Am. Midl. Nat. (2012) 168:18–29

Impact of Seed Predation by Mice on Wild Lupine in and near Oak Savannas

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ABSTRACT.—Wild blue lupine (*Lupinus perennis*) in the Oak Openings Region of Northwest Ohio is an important nitrogen fixer and serves as an essential food source for the federally endangered Karner Blue butterfly (*Lycaeides melissa samuelis*). In order to examine potential factors that might be affecting mice predation on wild blue lupine seeds in oak savannas, we used seed trays placed in the open or on the forested edge to estimate seed predation rate. We recorded management histories, performed vegetation surveys, and used GIS to find spatial variables related to prescribed burning and edge to assess how they affect seed predation. Our major findings were that seed removal by mice for the summer averaged across sites was 22%, seed removal varied significantly across time ($P < 0.05$), and was more likely in areas with increased crypto-biotic crust ($P < 0.0001$). Seed predation rates increased under more prescribed burns over the last 10 y ($P = 0.034$) and 19 years ($P = 0.0001$). This leads us to support current management practices of a rotation of prescribed burning in open to partially closed canopy areas to create a balance between promoting lupine growth and minimal seed predation.

INTRODUCTION

The Oak Openings Region of Northwest Ohio has many different ecosystems intermixed in a mosaic of small to large habitat patches that have been diminished by human development and fire suppression. It contains globally rare communities such as sand barrens, wet/sand prairies, white and pin oak flatwoods, black oak/lupine barrens (oak savanna), and oak woodlands that developed on deposits of postglacial lake sand (EPA, 2006). Many endangered or threatened species are dependent on these rare natural communities found in the Oak Openings Region, including the Karner Blue butterfly (*Lycaeides melissa samuelis*; ODNR, 2008). Oak savannas are currently only found on 0.02% of its former landscape in the Midwest Region of the United States (Nuzzo, 1985). Oak savanna can be described as an area dominated by scattered oak (canopy cover 5–80%) on well-drained, sandy soils created from glacial outwash, supporting an understory consisting of graminoids and shrubs with indicator species such as little blue stem (*Schizachyrium scoparium)* and wild blue lupine (*Lupinus perennis*; Faber-Langendoen, 2001).

This study will focus mainly on oak savannas where wild blue lupine is found and at the edges of these areas where they transition into oak woodland. These oak woodlands are oak dominant areas with 80–100% canopy cover based on the Faber-Langendoen's (2001) description of Black Oak – White Oak/Blueberry Forests. The perennial wild blue lupine (lupine) is found in full to partially sunny areas with nutrient poor and sandy soils (Gleason and Cronquist, 1991). Lupine is an important indicator of oak savanna and valuable for its nitrogen fixing ability, which increases nitrogen availability for associated non-fixing species (USFWS, 2003; Lee *et al.*, 2003). Lupine also serves as the only food source for the larval stage of the federally endangered Karner Blue butterfly, and is also used by larvae of state endangered Frosted Elfin (*Incisalia irus*), and Persius Dusky Wing (*Erynnis persius*)

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butterflies (USFWS, 2003). Lupine is also currently under potentially threatened status in Ohio (Ohio Department of Natural Resources, 2010). The effects of seed predation on lupine by small mammals, specifically white-footed mice (*Peromyscus leucopus*) and deer mice (*Peromyscus maniculatus*), has not been studied in Midwest oak savannas. Preliminary data indicated that mice eat lupine seeds that had been dispersed from the plant and were placed on the ground; ballistic dispersal makes seeds readily available, while flexible stems make it less likely that mice would gather seeds from climbing the plant. Californian studies on bush lupine (*Lupinus arboreus*) showed that seed predation by mice decreased seedling recruitment, seed bank size, and adult lupine numbers (Kaufmann and Maron, 2006; Maron and Kaufmann, 2006). Oak savannas in the Midwest occur as a mosaic, where many of the habitats are patchy and dominated by edges. The population dynamics of a plant experiencing an edge effect from seed predation by rodents can be influenced by vegetation structure (Kollmann and Buschor, 2002). More structural complexity at the forest edge from increased shrub and herbaceous plants provides more cover and food availability than the interior (Gehlhausen *et al.*, 2000; Kollmann and Buschor, 2002). This edge habitat can lead mice to forage up to 10 m in the adjacent habitat (Wolf and Batzli, 2004), which could lead mice to lupine habitat adjacent to the forested areas.

