BUTTERFLY CONSERVATION IN OAK SAVANNA: SITE CHARACTERIZATION, NECTAR RESOURCES, AND THE EFFECTS OF MANAGEMENT

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ABSTRACT

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Oak savanna is a globally imperiled plant community characterized by scattered oak trees and an herbaceous ground layer. The Oak Openings Region in northwest Ohio was once dominated by oak savanna however, since European settlement the amount of oak savanna has been significantly reduced. Despite the large reduction in area, what remains continues to support high levels of biodiversity including several rare butterfly species such as the federally endangered Karner blue butterfly (*Lycaeides melissa samuelis*). To improve butterfly conservation efforts, this study sought to characterize and compare oak savanna sites, determine how butterflies utilize nectar resources, and assess the effects of land management practices in the Oak Openings Region.

We conducted vegetation surveys at four oak savanna sites. Transects were established at each site and a quadrat frame was placed every 10 m along the transects. At each quadrat we recorded several factors known to be important to butterflies, such as flowering plant density, canopy cover, vegetation height etc. We also conducted opportunistic behavioral observations of butterflies, recording behavior at 10 minute intervals. Lastly, we obtained land management records from local agencies.

Sites varied greatly with respect to the measured factors. Flowering plant densities were low compared to a previous study used to evaluate potential reintroduction sites for the Karner blue butterfly in northwest Ohio. Across sites, butterflies most often fed from butterfly weed (*Asclepias tuberosa*) and scaly blazing star (*Liatris squarrosa*), but these species were not always the most abundant, indicating a possible preference. All sites were actively managed,

however, no significant relationships were found between management practices and the measured factors or species richness.

Based on our knowledge of quality butterfly habitat, the “Bowl” site at Meilke Road Savanna Wildlife Area was the most suitable site for butterflies overall. Managers should work to increase nectar plant densities including butterfly weed and scaly blazing star. A relatively open, heterogeneous canopy should also be maintained. More spatially detailed land management records are needed to better assess the effects of management on butterflies and their habitat. A better understanding of oak savanna butterflies will lead to improved management and more successful conservation.

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INTRODUCTION

Oak savanna

Conserving biodiversity in human-dominated landscapes presents unique challenges. Many butterfly species for example, require open habitat maintained by disturbance, but natural disturbance, such as fire or grazing, is often eliminated in these landscapes (New 1993; Smallidge & Leopold 1997). Oak savanna is a fire-dependent community that was once common across much of the north-central United States (~110,000-130,000 km^2). This community is characterized by scattered oak trees and an herbaceous ground layer made up predominately of grasses. Canopy cover can range from 10-80% (Nuzzo 1986). Since European settlement, fire suppression and changes in land use (agriculture, urbanization etc.) have significantly reduced the amount of oak savanna. Today, only 0.02% (~26 km^2) of the original extent remains (Nuzzo 1986) and oak savanna is now considered globally imperiled (Faber-Langendoen 2001). Despite this large reduction in area, what remains continues to support high levels of biodiversity (Leach & Givnish 1999).

Oak Openings Region

The Oak Openings Region in northwest Ohio, USA was historically dominated by oak savanna. This region is approximately 476 km^2 and is located in Lucas, Fulton, and Henry counties (41º 35' N, 83º 47' W) (Brewer & Vankat 2004). The average monthly temperature ranges from -4.5 Cº in January to 22.8 Cº in July (NOAA 2010b), while average annual precipitation is 85 cm (NOAA 2010a). The soils are sandy (up to 12 m of sand) and overlay clay-rich glacial till. Water drains quickly except in low lying areas where less sand has been deposited. These low lying areas often have standing water in winter and spring.

The Oak Openings Region supports a heterogeneous mosaic of plant communities many of which are globally vulnerable or imperiled (Faber-Langendoen 2001). In addition to oak savanna, the region is made up of wet prairie, sand prairie, floodplain forest, oak barrens, and oak woodlands. Each of these plant communities was historically maintained by fire (Brewer & Vankat 2004). Variation in the intensity and frequency of fire, as well as fluctuating levels of precipitation, result in a dynamic system. The plant communities in the Oak Openings Region support more state endangered, threatened, potentially threatened, or of concern species (143 plants and 23 animals) than any other area of similar size in the state of Ohio (ODNR Division of Wildlife 2010; ODNR Division of Natural Areas and Preserves 2011).

