in terms of abundance of oak stems was CR which also had the largest number oak stems observed in a week with 204. The most stable site in terms of abundance of oak stems was WT which only varied by 5 oak stems per week. This site was also the one with the least number of oaks with only 22 observed in one week. As with cumulative browsing on lupine leaves, cumulative browsing on stems of oak was highest in CR (2.1%).

For quadrat scale effects on presence or absence of oaks and the presence or absence of browsing on oaks the same model was used as that for lupine, except that presence or absence of browsing of oaks and lupine were swapped (the one that had been the response variable was placed in the model as an explanatory variable). Significant variables for predicting the presence or absence of oaks were distance to nearest road (R^2=0.0598). In other words, the presence of oaks was more likely in sites that were further from roads. The variables that were not significant were presence or absence of lupine, distance to water and presence or absence of browsing on lupine. Significant variables for predicting the presence or absence of browsing on oaks were presence or absence of oaks and presence or absence of browsing on lupine (R^2=0.2746). Browsing on oaks, therefore, was positively associated with the presence of oaks and browsing on lupine. Variables that were not significant in this regression were distance to nearest road, distance to water and presence or absence of lupine. Table 3 details the coefficients of each variable and the intercepts of the models.

Based on the Getis-Ord Gi* test we found browsing on oaks to be significantly spatially clustered in quadrats CR13 and CR16. This sole hotspot indicated that more intense browsing of oak stems only occurred near those two quadrats in CR. Mean oak distribution showed suggestive hot spots in quadrats CH14, CR11, CR12, and CR13. This indicated that one part of CH was relatively rich in oak stems while a larger area of CR was especially rich in oak stems. We did not find any significant cold spots of any type. When considered with the high proportion of quadrats that contain oak stems this suggests a fairly even distribution of oaks across most sites.

Additional Statistics

We also ran multiple non-parametric Kruskal-Wallis one way ANOVAs to compare sites and quadrat characteristics for significant effects on browsing of either oaks or lupine by deer. We tested mean browsing of lupine during flowering (before June 16th 2008) versus the overall mean browsing on lupine leaves, mean browsing of lupine during the rest of the season versus the overall mean browsing on lupine leaves, compared browsing of lupine between flowering and after flowering at the site scale, browsing of lupine and oaks versus area of site, browsing of both lupine and oaks versus proportion of the site that was open canopy, closed canopy and oak savanna. We also compared browsing of lupine versus mean abundance of oaks, and browsing of oaks versus mean abundance of lupine at the site scale. At the quadrat scale we tested the effects of mean oak abundance and mean lupine abundance on browsing of oaks and also on browsing of lupine. None of the comparisons run were significant at the 0.05 probability level.

Sand Pans

Due to the inclement weather conditions the sand pans did not yield sufficient replications to attempt statistical analysis, n=2 for 4 of the 6 sites. For the sand pans that did stay out the full 24 hours there was no greater likelihood of a pan being encountered in a site versus in the woods adjacent to a site. Two tracks were observed in 'Site' pans, and two observed in 'Woods' pans. Animals other than deer encountered the pans. We found several in the failed trial in MS on June 9th that had portions of the mud removed, perhaps by raccoons.

Discussion

Heterogeneity

Previous studies of deer concentrated on the less structurally heterogenous landscapes of the forest (Kramer et al. 2006, Klaver et al. 2008, Gubanyi et al 2008, Coulombe Cote and Hout 2008), open grassland (Kie and Bowyer 1999, Hellickson et al 2008), or agricultural settings (Conover and Kania 1995, Mower et al. 1997, Brinkman et al. 2004, Stewart et al. 2006), though see Greenwald and Waite (2008). This study focused on the oak savanna habitat within the complex and varied mosaic of the Oak Openings Region. Savannas such as these are scarce worldwide and thus interesting to study (Grundel and Pavlovic 2007), as well as being valuable for a variety of species (Grundel and Pavlovic 2007). At both the site scale and quadrat scale heterogeneity was evident in these oak savannas (Fig 6). The guidelines for an oak savanna point to the inherent variability as the range of canopy cover can be from 5 to 80% and still be classified a 'Midwest Sand Oak Savanna' as long as it occurs on sandy soil and contains lupine (Faber-Langendoen 2001). This heterogeneity is indicative of the factors that make the entire Oak Openings Region a local hot spot of biodiversity in northwest Ohio. The study sites differed greatly in appearance and in vital characteristics such as proportion of various cover types, distribution of lupine and oaks, and size (Table 1, Table 2, Table 3). Characteristic effects of deer browsing may be mitigated by the wide diversity of habitat types that offer the deer a larger variety of food sources, even in the leanest months of the year. Deer, being generalist browsers, would be apt to exploit this diversity of food resources (Kie and Bowyer 1999). This allowed for complex interactions between heterogeneity at the site level and deer browsing. This is supported by our findings that different factors influence deer browsing at different scales. A correlation between browsing events on oaks and lupine suggests that once deer select an area to browse, they sample different types of vegetation and this might have been significant with a larger sample size. The deer could also have been reacting to a combination of features that make any of the sites good areas to feed. The results of the Getis-Ord Gi* test suggested a different pattern of clustering for the lupine distribution at the site scale when compared with the clustering pattern for distribution of oaks. This extended even to concentrations in different sites, oak hotspots occurred in CH and CR while those for lupine distribution occurred in MS and RR. The spatial aspect of this study was instrumental in elucidating otherwise invisible trends such as these hotspots.

Scale and Management

Scale is an important factor to consider when studying deer as they select different characteristics of the habitat for different uses at various scales (Klaver et al 2006, Hellickson et al 2008, Walters 2001). We assessed effects of deer browsing on oaks and lupine at two scales, the site and the 1 m^2 quadrat. Differences in which variables were important were evident at both scales from the correlations. This suggests extreme heterogeneity at both the fine scale of the quadrats and the broader site scale. Heterogeneity at these scales may also be influenced by an interaction not captured in the variables we measured, such as an interaction with the sub-canopy layer that is present in MS and WT. There could also be factors that extend beyond the timescale at which we worked. We were limited to a single growing season, so we may have missed interactions that work on a yearly cycle or multi-year cycle such as the current regime of management. A greater number of sites at a wider variety of sizes would improve our understanding and ability to detect scale dependent effects. We found interesting correlations between closed canopy cover and burning and mowing. The correlation between increased burns and an increase in the proportion of closed canopy at a site suggests that burns may promote woody growth which results in greater canopy cover at the site scale, or that burns are targeted at those sites with high canopy cover. We also found a correlation between mowing and reduced proportion of the site with closed canopy which may indicate that mowing reduces canopy cover at the site level or is used on those sites that have less canopy cover. These could indicate management effects or effects of prior management.

Lupine Browsing

We predicted that proportion of lupine leaves browsed would not be high if deer were not abundant or were not selecting for lupine as a food source. Based on the low proportion of lupine leaves browsed at any site compared to proportion of oak stems browsed at the same sites (Table 1) it appears unlikely that the deer are selectively browsing lupine leaves, though they may occasionally sample them. The spatial and statistical tests also indicate a general lack of intensive browsing by deer on lupine. The clustering analysis using Getis-Ord Gi* test failed due to a lack of variation in the data; taken with the observation that proportion of oak stems browsed was an order of magnitude greater than proportion of lupine leaves browsed indicated that the deer did not favor lupine leaves as a food source. It is reassuring that presence of lupine predicted browsing on lupine, but the link between browsing on oaks and browsing on lupine is interesting. The recurrence of browsing on one species as a predictor for browsing on the other is suggestive of the deer choosing a place to browse and sampling a variety of vegetation that occurs nearby. The sites could also be generally rich in food sources and attract deer to the area. Our lack of ability to predict lupine presence could also suggest that the factors controlling lupine presence may be weak or that we measured at an inappropriate scale to detect them. There are, however responses to browsing that may occur over longer time scales than one season so a low incidence of browsing may still stress a plant. Even minimal browsing may result in changes in plants the following year or for their entire lifespan (McNeil and Cushman 2005). This can result in decreased reproduction and slower growth than expected or the generation of chemical defensive compounds.

Lack of selection for lupine leaves as a food source could be a beneficial finding for the local agencies that manage these natural areas, since most are being managed for greater concentrations of lupine as potential habitat for the federally endangered Karner Blue Butterfly. Browsing on lupine was related to abundance of lupines leaves so there would likely be more browsing as lupine population sizes increased. Currently management practices detail burning one third of the habitat, mowing one third and leaving the other third alone in rotation (USFWS 2003). This works well for maintaining the open, transitional state needed for lupine. However, conditions that are good for growing lupine may not be optimal for all stages of the lifecycle of the Karner (Grundel, Pavlovic and Sulzman 1998) as the adults use a variety of plants for nectar sources while the larvae are dependent on the lupine for sustenance (Chan and Packard 2006, Grundel and Pavlovic 2007b). There may also be dynamic interactions between management actions and how a browser would use an area (Tracy and McNaughton 1996). We were not able to discern if the deer reacted directly to management in our study since none of our browsing metrics were significantly or strongly correlated with any of our measures of management.

Oak Browsing

We predicted heavier browsing on oak stems than on lupine since oaks are more palatable (Kramer, Bruinderink and Prins 2006) and a more widespread resource within the sites. This was supported by the data, which showed an order of magnitude greater browsing pressure on the proportion of oak stems browsed as compared to proportion of lupine leaves (Table 1). Despite the increase in magnitude of browsing pressure, only two quadrats, both in the same site showed a significant hot spot for browsing on oaks. The lack of other significant hot spots could indicate either steady, even browsing across most quadrats or very low level scattershot browsing. Distance to roads, which was significant in the prediction of oaks, may be an indication of disturbance in the area. This would suggest that presence of oak seedlings is slightly negatively correlated with increased disturbance. It is reassuring that presence of oaks predicted browsing on oaks, but the link between browsing on oaks and browsing on lupine is interesting. The recurrence of browsing on one species as a predictor for browsing on the other is suggestive of the deer choosing a place to browse and sampling a variety of vegetation that occurs nearby. Our results do not suggest a feeding preference for either oaks or lupine by the deer. Considering that current management aims to reduce recruitment by oaks and other trees to keep managed areas in an early successional state, the impact of browsing is an important one to consider. If deer are a constant force across sites, browsing as they walk they may help stave off succession to oak woodland from the oak savanna. Deer herbivory has been shown to adversely affect seedling growth of oaks in commercial settings (Oswalt et al. 2006). Should oaks prove to be a large part of the local deer diet, then perhaps we can use the ability of the deer to alter communities for our own restoration goals. If deer help keep open areas more open, then we may not need as frequent management for woody growth. Other studies have found that deer browsing on open areas may not reduce species diversity but does reduce area covered by each species (Casabon and Pothier 2008).

Other Possible Effects and Impacts

Our study assessed direct impacts on the lupine and oaks through browsing pressure. There are other effects that may be less evident such as trampling, reduction in variety or complexity of plant community through competition (Pellerin et al 2005, Greenwald et al 2008, Deveny and Fox 2006, Casabon and Pothier 2008), or differential light availability (Tracy and McNaughton 1996) and nutrient cycling (McNeil and Cushman 2005). These effects are likely to have an influence on our study sites since the variables we gathered data on were sporadic at explaining the variation present within our sites. For example, the trails were not used in the spatial or statistical analyses because they were too tangled and confused to parse into a usable layer. These deer trails, though, were evident at every site as were other signs of deer presence such as tracks and feces. The deer obviously use these sites to move through, even if they do not stop and browse with great frequency. If deer density increases in these areas we may see more impacts from deer merely walking from place to place.