Protected areas of oak savanna in the Midwest are being managed through prescribed burning and mowing to try to mitigate human impact and maintain their early successional state. For lupine, research has shown that it responds favorably to burning with increased leaf and seed production (Grigore and Tramer, 1996). Management guidelines for the Oak Openings Preserve Metropark are to burn prairies once every 2 y, savannas once every 3 y, and oak woodlands once every 4–5 y (L. Sprow, Oak Openings Preserve Metropark, pers. comm.). Mowing is also used to reduce shrub and saplings in the early-successional habitat, especially in areas unsuited for burning. Consideration for the protected butterflies of the area is also taken into account by dividing butterfly habitat up into thirds and rotating every year with 1/3 of the lupine stems burned, 1/3 mowed, and 1/3 left as Karner refugia (USFWS, 2003).

The results of management may affect foraging behavior in mice and lupine populations. It has been shown that an increased amount of leaf litter decreases mice foraging success (Reed, 2005), decreases lupine seedling recruitment (Pavlovic and Grundel, 2009), and decreases lupine size (Pickens, 2006; Pickens and Root, 2008, 2009). Jacksy (1997) did not find an effect of prescribed burning on *Peromyscus leucopus* numbers in the Oak Openings Preserve Metropark, but the study did not examine if changes occurred in foraging behavior. In this study, our objectives were to estimate predation rate on *Lupinus perennis* seeds by mice, identify any vegetation characteristic that increased seed predation, and to observe if it was correlated with prescribed burning. We hypothesize that the management of this habitat mosaic may be influencing amount of lupine seed predation in and near oak savannas. We predict that seed predation would increase with decreased ground cover, at the edge of savannas, and with more prescribed burns.

Methods

We examined the extent of seed predation, along with the abundance and distribution of lupine on six different lupine populations from Apr. to Sept. 2008. All sites were located in the Oak Openings Preserve Metropark (41″32–34′N × 83″50–51′W), which is the largest of the Metroparks of the Toledo Area located near Whitehouse, Ohio (Fig. 1). These sites were chosen based on areas of historic, persistent populations of lupine, and then limited to populations that were in oak savanna and adjacent to woodlands. The area of our sites