The region has undergone significant changes since settlement by Europeans in the 1880s. It is now highly fragmented and consists of residential, commercial, industrial, agricultural, and natural areas. Today, natural and semi-natural areas make up approximately 25% of the region (Fig. 1) (Schetter & Root 2011). Oak savanna which formerly covered about 206 km^2, has been reduced to <2 km^2 (Brewer & Vankat 2004). Large areas of land have been converted to agriculture (primarily in the south) and, in the north, the city of Toledo continues to expand. A reduction in the water table from ditching to improve drainage has lowered groundwater, permitting the growth of woody plants in historically wet areas (U.S. Environmental Protection Agency 2006). Fire suppression has also encouraged the growth of woody plants in both dry and seasonally wet areas (Brewer & Vankat 2004; U.S. Environmental Protection Agency 2006). As a result of increased cover by woody species, many native herbaceous understory plants have declined in numbers (U.S. Environmental Protection Agency 2006).

Several agencies including the Metroparks of the Toledo Area, The Nature Conservancy, and the Ohio Division of Wildlife are working together to address these threats and protect the region. Land acquisition, restoration, active management (including prescribed fire and mowing), and educational programs have all been implemented. One of the primary targets of these efforts has been the federally endangered (Andow et al. 2003) Karner blue butterfly (Karner blue) (*Lycaeides melissa samuelis*).

Butterflies

Butterflies are important taxa inhabiting every continent except Antarctica. Over 17,000 species have been identified. Butterflies are on the decline worldwide primarily due to habitat loss and degradation (Maes & Van Dyck 2001; Van Swaay et al. 2006). Because of their charismatic nature, they are often used to garner public support for conservation (Samways 2005). In doing so, other species (including other insects) are also protected. For example, in southern Africa the threatened Karkloof blue butterfly (*Orachrysops ariadne*) has become a flagship species and a reserve was created specifically for the butterfly and its ant host (Samways 2005). Butterflies may also serve as indicators. Mac Nally and Fleishman (2002) found that a sub-set of butterfly species was correlated with the species richness (i.e. number of species) of the larger butterfly assemblage in the Great Basin, USA. Sub-sets of butterfly species were also found to predict species richness of other taxa (birds) (Fleishman et al. 2005). Butterflies contribute to pollination and some plant species have evolved to rely primarily on butterfly pollinators (Jennersten 1984; Fishbein & Venable 1996; Ramírez 2004; Johnson et al. 2009). In one study, the frequency of butterfly-pollinated plant species increased from forest to open areas indicating an association between butterfly pollination and open habitats (Ramírez 2004). Lastly, butterflies are a critical component of the food web. Abundance and biomass of lepidopteron larvae have been positively correlated with productivity and nestling growth rates of insectivorous birds, especially neo-tropical migrants that breed in temperate forests (Graber & Graber 1983; Sample et al. 1993; Naef-Daenzer et al. 2000). Hagar et al. (2007) found that Wilson's Warbler (*Wilsonia pusilla*) ate more lepidopteron larvae than expected based on availability indicating a possible preference.

Quality butterfly habitat contains food resources for larvae and adults as well as structural elements and variation in topography. Butterfly abundance is often associated with host plant density (Herms et al. 1996; Fred & Brommer 2003). Nectar density has also been positively correlated with butterfly abundance and richness (Shepherd & Debinski 2005; Öckinger & Smith 2006; Clark et al. 2007). Feeding on nectar by adults most likely contributes to increased longevity and fecundity (Chew & Robbins 1989). Structural elements are created through the vegetation (shrubs, tall grasses, leaf litter etc.) and allow butterflies to thermoregulate, roost, overwinter, locate mates, escape predators etc. (Dennis et al. 2006). Reeder et al. (2005) found significant positive associations between butterflies and sub-canopy vegetation height and density. Variation in both vegetation structure and topography (such as canopy cover and elevation) creates important microclimates (Grundel et al. 1998; Fleishman et al. 2000; Lane & Andow 2003). Because butterflies are highly sensitive to daily and seasonal changes in climate, their ability to move to more suitable locations (at both small and large scales) is vital and results in more stable and persistent populations (Oliver et al. 2010). At larger scales, different habitat types can provide different microclimates (Geiger 1965; Rosenberg 1974), therefore heterogeneity at both the local and landscape scale will be increasingly important as butterflies respond to climate change.

Butterflies in the Oak Openings Region

The Oak Openings Region supports a high diversity of butterfly species (at least 69 species total were recorded from 1999 to 2008) (Schaefer 2009). Several rare species utilize oak savanna including the dusted skipper (*Atrytonopsis hianna*) (state listed species of concern), frosted elfin (*Incisalia irus*) (state endangered), Persius duskywing (*Erynnis persius*) (state endangered), and the federally endangered Karner blue (Andow et al. 2003; ODNR Division of Wildlife 2010).