Climate change is a looming specter in any study in the recent past as the effects become more and more evident with range shifts being found in taxa as diverse as plants and birds. Such widespread effects should affect our management actions. Also of concern are the predictions from various climate models of how the climate may change in different regions of the world. Data from the National Oceanic and Atmospheric Administration for this region places normal precipitation for May at 4.25 in, June 4.42in, July 3.97 in and August 3.18 in based on readings from 1971-2000 at the Toledo Express Airport (NOAA 2002). For the 2008 summer May received 2.51 in of precipitation, June 5.55 in, July 5.37 in and August 1.12 in also recorded at the Toledo Express Airport (NOAA 2008). Total rainfall differed by only 0.12 in, but was in a completely different pattern than normal, which may account for some of the odd trends we observed. Altered patterns of precipitation can alter the growth and reproductive cycles of plants. One of the odd trends was lupine senescence, which differed even from the previous year in which the lupine began to senesce at the end of June in three of the same sites (CH, CR and WT) (Plenzler 2008), while lupine in this study did not show signs of senescence until after July 15th. This means that the lupine were available later in the season, which could impact a host of other animals and plants, if not the deer. The fact that the lupine delayed senescing may not have directly affected our results, but the reason they did not senesce could have. The atypical pattern of rainfall may have caused other plants to flourish or get outcompeted which would have affected the resources available for the deer to consume throughout the growing season. In a more typical year we would expect the lupine to have senesced sooner and not to be available to be eaten by deer, or Karners later in the season. Also, less rain at the height of the growing season in a typical year might have altered how both lupine and oaks responded to browsing. For example, new seedlings and leaves were continually being generated by lupine during the 2008 field season; this might not have been possible without the additional rainfall.

Conclusion

The methods detailed in this study are easy to execute and maintain and are adaptable to many other species and circumstances. The quadrats used could easily be made permanent to study the same sites reliably over time. They are also unobtrusive and the metal tags are durable enough to last multiple seasons. The ability to use these methods for rapid (single season) assessment of an area makes them valuable as well as the ability to easily extend observations for several seasons if given the opportunity. Once a routine had been established, one field person could gather quadrat data from each site at a rate of about one hour per site. This would also be useful as an early warning sign of rising deer densities and adverse impacts. If deer density remains relatively stable then perhaps management effects could be analyzed. If we were to continue this study there would be some changes to the methodology. The sand pans, while interesting, were not particularly effective at assessing deer use of the site. Use might be easier to characterize with motion activated cameras, which could be set at a site before sunset and picked up after dawn the next morning to avoid possible human disturbance and cover the periods of higher deer activity. We would also strive to sample a greater and similar proportion of each study site. Additional measurements would include more characterization of the sites at the structural level, if not full vegetation surveys.

This study strove to shed some light on the complex interactions between the oak savanna, lupine and how deer browsing impacts both. Unsurprisingly, the complexity extended to every level of analysis in this fascinating system. A few trends emerge, though. There was extensive heterogeneity at both the quadrat and site scale and this manifested in unique sites that may react to disturbance in unexpected and equally unique ways. Oak seedlings and lupine had distinct distributions and unique hot spots spatially. This means that areas with high oak abundance were unlikely to be optimal for lupine and the reverse. An interesting point, in the model of lupine browsing, presence of browsing on oaks was significant and did explain much of the variation. Perhaps there is some structural feature associated with increased oak stems that impacts how deer perceive lupine. Or the deer may gather to browse on the oak stems and happen to notice lupine in the area. These results should be viewed with caution as they are based solely on one field season conducted only over the growing season and may miss longer temporal scale events such as yearly changes in activity budget or group size and composition (Sorenson and Taylor 1995).

As the year may have been abnormal in precipitation pattern, which would influence plant growth and response to browsing, all results must be treated with caution. Our recommendation is to monitor the effects of current management practices more closely and our methods would be easy to apply in this endeavor. Collecting yearly data in this method would serve as an early warning of any emerging trends in lupine abundance, oak abundance or browsing on either lupine or oaks. This study serves to lay the foundation and provide a basis of comparison for subsequent studies in the area. Since the area is such a unique collection of globally rare habitats (Grundel and Pavlovic 2007), filling in gaps in current knowledge is a key concern. The deer populations in the area have great potential to impact this unique area through the populations of lupine and oak, but as of now they are not yet at sufficient density to influence the plant community.

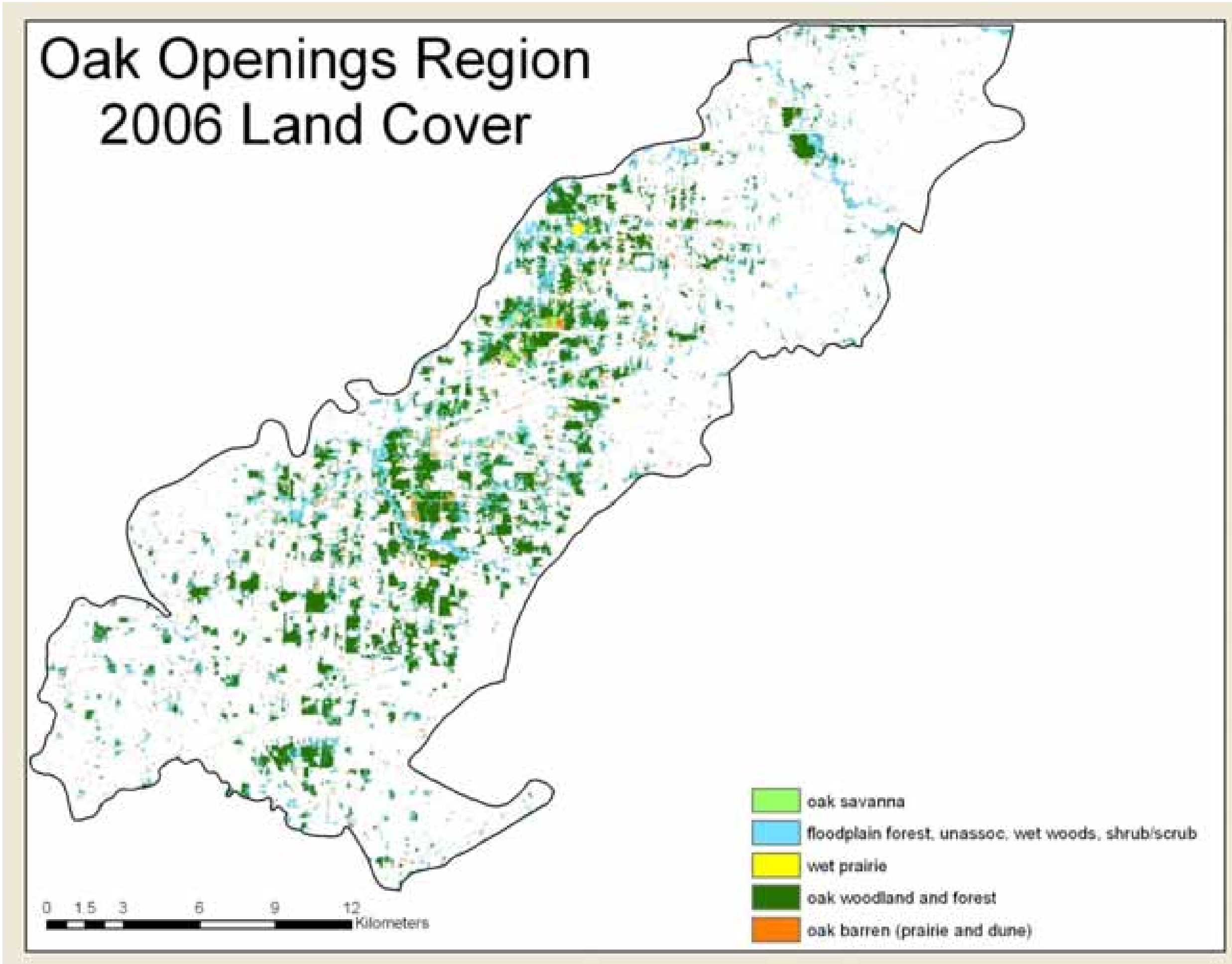

Figure 1. Oak Openings Region 2006 Land Cover. Map of 2006 natural landcover types in the Oak Openings region by Tim Schetter (Schetter and Root in prep). Note the extensive fragmentation and visibility of roads within the protected areas. This map was derived from LANDSAT 7 data.

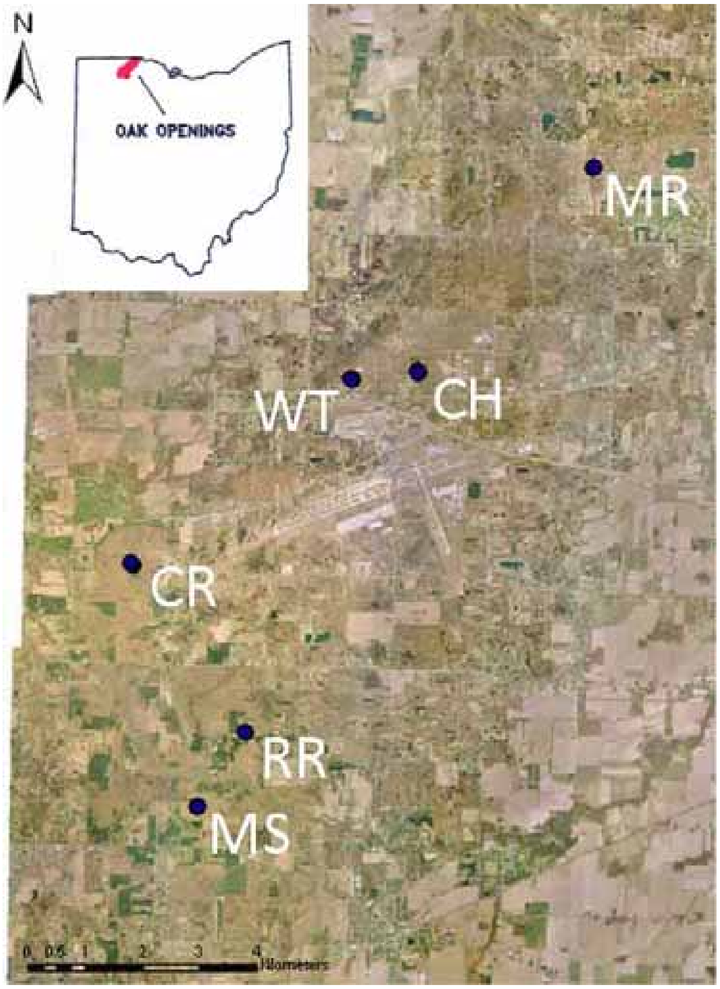

Figure 2: Study sites in the Oak Openings Region of Northwest Ohio. The northernmost site is MR, the two in the middle of the area are CH and WT, the three in the southwestern corner of the map are, from north to south, CR, RR and MS. Note that sites are all within 10 km of another site.