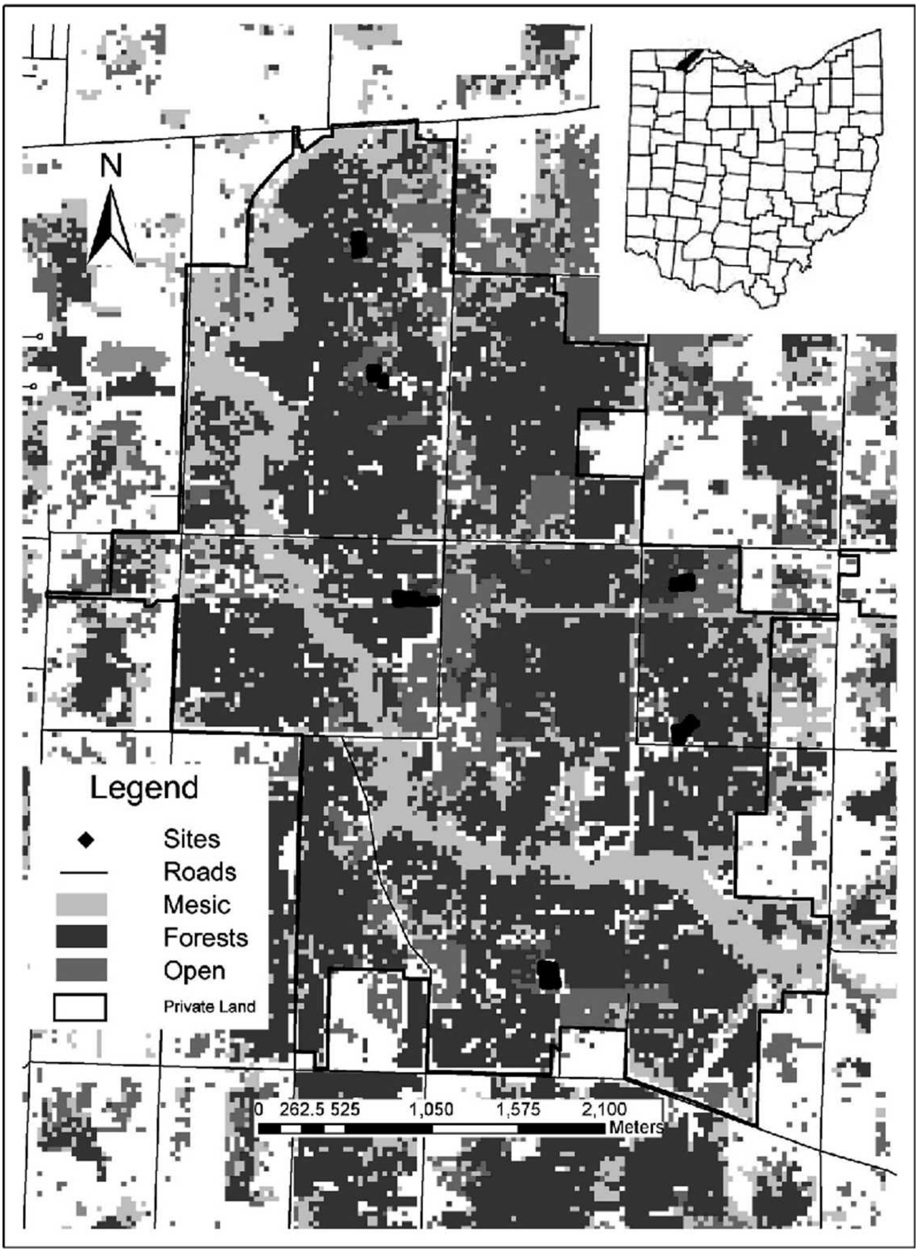

FIG. 1.—Map of study sites in the natural areas of Northwest Ohio's Oak Openings Preserve Metropark. Mesic areas include running/standing water and floodplain forest, forests includes swamp/upland and conifer forests, and open includes oak savanna, shrub/scrub, and barrens

ranged from 245–1587 m^2. Selected sites were at least 0.70 km from each other to reduce the probability that mice populations and management practices would overlap. Site management histories for prescribed burning were collected from the park and are categorized in Table 1 by number of prescribed burns over variable time allotments (5, 10, and 19 y) per site.

To estimate seed predation eight seed trays were set out on the ground at each of the six sites, four along the woodland edge, and four within the oak savanna. Seed trays were placed at spots at least 20 m apart along transect lines. Transects were 20 m apart from each other and kept 20 m away from roads, trails, and water-bodies to minimize other edge effects. The seed trays were a flat 506.5 cm^2 circular aluminum tray with one cm high edges filled with sand and held in the ground with 18-gauge wire U-hook. The trays were covered completely with a cylinder made of insect screening (15.24H × 22.86 cm diameter) except for four evenly spaced 2.5 × 2.5 cm square openings cut out along the bottom edge to allow only small animals to enter (Fig. 2). Tray screens were held in place with at least four 12- gauge wire U-hooks. We added 15 lupine seeds of random seed coat colors to each tray; the number of seeds mimicked the density used by Maron and Simms (1997), who utilized 30 bush lupine seeds in a 929 cm^2 enclosure. Previously collected lupine seeds from Northwest Ohio were used until seed collection was performed that year on 20 Jul. After this date new seeds were placed 10 per seed tray because of limited supply. Therefore, during analysis number of seeds removed per trial was calculated as proportion of seeds removed in order to combine trays with 15 seeds and 10 seeds present. Lupine seeds were added to the trays in May, and recounted every 4–8 d (if weather permitted) until mid-Aug. Due to known mice preference for sunflower seeds (Sullivan, 1979; Sullivan and Sullivan, 1982) one black sunflower seed was also added to the tray. If it was eaten or removed, we assumed a mouse had entered the tray to eat the sunflower seed. If the sunflower seed remained the data was not analyzed. This allowed us to assess what we assume is specifically seed predation by mice and does not take into account trays that may have lost lupine seeds by ants, wind, or other small mammals. The number of missing seeds was counted and then we replaced seeds so trays had the initial number (15 or 10) even if the sunflower seed was not removed. If a seed had germinated it was replaced as well.

We gathered data for our vegetation survey from one m^2 quadrats placed every 20 m along the parallel transects running North-South through the oak savanna and along the edge of each site. In this study edge was defined as in Kollmann and Bushor (2002) and was considered as a 20 m wide margin that separates oak savanna and woodland. We recorded the percent vegetation type, vegetation density, and leaf litter depth from each one m^2 quadrat. These measurements were done both before and after lupine seedpods developed (13 May and 18 Jun.) at each site. Photos were taken of each quadrat's ground cover in order to assess percent cover of each vegetation type, which was categorized into bare ground, leaf litter, sapling/shrubs, graminoids, crypto-biotic crust (soil crust containing moss/lichens/algae), ferns, other angiosperms, and lupine. We applied a 10 by 10 grid to each photo in Adobe Photoshop (Adobe Systems Incorporated, San Jose, California, USA), converted the number of squares in which a vegetation type was found into a percentage, and then averaged it over time and space. A Robel pole is used to measure the visual obstruction made by vegetation structure by viewing its height from a distance (Robel, 1970), we refer to this as vegetation density. We averaged the vegetation density from the North and East cardinal directions 3 m away from a Robel pole placed at the center of the quadrat and viewed from a height of one and a half meters (Robel, 1970). Leaf litter depth was averaged from two random points in the quadrat. Lupine abundance of each site was

TABLE 1.—Site management history for the number of prescribed burning events over the last 5 y, 10 y and 19 y

Site	Burns (5 y)	Burns (10 y)	Burns (19 y)
A	3	5	8
B	0	0	0
C	2	0	2
D	2	4	5
E	0	0	0
F	3	5	9

estimated by the Oak Openings Preserve staff by counting the number of flowering adult lupine stems in each population.

Geographical Information System (GIS) was used to map out the locations of all seed trays. Locations were determined using a handheld GPS unit (Garmin eTrex). Each location was queried to find landscape variables extracted from satellite data using ArcMap 9.2 (ESRI, Redlands, California, USA). A LANDSAT image (7 Jul. 2008, Path 20, Row 31) was pan sharpened using color-space transformation to convert the true color images between the red/blue/green and hue/lightness/saturation images so that the spatial resolution of the images was increased to 10 m pixels. From these spatial layers, we extracted estimated NDVI, and distances from horse trails, water, and roads.

Our data were not normally distributed so we performed a Kruskal-Wallis one-way ANOVA on Ranks (KW test) (NCSS, Kaysville, UT, USA) between site, time, and amount of seed predation over the collection period. Location was designated as those trays either at the edge or in the open oak savanna portion of the site. A Spearman correlation was done with seed predation values and prescribed burning using JMP 9 (SAS Institute Inc., Cary, NC, USA). Management practices were categorized into number of (a) prescribed burns done in

FIG. 2.—Photo of a seed tray used to detect levels of seed predation by mice. Seeds were placed in the tray and checked weekly for predation. The mesh screening had four equally spaced doors that allowed small mammal entry

the past 5 y, (b) in the past 10 y, and (c) the past 19 y. Finally, we used the KW test to see if there was a difference in seed predation when using the old seeds versus the new seeds collected that year.