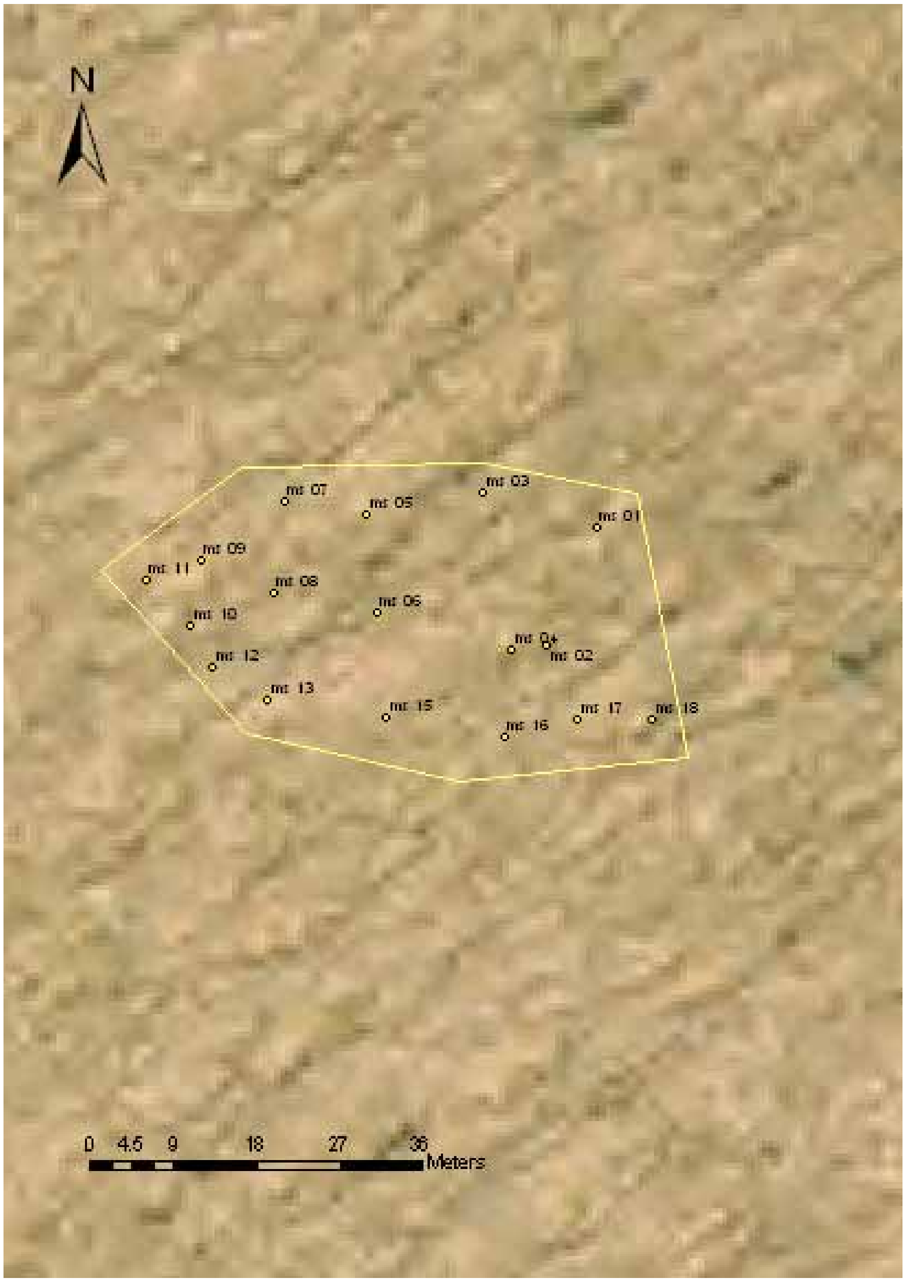

Figure 3. Site Layout. One of the large sites, MS within OOMP. Mary's Savanna had 17 quadrats and was the southernmost site within OOMP. Transects (not marked) ran roughly North-South in parallel lines.

Figure 4. Field Techniques and Site Setup. A) We used 1m^2 quadrats with 1" metal tags at the corners (insert) to sample our sites. B) A. Kuntz searching a quadrat in CH, counting lupine leaves. C) Site setup at RR, marking one of the quadrats with a portable GPS unit (eTrex Vista HCx by Garmin). Pictures by A.Kuntz and J.Kniss.

Figure 5. A Sand Pan. One of the ‘Site’ sand pans before use. Sand from the nearest horse trail would be smoothed into the pan and a picture taken before leaving it in place for 24 hours. Sand pans proved ineffective due to frequency of rainy days during the field season.

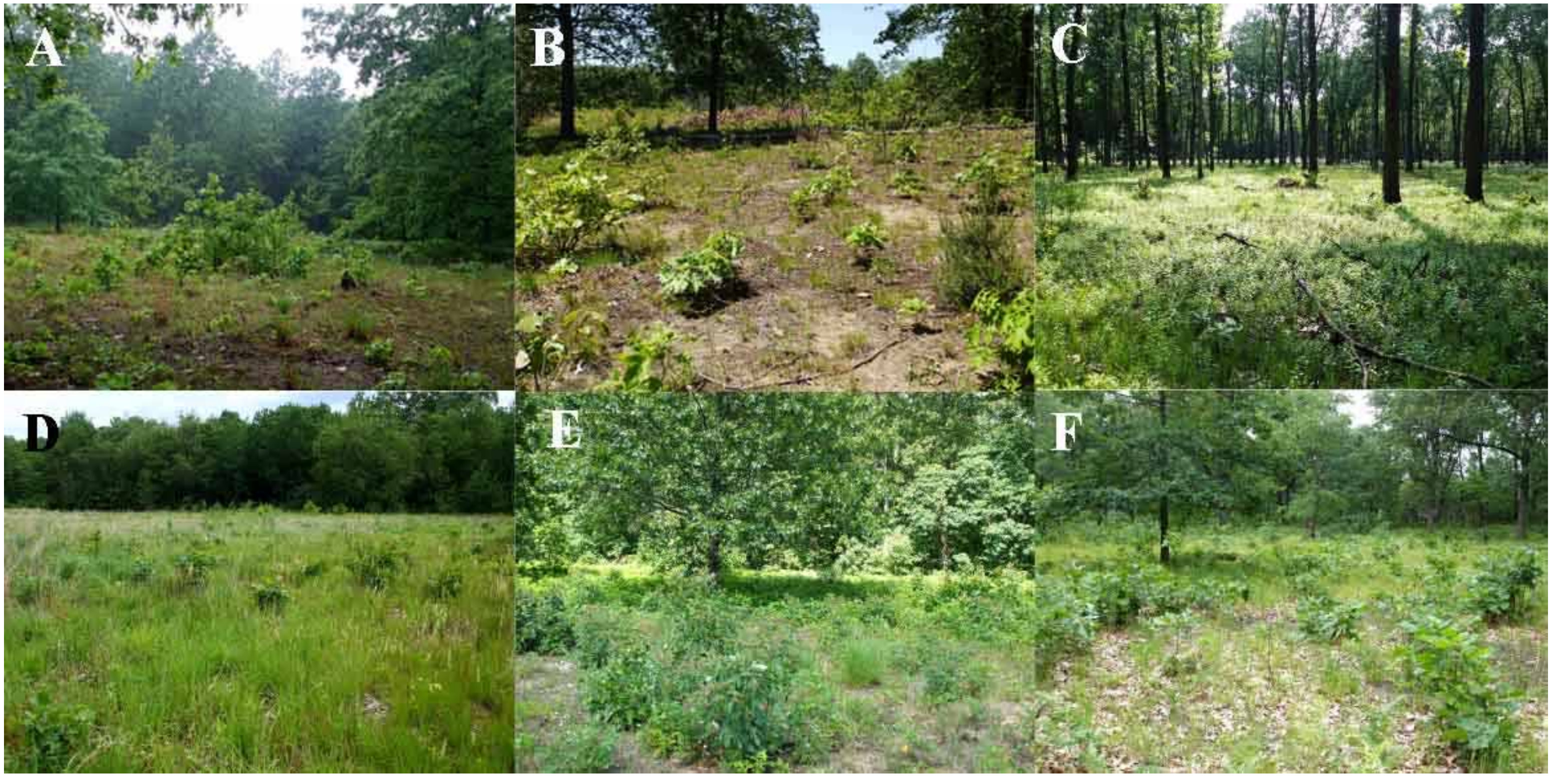

Figure 6. Site Pictures. A) CR in OOMP a perennially shrubby site. Note the young oaks spread throughout the site. B) RR in OOMP, a sandy open site with many small oaks. C) MS in OOMP the site with the most extensive canopy cover in our study. It also had a dense understory of bracken ferns. D) CH in Kitty Todd Nature Preserve, the most open site, though there are small oaks hiding in the grass. This picture was taken in mid-June, before the grass grew to over 6ft in height. E) WT in Kitty Todd Nature Preserve, one end of the site was nearly bare sand; the other was covered in bracken ferns. F) MR in Meilke Road Savanna, this site had woody litter which the young oaks pushed through. All pictures taken by A. Kuntz.

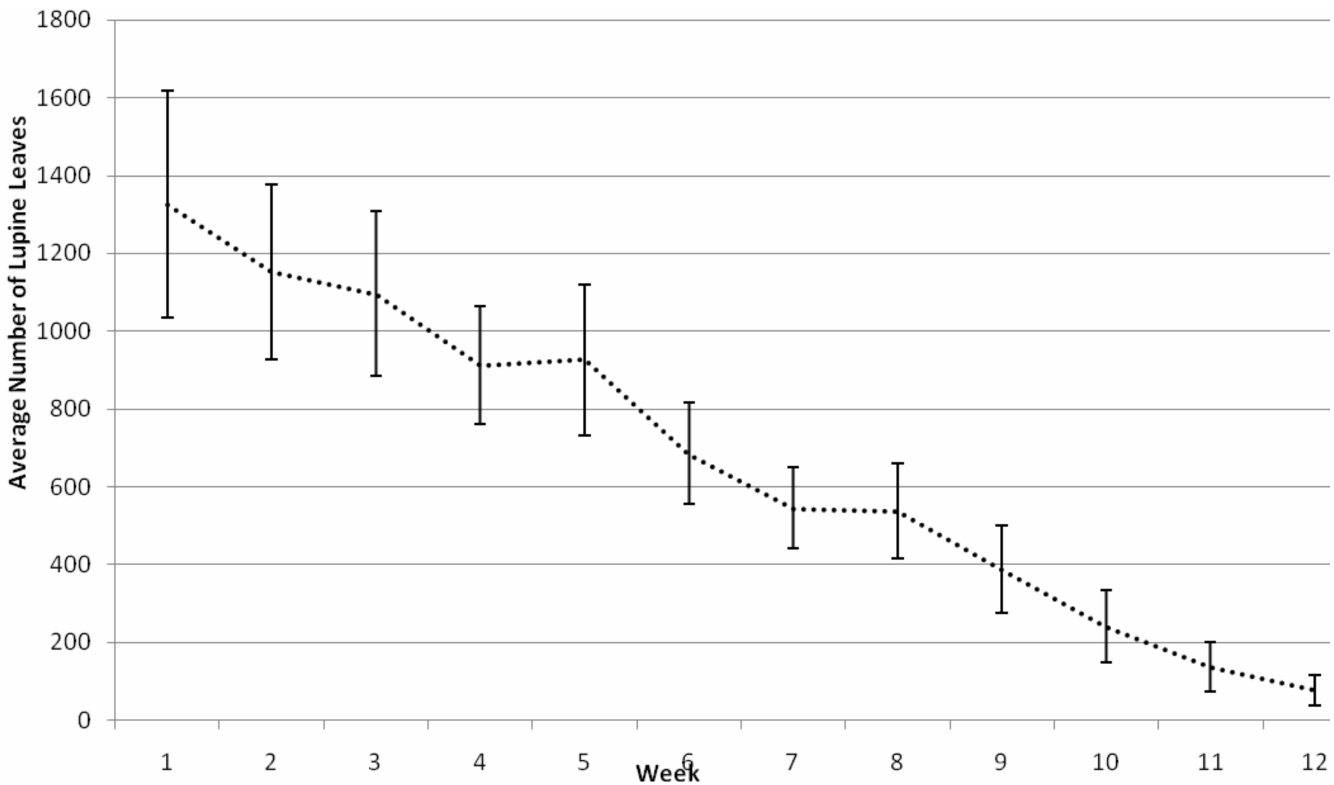

Figure 7. Average Abundance of Lupine Leaves Over Time. General trend in average abundance of lupine leaves observed over time averaged across all six sites and all 81 quadrats. The bars indicate ± SE of mean number of lupine leaves.