We ran a forward stepwise logistic regression using SAS software (version 9.1, 2003) to assess if presence of seed predation was affected by any of our explanatory variables. Analyses used presence of seed predation as the response variable, and included data from each seed tray location. We examined the average percent cover of each vegetation type between May and Jun., vegetation density, and other variables extracted from satellite data using ArcMap 9.2. We used the Spearman Rank Correlation to eliminate variables highly correlated (>0.70) with each other from the logistic regression. P-value was used to find the most predictive explanatory variable(s) for the logistic regression.

RESULTS

Lupine stem counts in 2008 showed a wide range (100–6800) of plant abundances across sites. There was no difference in seed predation for old seeds versus the new seeds (KW test, $P > 0.05$). On average across all sites, 22% of the lupine seeds were removed and possibly eaten from seed trays over the sampling period from 6 Jun.–20 Aug. The average proportion of seeds removed was similar for all trays across sites (Fig. 3) (KW test, $P > 0.05$). When we compared the proportion of seeds consumed for all trays, the differences in seed removal significantly changed over time (Fig. 4) (KW test, $P < 0.0001$). Seed predation was low in early spring, increased with a peak at the end of Jul., and declined to low levels again in Aug. (Fig. 4). The forward stepwise logistic regression performed on seed tray across sites found that crypto-biotic crust coverage was the only significant variable to increase seed predation occurrence ($P < 0.0001$). Edges differed between sites in predation levels ($P = 0.016$), and savannas were different between sites as well ($P = 0.042$). Both edge and oak savanna predation was higher in site F and site D by at least 10% when compared to the other sites with site E having the least predation. Although, seed predation was not significantly different when we combined all sites and compared all edge seed trays to all oak savanna seed trays ($P > 0.05$). We found that the seed predation averaged over time for all sites was significantly different along just the edge ($P = 0.002$), or within just the oak savanna ($P = 0.0003$) (Fig. 4). The seasonal patterns for edge and savanna were similar to the pattern seen for the average of all trays (Fig. 4).

Across all sites, the amount of prescribed burns over the last 10 y was positively and significantly correlated with seed predation (Spearman's $\rho = 0.15$, $P = 0.032$). Seed predation averages were also positively and significantly correlated with the total number of burns over the last 19 y (Spearman's $\rho = 0.20$, $P = 0.005$). Prescribed burns over the last 5 y (Spearman's $\rho = 0.11$, $P = 0.11$) did not significantly correlate with seed predation. This indicates that there may be a link between increased seed predation rates that occurred and increased management events over time.

DISCUSSION

Our summer average seed predation was 22%, but our averages varied over time from 0–58%. Other studies about seed predation by mice show similar results where predation can be variable but have an impact on the plant population dynamics (Hulme, 1994; Maron and Simms, 1997; Kollmann and Buschor, 2002; Cote *et al.*, 2003; Deveny and Fox, 2006). The seed trays used in this experiment best resembles a seed bank with its constant output and not the year-to-year variation in lupine seed output. There is a noticeable jump in seed predation at the end of Jul., which occurred after switching to new seed in the trays. This

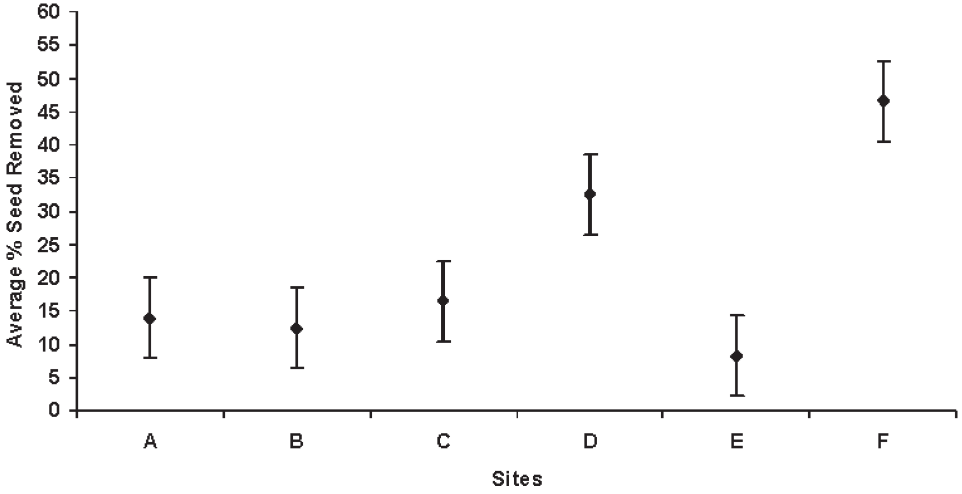

FIG. 3.—Average across time for percent of lupine seeds removed by mice at each single site. Differences between sites were not significant (P > 0.05). Bars represent the standard errors

correlates with the natural timing of seed dispersal in lupine, and may reflect predation that occurs because lupine has become a more abundant food source over time. New lupine seeds also may have a better olfactory cue for mice than those in the seed bank or those in the trays that were from the previous year. This time of the year may also reflect an annual fluctuation of seed predation associated with increased mice numbers rather than seed availability. Although this study was only conducted over one field season, other studies in

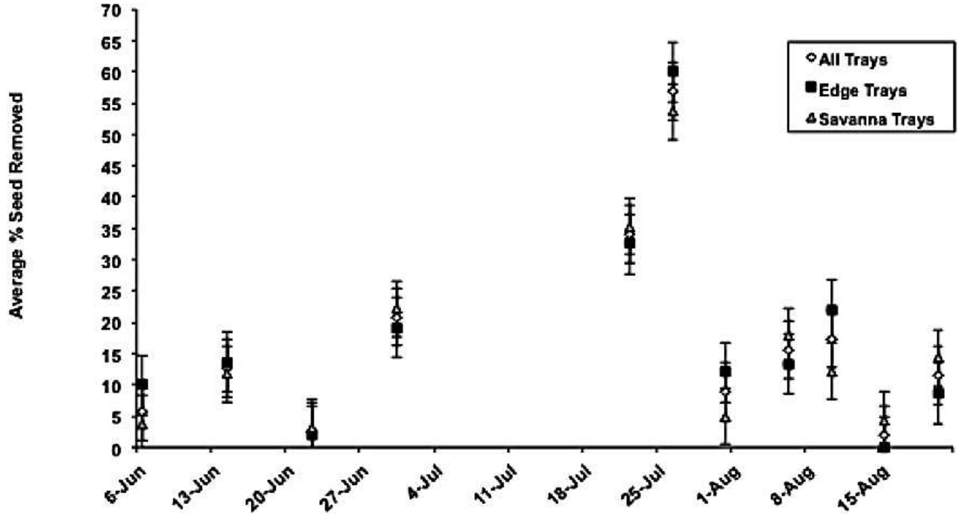

FIG. 4.—Average percentage of seeds removed per week across all sites (*e.g.*, level of seed predation) by location (edge habitat or open oak savanna) was significantly different over time (P < 0.0001). Bars represent standard errors

Northwest Ohio document a similar seasonal mouse population increase (Jacksy, 1997; Lewellen and Vessey, 1999). The high variation in our lupine population abundances makes protecting and monitoring the smaller populations, such as site C or site E, of greater importance since seed predation can reduce their population size significantly. Even this relatively small average amount of seed predation may have an impact on the long-term success of lupine in an area because it may add demographic declines to other potential problems, such as reduced habitat, fragmentation, and inbreeding load (Michaels *et al.*, 2008), particularly for smaller lupine populations.