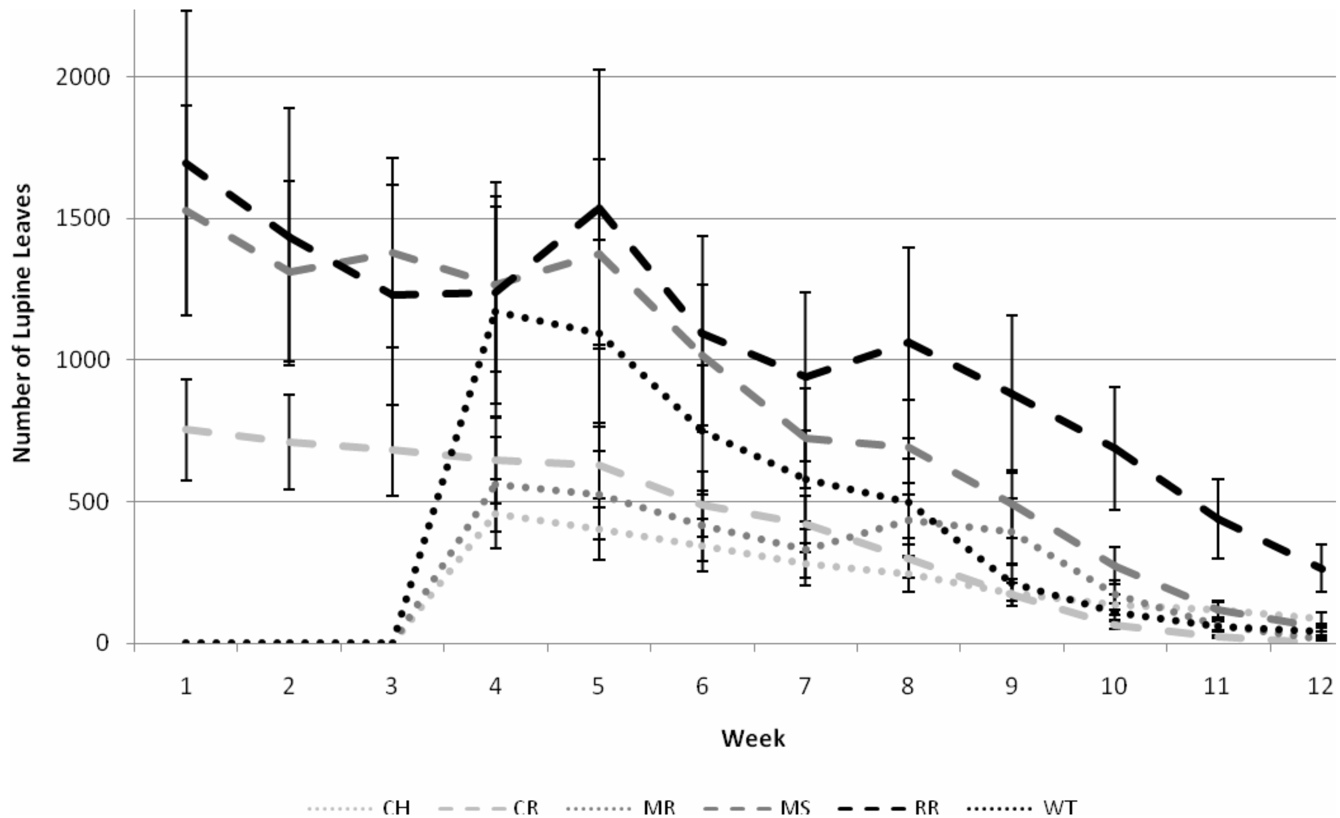

Figure 8. Raw Lupine Leaf Abundance by Site. Lupine leaf abundance by site over time with ± standard error. This shows raw abundance of lupine leaves by site over time. Sites CH, MR, and WT were set up in week 3 so data for them is only available from week 4 onward. Lines do not represent true trends but are an aid to site identification.

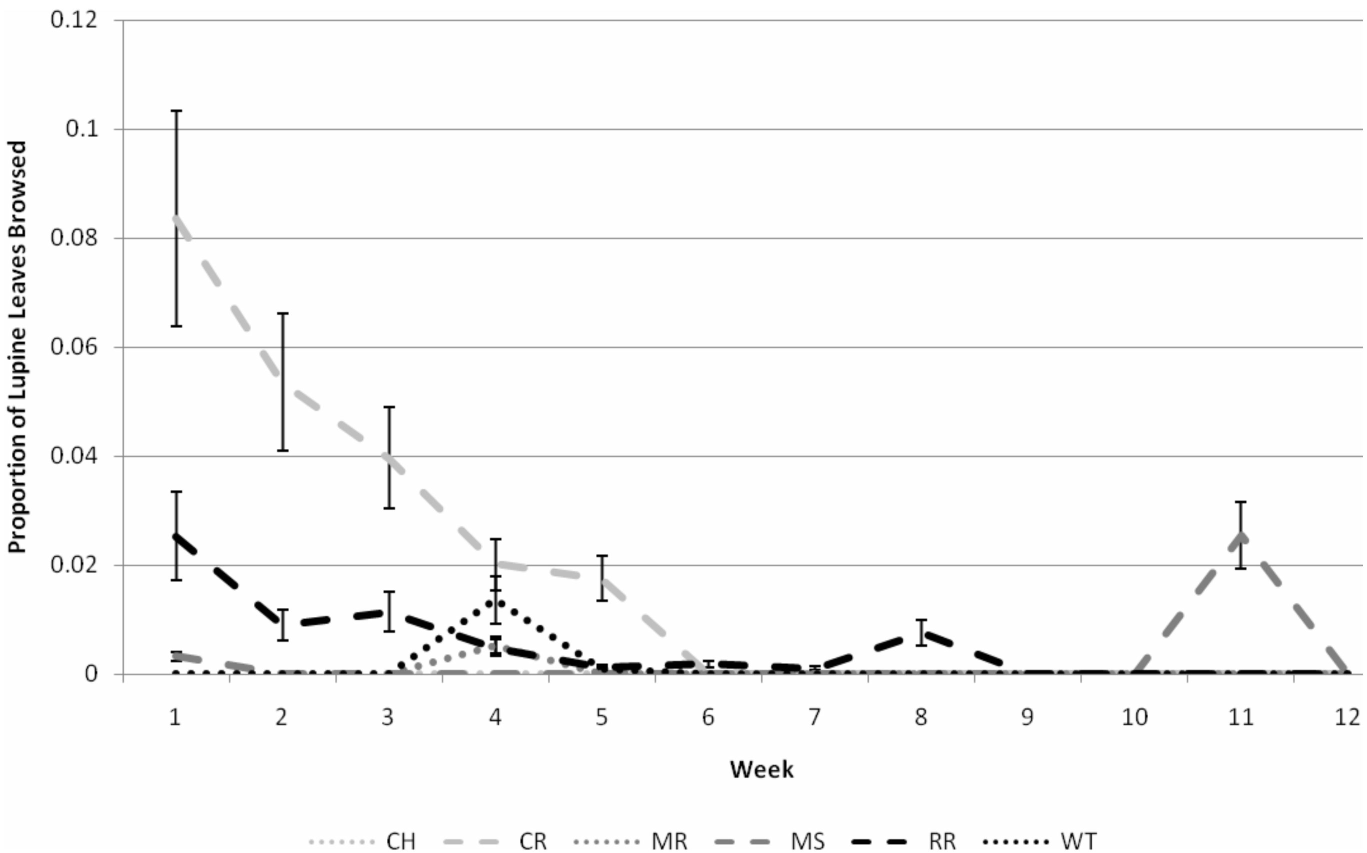

Figure 9. Proportion of Lupine Leaves Browsed by Site Over Time. The points represent proportion of lupine leaves browsed with ± standard error. Note how little overall browsing occurs, with CR during week recording the highest level of browsing on lupine. Lines do not represent true trends but are an aid to site identification.

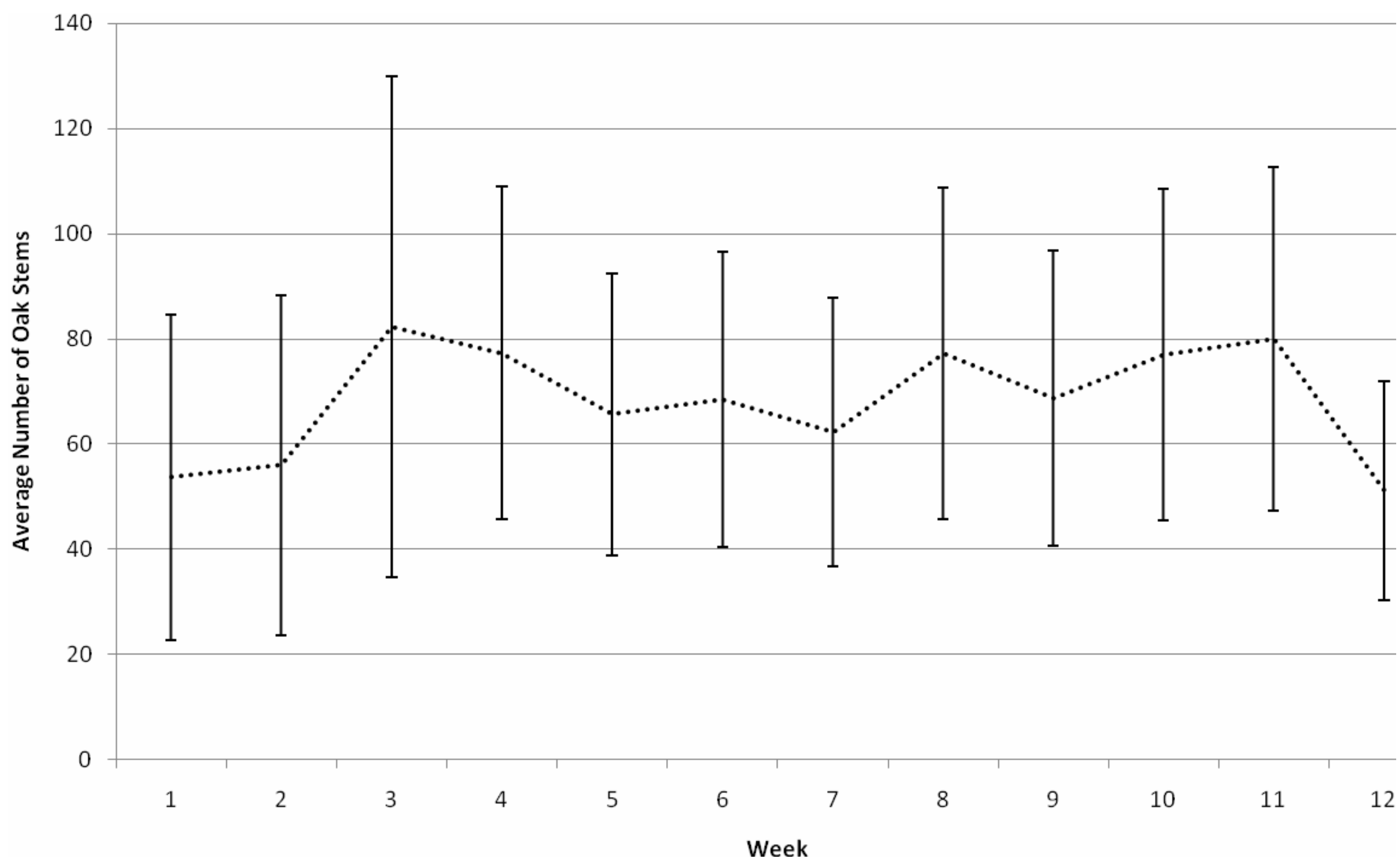

Figure 10. Average Number of Oak Stems Per Site Over Time. Oak abundance over time was relatively steady, bars are ± SE. All six sites were used to calculate the average, though CH, MR and WT only factor in at week 4. Note the large standard error bars, this hints at the heterogeneity of the sites.