The importance of crypto-biotic crusts in the analyses may also reflect foraging decisions at the small visual scale of a mouse. This surface may facilitate seed or seed tray discovery and may have reduced mouse predation since crypto-biotic crust is darker than bare sandy soil substrate and quieter than leaf litter to move through (Reed *et al.*, 2005; Roche, 1999). Crypto-biotic crust may also benefit mice by providing either hydration from dew on the moss or an area where fungi or other food sources may be found. It is possible that mice will have retained landscape information under brighter conditions and then move into crypto-biotic crust areas under darker conditions to reduce predation while foraging (Zollner and Lima, 1999). Other studies have found that more bush lupine seeds were removed in dune areas than grasslands, which are also areas where crypto-biotic crust may have favorable growing conditions (Maron and Simms, 1997; Maron and Kauffman, 2006; Kauffman and Maron, 2006).

There was a difference in seed predation averaged across time but no significant difference between the edge and open savanna seed predation across time. Other factors influencing seed predation may operate at a different scale than what our study measured. The variability between sites probably influences our ability to detect significant edge effects as well. In the Oak Openings, each site is distinct (*e.g.,* exhibiting different amounts of cover and structure), which makes detecting differences more difficult.

Other factors outside the scope of our study that may be affecting seed predation could be dependent on the spatial distribution and cost of foraging for lupine. If the seed is not evenly distributed from the savanna to the edge, conspecific seeds' density dependence can conceal edge effects on rodent seed predation as well (Chauvet and Forget, 2005). Therefore, if lupine is growing on the edge we may not see a lot eaten because other seeds and food are there creating a hidden edge effect. This would especially be the case if the mice in our study were using the same foraging rate independent of the amount of lupine and is worth looking into for future research. Costs associated with foraging, such as foraging competitors, exposure to predators, and energy expense to reach food eventually deter foraging. The foraging rate when the forager stops is called the quitting harvest rate (Shi, 1980). If the increase in cost of foraging is more than the increase in lupine seed density then there is no benefit for mice to forage longer in that area (Mitchell *et al.*, 1990; Davidson *et al.*, 2001). Increased lupine stem abundances in oak savannas did not correspond directly in our study to increases in seed predation; one suggestion for this is that mice may be using the ''fixed time rule'' where the probability of lupine seeds being consumed is independent of the number of lupine stems found in the foraging patch (Morris and Davidson, 2000). These factors may be concealing or preventing a detectable edge effect on rodent seed predation within sites, or perhaps an edge effect on lupine seed predation simply does not exist.

Prescribed burning may make it easier for mice to move through vegetation and locate food because of reduced leaf litter (Grigore and Tramer, 1996; Reed, 2005; Plenzler, 2008). Our results support this theory as we found a positive correlation of predation at sites with more prescribed burns. However, there is an apparent time lag before burning increases seed predation because predation does not correlate significantly within the first 5 y following a prescribed burn. Seed predation only starts to have a positive correlation with the number of burns over the 10 y and 19 y treatment periods. This time lag may also relate to other delayed responses in habitat structure that influence predation risk. For example, increased management activity since the year 2000 was shown to be significantly correlated with increased sapling density and reduced leaf litter across the same Oak Openings region (Plenzler, 2008). In addition, lupine seeds can remain dormant in the seed bank before sprouting for many years depending on temperature fluctuation (Grigore *et al.*, 1996; Mackay *et al.*, 1996). Therefore, management technique frequencies are as important to consider as the type of management chosen. Our results also show less seed predation in sites with no management, which may correspond to previous findings that areas with no management have lupine of decreased quality and more leaf litter (Reed, 2005; Pickens and Root, 2008; Plenzler, 2008). Overall, lupine will persist in areas managed to keep oak savannas at their mid-successional state, and although our study shows an increase in seed predation as a result, prescribed fires also allow for increased lupine vegetative growth and seed set (Grigore and Tramer, 1996).