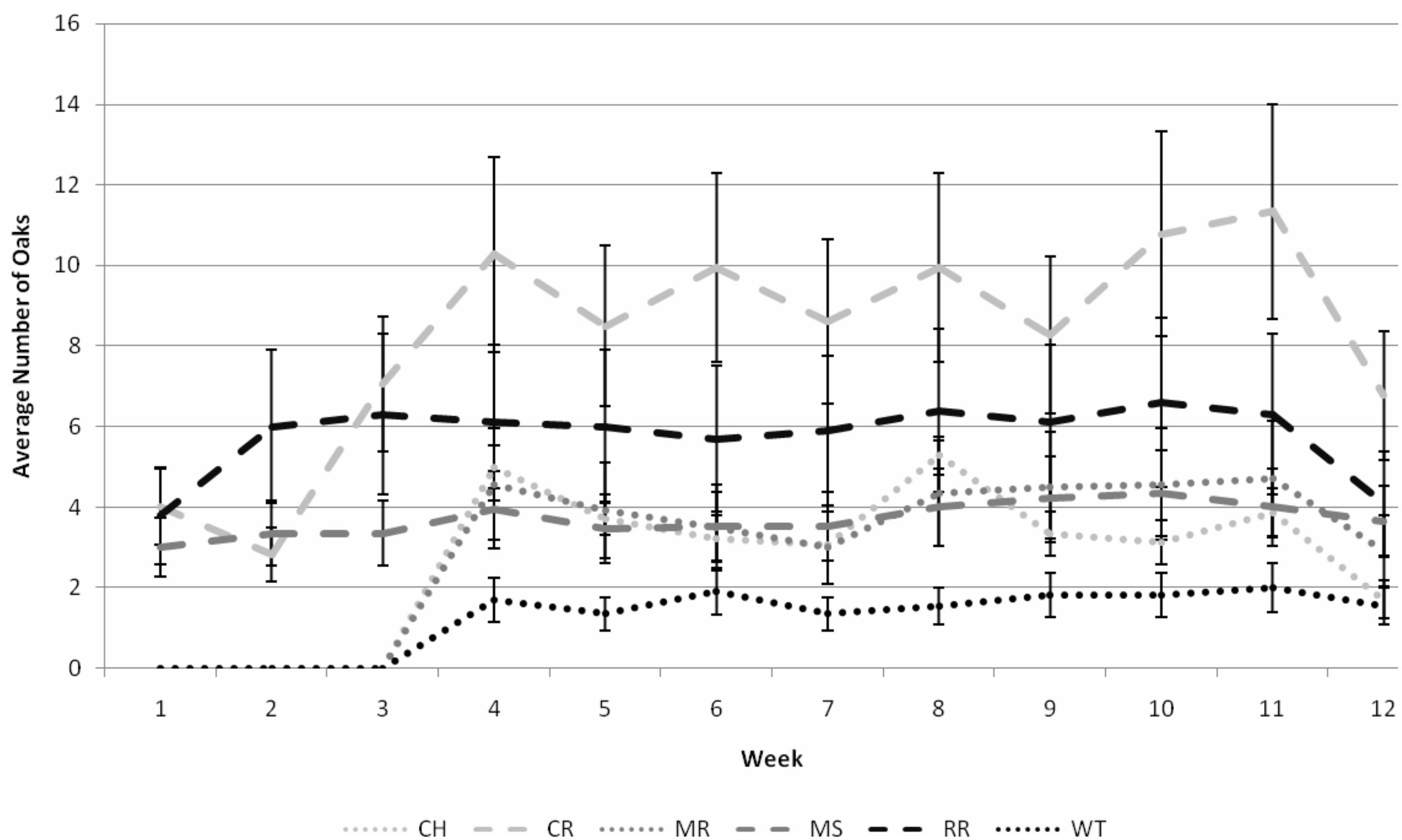

Figure 11. Average Number of Oaks Per Site Over Time. The bars are ± standard error. Sites CH, MR, and WT were set up in week 3 so data for them is only available from week 4 onward. Lines do not represent true trends but are an aid to site identification. Mean number of oaks was averaged using the total number of quadrats within a site.

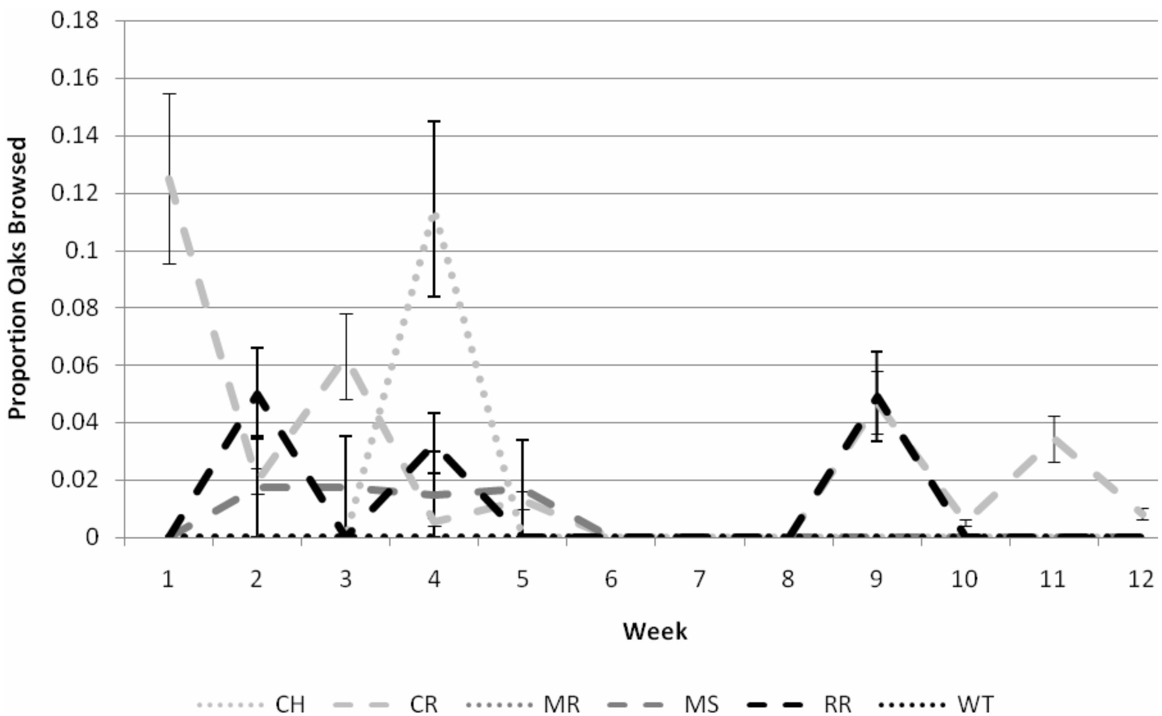

Figure 12. Proportion of Oaks Browsed by Site Over Time. The bars are ± standard error. Proportion of oaks browsed was measured as number of stems showing signs of browsing divided by total number of available stems in the quadrat. Lines do not represent true trends but are an aid to site identification. Sites CH, MR, and WT were set up in week 3 so data for them is only available from week 4 onward.

Table 1. Summary of Distinctive Site Features. Our study focused on three parks in the area; these were Kitty Todd Nature Preserve (KT) managed by The Nature Conservancy, Oak Openings Preserve Metropark (OOMP) managed by Metroparks of the Toledo Area and Meilke Road Savanna (MR) managed by the Ohio Division of Natural Resources. Sites were divided into two categories based on number of quadrats and size. Those less than 0.10 ha and with fewer than 12 quadrats were 'small' sites (MR, RR, WT) and those greater than 0.10 ha and with more than 12 quadrats were 'large' sites. Proportions of each site with particular land covers are derived from a map using the 2006 Landsat 7 image (Schetter and Root in prep). Information about management history on each site was obtained from the organizations that own them. Note the variation in management history. These site characteristics were used as variables in the forward stepwise logisitc regression at the site scale.

Site	Park	Area (ha)	Number quadrats	Proportion Non-vegetated Cover	Proportion Oak Savanna	Proportion Open Canopy	Proportion Closed Canopy	Distance to Nearest Road (m)	Mean Distance to Water (m)	Number of Years With Management Actions	Number of Burns	Number of Mows	Number of Years in the Last Five With Management Actions
CH	KT	0.15	14	0	0	1	0	67.17	331.44	11	2	7	3
CR	OOMP	0.34	18	0	0.49	0.5	0.002	139.15	95.83	4	2	0	0
MR	MR	0.04	11	0.48	0	0.5	0.031	222.47	252.56	3	2	0	3
MS	OOMP	0.17	17	0	0.826	0	0.233	474.28	405.74	14	9	0	5
RR	OOMP	0.04	10	0.556	0	0.427	0	40.61	497.09	6	0	1	4
WT	KT	0.06	11	0	0	1	0	238.91	586.85	6	0	5	5

Table 2. Summary of Lupine Characteristics by Site. The average proportion of quadrats with lupine shows dispersion within the site and allows comparison between sites, maximum lupine assesses abundance, the range shows the change in abundance over the season, maximum number of leaves browsed shows raw browsing pressure and the cumulative proportion browsed allows for comparisions between sites. These site characteristics were used as variables in the forward stepwise logisitcs regressions at the site scale. Means for oak stems and lupine leaves are per $1m^2$ quadrat. Cumulative browsing measures assume that each leaf or stem has a new opportunity to be browsed each week and is calculated total number browsed / total cumulative opportunities for browsing.

Site	Average Proportion Quadrats With Lupine	Max Lupine Leaves at Site	Maximum # Leaves Browsed in a Week	Cumulative Browsing
CH	0.29	456	0	0
CR	0.2	754	63	0.031
MR	0.39	561	3	0.001
MS	0.32	1529	5	0.001
RR	0.59	1696	43	0.007
WT	0.39	1171	16	0.004

Table 3. Quadrat Scale Stepwise Forward Logistic Regressions. These were the four models for quadrat scale variables. All response variables are presence or absence of lupine (P_A_LUP), oaks (P_A_OAK), browsing on lupine (P_A_br_LUP) or browsing on oaks (P_A_br_OAK). To be entered into the models a variable had to be significant at the 0.05 level. DIST_roads was the distance of the sample location to the nearest road. Our best model predicted browsing on lupine using only presence or absence of lupine and presence or absence of browsing on oaks.

Response Variable	Significant Variables	Coefficients	Model R^2	Intercept
P_A_LUP	none			0.1236
P_A_OAK	DIST_roads	-0.0035	0.0598	0.2682
P_A_br_OAK	P_A_OAK P_A_br_LUP	9.2433 0.9443	0.2746	9.4379
P_A_br_LUP	P_A_LUP P_A_br_oak	9.6650 1.0256	0.4354	10.033

Table 4. Summary of Oak Characteristics by Site. The average proportion of quadrats with oaks shows dispersion within the site, maximum oaks assesses abundance, the range shows the change in abundance over the season, maximum number of stems browsed shows raw browsing pressure and the cumulative proportion browsed allows for comparisions between sites. These site characteristics were used as variables in the forward stepwise logisitcs regressions at the site scale. Means for oak stems and lupine leaves are per $1m^2$ quadrat. Cumulative browsing measures assume that each leaf or stem has a new opportunity to be browsed each week and is calculated total number browsed / total cumulative opportunities for browsing.