Since we surveyed over a single growing season, we were unable to assess annual variations in lupine seed predation, so we cannot determine if our peaks in seed removal were based on random movement or on annual variation. However, annual variation is likely since others have shown that mice respond to pulse resource foods such as acorns (Wolff, 1996; Schradin and Pillay, 2006; Marcello *et al.*, 2008). By using a seed tray design that limited the entry to small predators (2.5 cm^2), however, we were able to exclude predation by larger mammals and birds. Although the design did not exclude insects, reptiles, or amphibians, only ants were observed inside and were not able to move seeds by themselves or cooperatively; therefore, we do not believe they were responsible for any seed removal. One of the benefits of our seed tray design is that it did not draw attention from park visitors, although other large mammals could dismantle it. The tray design also allowed for a more natural setting for the seeds and did not disturb the surrounding vegetation as larger enclosures could. Although this may not convey natural seed predation behavior due to the presence of manmade material, this form of seed tray could be a useful new tool to capture only small mammal seed predation.

We found seed predation by mice on wild lupine was mostly below 30% during the entire spring and summer seasons (22% on average). With our data, we identified crypto-biotic crust as the key predictor of seed predation. Overall, our results show that there is no difference in seed predation rates between the edge and oak savannas, and an increase in seed predation rates occurs with increased management events. These data have highlighted some of the critical factors that affect the interactions between white-footed mice and wild lupine.

Our research shows that after prescribed burns the amount of seed predation tends to increase. Prescribed burnings have been shown to increase lupine growth and not negatively affect mice population numbers (Grigore and Tramer, 1996; Jacksy, 1997). This seems to suggest that the current management plan consisting of a mix of prescribed fires and mowing is the best management approach to balance seed predation with lupine growth. To assess if the current management protocol timing is the most beneficial, a more in depth analysis of vegetation structure change could be performed. Previous research in the area has shown a positive benefit of lupine nutritional quality for the Karner Blue butterfly when vegetation density was between 0–2.5 dm (Pickens and Root, 2008), suggesting that mowing when it is less than 3 dm and burning when it is 3-4 dm may be beneficial. Our explanatory variable for seed predation, crypto-biotic crust, is usually found in an area of very low to no vegetation density, indicating the need to postpone burning until more vegetation coverage occurs. This could allow a buildup of detritus to form, which may for a time potentially deter mice from that area as it would make for a noisy place to roam (Reed, 2005), and thus increase lupine seed abundance until a prescribed burn is performed when there would be enough fuel for the fire to burn. Although there are many other factors that determine if a prescribed burn will be performed, this approach would allow managers to assess site priority when the goal is to increase wild lupine. This in turn will help the federally endangered Karner Blue butterfly expand its range naturally, since it has been shown to re-enter areas after prescribed burns (Kwilosz and Knutson, 1999). The current management strategy for Karner sites requires each site to have 1/3 mowed, 1/3 burned, and 1/3 left for refugia annually (Kwilosz and Knutson, 1999); however, this rotation is based on time and not on vegetation density. We recommend that vegetation density is taken into consideration as well as time in order to assess the effects of management on mice seed predation and lupine quality. Future research should focus on the effects of management on the resulting lupine population dynamics in order to evaluate the effects of this management rotation on Karner sites.

Acknowledgments.—We would like to thank E. Gomezdelcampo and P. Gorsevski for assisting with this project. The project would not have been possible without the help of volunteers S. Woods, R. Witters, and J. Barger. We are also grateful to the Metroparks of the Toledo area, especially all those at Oak Openings Preserve, who enabled us to perform our experiments and shared valuable data. We would also like to thank K. Baczynski, M. Coulter, H. Harms, A. Kuntz, J. Sewald, T. Scheeter, S. Wilson, and L. Yarrish, who have all assisted on this project.

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SUBMITTED 6 DECEMBER 2010 ACCEPTED 22 NOVEMBER 2011