Site	Average Proportion Quadrats With Oak	Max Oak Stems at Site	Maximum # Stems Browsed in a Week	Cumulative Browsing
CH	0.11	70	8	0.0177
CR	0.64	204	9	0.021
MR	0.64	66	0	0
MS	0.75	74	1	0.005
RR	0.9	64	3	0.012
WT	0.2	22	0	0

CHAPTER 2: DEER DISTRIBUTION AND MOVEMENTS WITHIN OAK OPENINGS PRESERVE METROPARK

Introduction

Urban Pests

Experiencing wildlife can be the high point of a trip to a local park or natural area. However, in some cases wild animals can become nuisances to humans, especially when natural areas are interspersed with housing developments. The animals that become nuisance species are generally widespread, adaptable and generalists. Some common vertebrate nuisance species throughout the United States include raccoons, opossums, and white-tailed deer. These species are all generalists which can survive and thrive in close proximity to humans. This study focuses on the movements and distribution of one such generalist, white-tailed deer in part of a unique region of Northwest Ohio.

Generalists such as deer tend to favor the edge of habitats, where a mixture of plant species congregate to take advantage of increased light and access to moisture. Deer seek out dense food resources that abut ready shelter on the wooded edge. Generally, the more fragmented an area is, the more edge it will have. The Oak Openings Region is a very heterogeneous area of Northwest Ohio that is under increasing threat from development to the north from Toledo, Ohio and to the south from expanding agriculture (Abella et al. 2007).

Deer Characteristics

White-tailed deer (*Odocoileus virginianus*) are generalist herbivores that can be very plastic in diet and behavior (Halls 1984, Cash and Fulbright 2005, Pellerin et al. 2006). Kie and

Bowyer (1999) found little evidence of different dietary niches for male and female white-tailed deer in their study, which artificially manipulated densities of deer. Both sexes browse a variety of grasses and forbs (Kie and Bowyer 1999), subsisting on woody material in lean times (Coulombe, Cote and Huot 2008) and supplementing their diet with a variety of fruits and very rarely, animal matter such as eggs (Ellis-Felege et al 2008). There is temporal variation in the diet of white-tailed deer as the species available to consume change with the seasons (Coulombe, Cote and Huot 2008). Deer have been known to severely reduce the abundance of favored browse species (Kirschbaum and Anacker 2005) and, when population pressure is intense, even unpalatable plant species suffer (Sekura et al. 2005, Pellerin et al. 2006).

According to the literature, deer are generally crepuscular, favoring dawn and dusk for feeding but this may change in response to predation or anthropogenic factors (Halls 1984, Dumont at al. 2000). The reproductive capability of a doe varies according to condition, but females may produce up to three fawns per year, after the first year. The births center around May to early June and fawns are even more elusive than adults. White-tailed deer (*Odocoileus virginianus*) and the associated subspecies have colonized a range that extends from Mexico to Canada and all but the southwestern portions of the US where the mule deer is a competitor (Heffelfinger 2006). They exist in habitats ranging from plains and prairie in Texas to the forests of Maine and they even come into suburban developments (DeNicola, Ettinger and Almendinger 2008).

Deer may be migratory or non-migratory in the US depending on environmental conditions, especially availability of browse and shelter during the winter months (Dumont et al 2000). Home ranges vary by sex with males generally covering more area than females (Kie and Bowyer 1999). In the Oak Openings Region of Ohio, there is no documentation of migratory behavior in the local deer populations. When dispersing from their natal herds deer can travel fairly far; this places them at risk from encounters with cars and other anthropogenic hazards in this area of Ohio. One study found that juvenile males may travel between 9 km (for a spring dispersing yearling) and 5 km, for one that disperses in fall (Long et al 2008). It should be noted that the maximum dispersal distances for spring and fall recorded by Long and colleagues (2008) were both over 40 km. This implies that deer could disperse between most of the Metroparks of the Toledo Area if they avoided automobile-caused mortality.

Overabundant Deer

Herbivores can cause changes in species assemblages (Halls 1984, Stromayer and Warren 1997, Kie and Bowyer 1999, Dumont et al. 2000, Bugmann and Weisberg 2003, Rooney and Waller 2003, Gordon et al. 2004, Kraft et al. 2004, Cash and Fulbright 2005, Kirschbaum and Anacker 2005, McGraw and Furedi 2005, Sekura et al. 2005, Pellerin et al. 2006, Tremblay et al. 2007, Washburn and Seamans 2007, Gubanyi et al. 2008, Holmes et al. 2008, MacDougall and Wilson 2008). Grazing or browsing pressure and the selectivity of certain species of large herbivores, whether domesticated or wild can shift which species of plants can survive and thrive in a variety of environments around the world (Bugman and Weisberg 2003, Cash and Fulbright 2005). This can be for a variety of reasons ranging from direct pressure of browsing or herbivory (Halls 1984, Bugman and Weisberg 2003, Rooney and Waller 2003, Kraft et al. 2004, Cash and Fulbright 2005, Kirschbaum and Anacker 2005, McGraw and Furedi 2005, Tremblay et al. 2007) to physical effects such as trampling (Halls 1984, Rooney and Waller 2003, Pellerin et al. 2006) or indirect effects such as spread of non-native plants (Vavra et al. 2007). Nevertheless, this means that very different plant communities can result from introduction or increased abundance of an herbivore. This project focuses on one herbivore common to the

United States, white-tailed deer and the mosaic of habitats found within Oak Openings Preserve Metropark (OOMP) in northwest Ohio.

Deer in particular are a concern in parts of the United States due to growing populations and worry over increases in deer vehicle collisions as well as the ever present threat of disease (Stout et al. 1993, Jones et al. 1998, Belant and Seamans 2000, Kilpatrick and LaBonte 2003, Brinkman et al. 2004, Tonkovich et al. 2004). White-tailed deer are very well studied and modeled from the perspective of hunting and damage to commercial crops (Halls 1984, Conover and Kania 1995, Mower et al. 1997, Belant and Seamans 2000, Brinkman et al. 2004, Felix et al. 2004, Gordon et al. 2004, Grund and Woolf 2004, Cooper et al. 2006, Felix et al. 2006, Stewart et al. 2006, Belant and Seamans 2007). This means most studies focus on the forest habitat (Rose and Harder 1985, Mech et al. 1987, Stromayer and Warren 1997, Jones et al. 1998, Dumont et al. 2000, Bugman and Weisberg 2003, Rooney and Waller 2003, Felix et al. 2004, Kraft et al. 2004, Kirschbaum and Anacker 2005, Mandujano 2005, McGraw and Furedi 2005, Belant and Seamans 2007, Tremblay et al. 2007, Kramer, Bruinderink and Prins 2008) in the northeast U.S. and agricultural landscapes (Conover and Kania 1995, Mower et al. 1997, Brinkman et al. 2004, Stewart et al. 2007, Seamans and Helon 2008). There are a few studies in other, more open habitat types such as prairies or grasslands (Sorensen and Taylor 1995, Kie and Bowyer 1997, Cooper et al. 2006, Smith et al. 2006, Washburn and Seamans 2007, Meek et al 2008). Comparatively few studies have been done in habitat mosaics like the Oak Openings Region of northwest Ohio, which is the focus of our study. The literature concerning the multifaceted and varied impacts of deer overabundance is vast; for a good summary of it see Russell et al. 2001, as a thorough discussion is beyond the scope of this study.

Oak Openings Region

The Oak Openings region spans parts of northwest Ohio and southern Michigan. Historically it covered between 11 and 13 million hectares of the Midwest, of which 0.02% remains as of 1985 (Nuzzo 1986). It contains a complex mosaic of habitats, some of which are globally rare, such as the wet prairie and oak savanna (Grundel et al. 1998, Green Ribbon 2004b). This results in an area rich in biodiversity as these habitats host one third of the plant species of concern for the state of Ohio (ODNR 2009b). A major threat to this unique collection of habitats is fragmentation. Agricultural expansion to the South and urban sprawl from the North threatens to squeeze the largest pieces of natural areas between them (Fig 1).

Local Deer Data

In Ohio deer are the dominant mammalian herbivore, state mammal and a good source of revenue through the sale of hunting licenses. Since 1943 there have been regulated deer harvests in the state with only five years warranting a closure of the season (ODNR 2007). At the state level take from hunters has shown an increasing trend since 1966. Currently across Ohio harvest from the yearly deer hunting season is on the rise with a record 252,017 harvested in the 2008-09 season (ODNR 2009a) and in Lucas county, the location of the Oak Openings region, deer vehicle collisions have also shown an increasing year to year trend with 414 reported in 2006 (ODNR 2007). In the 2006 season there were 561 deer harvested in Lucas County, which is an increase over the 421 from the previous year, but pales in comparison to Coshocton County in the middle-eastern part of Ohio, which is on the top five counties by any mode of deer harvest, with 5,426 deer harvested in 2006 (ODNR 2007). The statewide harvest data and country level data are valuable, but too broad scale to capture the impacts of local populations. Specifically within OOMP there is only anecdotal data about the deer population abundance and impacts.

Goals

This study addressed the lack of fine scale data about the abundance and spatial distribution of white-tailed deer within Oak Openings Preserve Metropark. The uniqueness and heterogeneity inherent in this area gave us an opportunity to observe deer that were neither in the forest nor completely in the open prairie and without hunting pressure from natural or anthropogenic sources while in the park. The goals of this study were to assess how the deer used the park in the spatial sense, estimate roughly how many deer used the park, and assess which features of the park were correlated with high use by deer. A secondary goal was to answer our questions about deer abundance and use of the park using methods of collecting data that were easy to replicate and relatively simple to understand so as to aid their adoption and implementation locally. Based on the literature we expected deer to favor areas high in edge, which offered more varied and abundant browse species, especially in the summer months. They should also value cover and a source of water. Depending on their level of habituation to humans deer can be either skittish or unconcerned about human presence.

Methods

Oak Openings Preserve Metropark

Our study was conducted in Oak Openings Preserve Metropark Lucas County, Ohio (lat. 41.5579 N, long. -83.3531 W). Oak Openings Preserve Metropark is the largest Metropark at over 1,500 ha and contains one of the sites for reintroduction of the federally endangered Karner Blue Butterfly. To aid in rapid collection of the data we broke the park up into 10 zones. The zones were not of equal size but were delineated by barriers such as roads. For a pictorial representation of the zones see Figure 13. Variables of interest that related to deer abundance were: area of zone, perimeter of zone, location of the central point within the zone, each weekly survey, and multiple measures of the Normalized Difference Vegetation Index (NDVI), which was a measure of land cover based on reflectance.

Deer Surveys

We conducted road based surveys of the deer population of Oak Openings Preserve Metropark (OOMP) weekly around sunset from May 29, 2008 until August 13, 2008. We chose road based surveys due to the accessibility of park areas by roads and their extensive coverage. Kie and Bowyer (1999) also took advantage of well placed roads to conduct their surveys of deer in Texas, and Halls (1984) mentioned roadside counts as a technique to survey deer. Others have used such diverse methods as fecal pellet counts, hair snares (Belant and Seamans 2007) and track density (Mandujano 2005) to estimate deer density and abundance. One survey night was missed due to rain which impeded sightings; this was June 25, 2008. Each survey began at a different, randomly chosen point on one of the roads leading into OOMP at least 75 minutes before sunset. Two observers were needed, one to drive and scan one side of the road, the other to record data and scan the other side. The surveys covered all portions of roads inside OOMP once per survey with speeds remaining below 5 mph and stops to confirm every deer sighting. Surveyors used only the naked eye to spot the deer, which were not too skittish of cars, and depended on natural light. Each time a deer or herd of deer was sighted the observer noted the time, number of deer, and location using the zoned map of the park (Figure 14).

Statistical and Spatial Analyses

Statistical analyses were run with JMP v8.0 by the SAS Institute (2009). First we tested our data with a Shapiro Wilk test of normality, then we used a Spearman correlation to assess how correlated our variables were. For those pairs of variables that were highly correlated (greater than 0.7) we dropped one of the pair while the other was retained. We ran a forward stepwise logistic regression to explore factors affecting the maximum number of deer observed in each of the zones. Variables were only included in the model if they were significant at the 0.05 level.

We explored the spatial relationships with ArcGIS v 9.2 (ESRI 2007). Zone boundaries were digitized and projected using the GCS_WGS_1984 projection. Two layers were drawn from TIGER2000 line files for streams and roads in the area and used the GCS_WGS_1984 projection. We used an aerial photograph of Lucas County as the background for our maps for help with orientation (projection NAD_1983_StatePlane_Ohio_North_FIPS_3401(Feet)). All layers were reprojected using the UTM_NAD_1983_zone17 N projection to allow analysis using the NDVI raster. Our data were point and line type, while the aerial photograph and NDVI layer were both grids (made up of pixels). These layers were used to generate some of the variables we used on our forward stepwise logistic regression. We used the 'intersect' function in ArcToolbox to obtain the length of streams within each of the zone polygons. We used a 50 m buffer to either side of the roads to estimate area surveyed for each of the zones. Proportion of the zone that was covered by closed canopy was hand measured using the aerial photograph as a reference.

Results

Total deer observed during a survey followed no discernable pattern week to week (Fig 15). The range of deer seen during a survey over the course of the study was from a low of 14 to a high of 46 with a mean of 28.55 deer sighted. Zones ranged from nearly 4,000 ha (Zone 1) to Zone 3 which covered more than 6,500 ha. The variation between zones for mean deer abundance was interesting, ranging from 0 to 4.64 (Fig 16). The mean number of deer observed during one survey night was 28.55 ± 10.54 deer. Based on the area surveyed our estimate of deer density within OOMP is 14.78 deer/km^2, though if we observed a large proportion of the deer within the park then our estimate drops to 1.88 deer/km^2. The first estimate is based on density in the area surveyed; the second assumes we encountered every deer within the park and is based on total park area. Table 5 summarizes pertinent characteristics of each zone.

We explored the effects of various parameters on explaining deer abundance through forward stepwise logistic regression to answer our questions about predicting deer observations. We used Spearman's correlation to assess correlations within our set of variables prior to running any regressions. One interesting correlation emerged. Area of a zone was strongly positively and significantly correlated (R^2= 0.78 $p<0.05$) with maximum deer observed in a zone. In other words, larger zones tended to be those where greater numbers of deer were observed. Four variables were suitable for inclusion in our zone scale model. These variables were; area surveyed in each zone, length of streams within the zone in kilometers, range in NDVI within the zone and proportion of the zone with a closed canopy. Our model used a categorical response variable based on the maximum number of deer seen in a zone during a single survey night. The only explanatory variable that was included in the model was kilometers of streams within a zone (Coe:-1.442). This means that higher deer presence is significantly, but not very strongly negatively correlated with increasing length of streams. The variables that were not significant were: area surveyed, range in NDVI and proportion of zone covered by heavy canopy (Intercepts: 1.548, 4.892, R^2=0.2585). It was interesting that NDVI was not strongly or significantly correlated with any of the other variables.

Discussion

Despite the small size of OOMP compared with the home range of an average deer, there were signs of movement of groups of deer throughout the park. There are a number of factors that could have complicated and confounded our search for signs of movement of deer within the park. The deer may be tempted to leave the safe haven of the park by outside sources of food, such as nearby agricultural fields (Halls 1984, Brinkman et al. 2004, Conover and Kania 1995). We may not have seen much difference in deer observed explained by canopy cover since zones did not vary greatly in canopy cover. Incorporating spatial measures into traditional studies is a powerful tool to provide new insights into trends within the data (Brinkman et al. 2004, Felix et al. 2007, Grund and Woolf 2004, Kramer, Bruinderink and Prins 2006, Shi et al. 2006, Walters 2001). As with any tool, knowing how it works and where weaknesses lie is key to using it correctly (Belant and Seamans 2008, Mandujano 2005). The lack of correlation with any other variable may indicate that NDVI does not adequately capture the salient points of variability in plant communities between zones in OOMP. We may also be analyzing at the wrong scale for NDVI to be useful. In our case only one landscape feature, streams, was found to explain any significant portion of the variation in maximum number of deer observed within a zone. This was a weakly negative correlation and surprising since we found no mention of water source as a variable of consideration in various deer habitat use models (Felix et al. 2007, Grund and Woolf 2004, Klaver et al. 2008, Meek et al. 2008, Shi et al. 2006, Walters 2001). We found that larger zones were correlated with increased deer sightings which could indicate that larger patches of vegetation are valued by deer. This would agree with Felix and colleagues (2007) whose model predicted deer presence based on seasonally changing food sources and shelter areas. Were we to extend this study another year we would look at a larger variety of land cover variables to better answer why the deer use a particular area. Others have found that amount of roads in an area is related to deer detection (Farrell and Tappe 2007), though we did not see this effect, perhaps because of the ubiquity and systematic placement of roads in the study area. Our measure of canopy cover within zones may have lacked significance as all zoned were at least 88% covered in heavy canopy (Table 5).

Deer are often assumed to be a force for community level alteration of plants in the absence of evidence, merely because they are a large herbivore that is widely distributed in the continental United States. However, we found that local deer density in OOMP was well below that which is considered a 'high' density of deer, which is generally >20 deer/km^2 (Denicola, Etter and Almendinger 2008). Other studies have found densities as high as 80 deer/km^2 in some areas (Denicola, Etter and Almendinger 2008). We also found little evidence of significant browsing on either oak seedlings or lupine (see ch 1 results). Previous accounts of deer abundance and density were largely anecdotal in this park. Our study estimates the mean number of deer in OOMP at 28.55 ±10.54 deer, which leads to a conservative estimate of 1.88 deer/km^2 or a more liberal estimate of 14 deer/km^2. This is a low density of deer compared to other studies (Denicola, Etter and Almendinger 2008, Eschtruth and Battles 2008), though it is within the range of 0.4-6.0 deer/km^2 estimated by Halls as normal for this part of the Midwest (Halls 1984). Also, one study found that road based surveys only capture 11% of the population and so estimates derived from road based surveys are conservative (Morellet et al. 2007). There is evidence of a growing population in the area based on deer vehicle collisions (DeNicola and Williams 2008, Wildlife 2007) and hunt records (ODNR 2009, Station 2007, Wildlife 2007).

If the density of deer were to dramatically increase we might expect to see the group size increase as they cluster into the shelter of the park. This assumes that they use can and do use

OOMP for food and shelter while suburban and agricultural areas adjacent to the park would offer food, but little shelter. Alternatively, there might be a movement out of the park at peak activity times as food sources inside the park were depleted by the growing population. Either possibility should be captured with repeated road-based surveys that pay close attention to timing of movement and group size, which has also been found to affect vigilance in deer (Lark and Slade 2008). We did measure time of deer sighting and group size; these variables could be incorporated into our existing forward stepwise logistic regression in the future. Management may also influence deer distributions and movements within the park. Since a common management technique in the area is to burn to reduce canopy cover and later seed for desired species the deer may move to take advantage of tender new growth following burns. This could be explored by monitoring deer activity in and around selected sites prior to and after burns.

Conclusion

We recommend using our rapid survey technique to monitor the deer population in OOMP. Currently Metroparks of the Toledo Area utilize motor vehicles as transportation for park rangers. While the rangers are driving the roads they (or a passenger) could be gathering data about the deer. The zoned map we generated makes marking position easy and the only other pieces of data needed are time sighted and number of deer. This type of survey is non-invasive and less intensive by far than a helicopter flyover or marking the deer with radio collars. Consistent monitoring of the deer population would give a warning if it began to spike or crash which would allow time for a change in management of the deer. Another warning sign of a population in need of reduction would be browse lines on the vegetation (Coomes et al. 2003, Gubanyi et al 2008, Kraft et al. 2004), which could be monitored using methods detailed in Ch 1. Broader warnings include a rise in deer-vehicle collisions (Farrell and Tappe 2007).

The deer do show some tendencies to cluster, but these are not evident when all weeks of the survey are averaged. In chapter 1, we found that the browsing by deer was correlated with different variables at the scales of the site and quadrat. This leads to question of what factors affect the deer most strongly at the zone level and beyond. Others have found that migratory deer select on multiple factors for winter ranges (Long et al 2008). Since the movements of the deer need not be migratory in scale to cover the entirety of OOMP, the deer certainly have the potential to have widespread impact on this unique and heterogeneous natural area. Only with monitoring do we stand a chance having forewarning of what this impact will be.

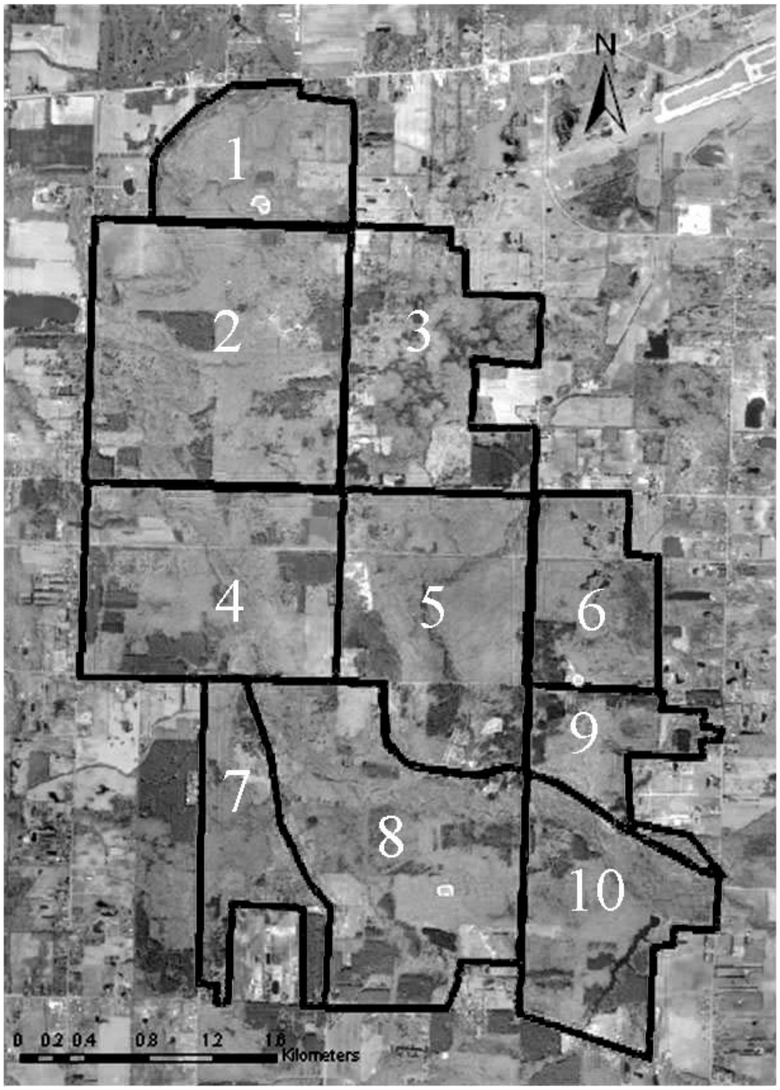

Figure 13. Map of Oak Openings Preserve Metropark with all 10 zones marked. Zones were utilized to aid rapid data collection when deer were sighted during surveys. Surveyors noted time, number of deer, and used the map to assign location by zone.

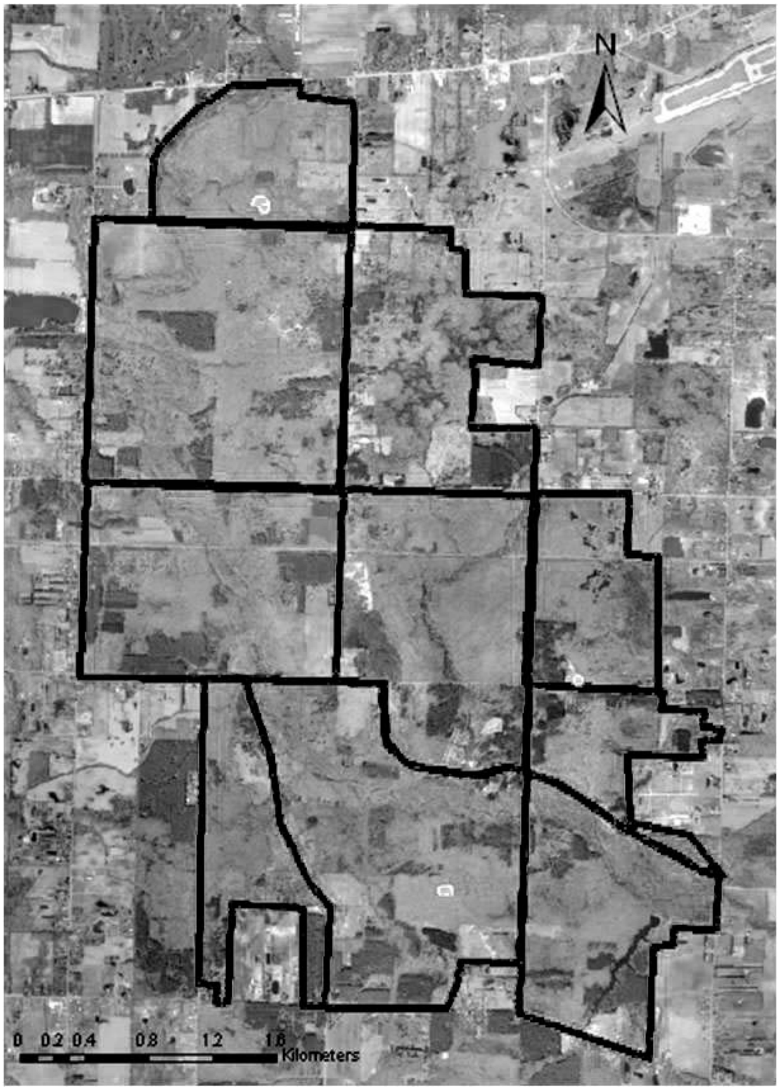

Figure 14. Zoned Map of OOMP. We split the park into 10 zones to aid rapid recording of position data when deer were sighted during weekly surveys. The three opaque polygons show sites identified in Ch 1 (CR, MS, RR). All internal roads in the park were used during deer surveys, in a different order each week to avoid sampling the same area at the same time of evening.

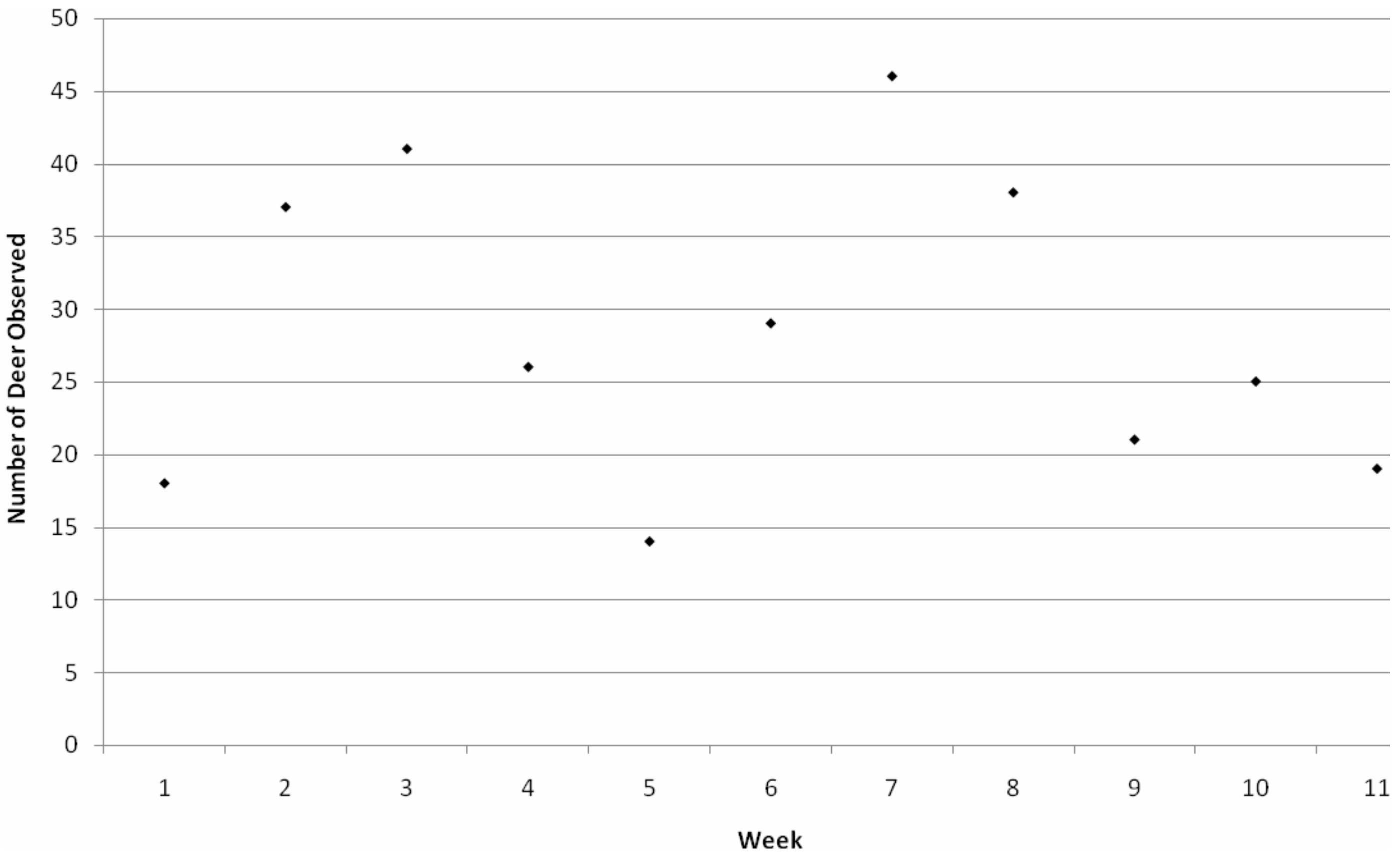

Figure 15. Total Deer Observed Over Time. During the once a week road surveys in OOMP the number of deer seen in a night ranged from 14 in week 5 to 46 in week 7. There is no consistent trend over time.

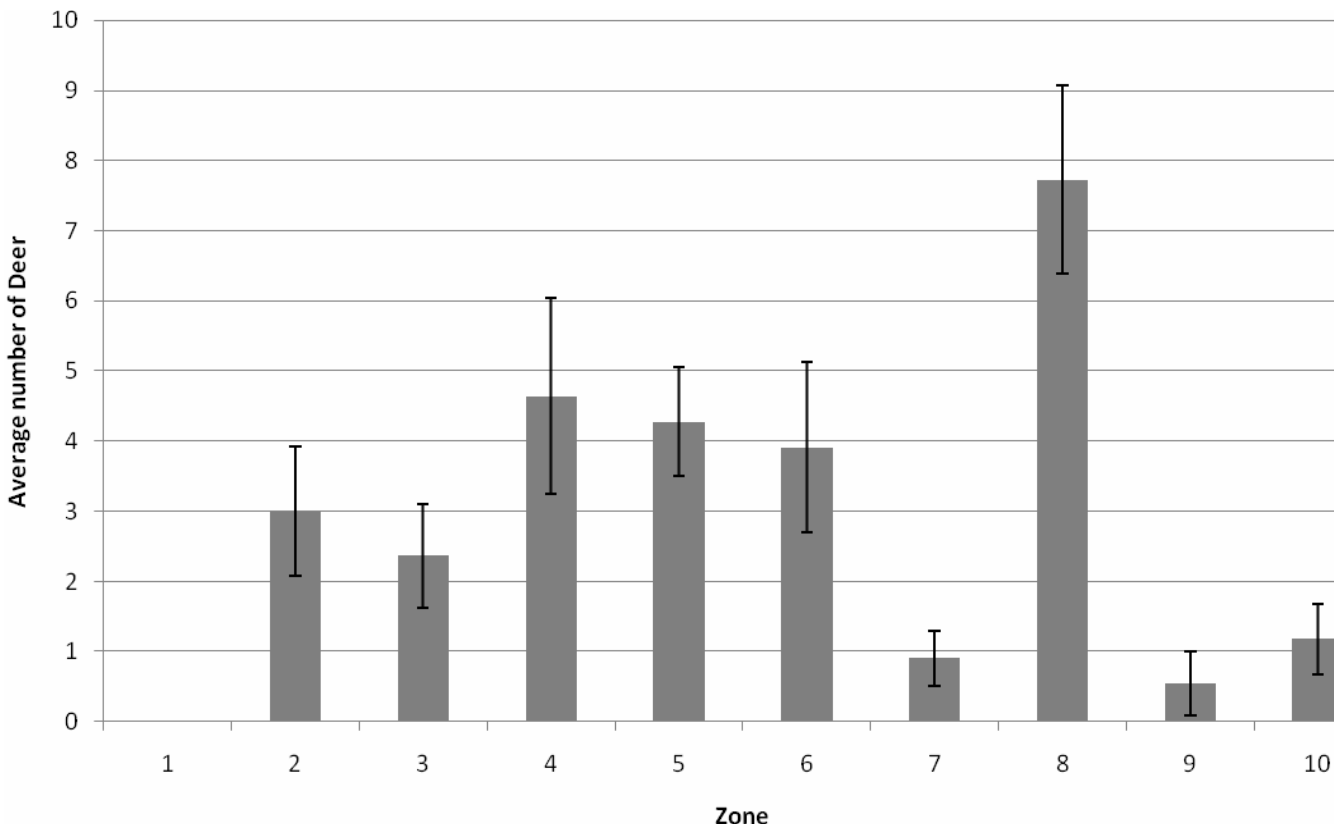

Figure 16. Mean Number of Deer per Zone. Averaging the sightings from all weeks of our surveys we see that some zones appear to have substantially more deer activity than others. The bars are ± SE and not terribly large errors. Still, zone is not a variable that explains significant amounts of the variation seen in mean deer abundance according to our forward stepwise logistic regression. Bars are numbered to match zones in Figure 13.

Table 5. Summary of Distinctive Zone Features. The area and perimeter give an idea of how large each zone is, while the deer measurements show mean and variability of occurrence in each zone. NDVI is used as a comparable measure of vegetation across zones. Length of streams and proportion of zone under heavy canopy were extracted from map layers.

Zone	Area (ha)	Perimeter (m)	Average Deer per Hectare Surveyed	Range of Deer	Range in NDVI	Length of Streams (km)	Proportion of Zone Covered by Heavy Canopy
1	96.318	3948.66	0	0	0.445541	2.48	0.93
2	262.305	6479.02	0.143541	10	0.403299	4.26	0.96
3	161.772	6551.29	0.085115	6	0.490123	2.33	0.90
4	193.439	5618.28	0.35124	13	0.502946	3.04	0.89
5	190.629	5763.02	0.316498	7	0.487765	2.04	0.92
6	91.183	4063.32	0.264485	11	0.325	1.18	0.94
7	87.545	6441.49	0.035373	4	0.375106	1.63	0.91
8	232.901	6982.8	0.343129	14	0.435754	4.73	0.89
9	67.426	5297.63	0.024715	5	0.366667	0.94	0.93
10	135.046	5268.75	0.123492	5	0.41156	3.16	0.90

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