The Karner blue was extirpated from the region in 1988 and placed on the federal endangered species list in 1992. Recovery efforts have resulted in oak savanna restoration and management targeted specifically for the Karner blue. Reintroduction of the butterfly began in 1998 and continues today. The Karner blue has become a flagship species in the area, drawing attention to the Oak Openings Region and oak savanna restoration.

Karner blue biology

The Karner blue has two broods annually. In Ohio, first brood adults fly from mid-May to mid-June and second brood adults fly from early July to mid-August (Andow et al. 2003; Ohio Karner Blue Butterfly Recovery Team 2005). The eggs laid by second brood females overwinter on the host plant wild blue lupine (lupine) (*Lupinus perennis*), on grasses, or on leaf litter and hatch the following spring. Ants tend the larvae protecting them from predators (Savignano 1990).

In addition to ants, lupine, light heterogeneity, and nectar resources have all been shown to be important for the Karner blue (Savignano 1990; Grundel et al. 1998; Lane & Andow 2003). Lupine is the Karner blue's sole larval host plant and is potentially threatened in Ohio (ODNR Division of Natural Areas and Preserves 2011). In Ohio, lupine generally flowers in mid-May and seed pods develop by mid-June (Grigore & Tramer 1996). The frosted elfin and Persius duskywing also use lupine, a legume and nitrogen fixer, as a host plant. While lupine grows best in full sun (Greenfield 1997), lupine nutritional quality (i.e. leaf nitrogen content) is greater in shade (Pickens & Root 2008). Karner blue females oviposit more frequently on lupine growing in moderate shade (especially during the second brood) and larval growth and survival is higher in partially shaded or closed canopies (Grundel et al. 1998; Lane & Andow 2003; Benjamins 2004). Open areas are important however, for adult feeding and mating; therefore, light heterogeneity is essential (Grundel et al. 1998). The Karner blue has been observed feeding from a variety of nectar plant species and studies have found that the Karner blue visits some species more frequently than others (Grundel & Pavlovic 2000). The Karner blue may be sensitive to the spatial distribution of lupine and nectar plants because of its somewhat limited mobility (Smith et al. 2002). The Karner blue rarely moves more than 0.1-0.2 km within a site, but when dispersing to other sites can travel between 0.5 and 2 km (Andow et al. 2003).

Research goals

To improve butterfly conservation in oak savanna this study sought to:

(1) Characterize and compare oak savanna sites.

Characterizing and comparing oak savanna sites with respect to factors known to be important for butterflies, such as nectar plant density, canopy cover, and vegetation height will give us a better understanding of variation across oak savanna. Determining existing levels of variation for these factors will help guide future management decisions. Some degree of heterogeneity among oak savanna sites is likely beneficial providing microclimates for butterflies and other taxa. We can also assess which sites may be suitable locations for the federally endangered Karner blue.

(2) Determine how butterflies utilize nectar resources in oak savanna.

Increased adult foraging has been noted in second brood Karner blues, possibly to compensate for lower host plant quality as larvae (Pickens & Root 2008). Therefore, we are especially interested in the availability of nectar resources during late summer corresponding to the timing of the Karner blue's second brood. Behavioral observations may lead to insights about preferred nectar species which are not known for most butterflies. Information about possible preferences could be integrated into management practices. Because access to sites currently occupied by the federally endangered Karner blue is often restricted by management agencies, butterflies of similar size (~3 cm wingspan) could possibly be used as surrogates for Karner blue behavior such as adult feeding. Other species specific knowledge that may emerge from behavioral studies is also extremely valuable.

(3) Assess the effects of management on oak savanna.

Management plays an important role in oak savanna restoration; however the effects on vegetation and butterflies are not clear. Understanding how management influences butterflies is essential for effective conservation. Restoration, which is often focused on the habitat requirements of the Karner blue, could potentially negatively impact other oak savanna species. A variety of management types may benefit the largest number of species and may create beneficial microclimates (Vogel et al. 2007).

More specifically, our research questions were:

(1) How do the measured factors vary across sites? Can these factors be used to predict nectar plant and butterfly richness?

(2) What is the density and species composition of nectar resources in late summer? Is there a preference for certain nectar species?

(3) How does management influence the measured factors? How does management influence nectar plant and butterfly richness?

We addressed these questions at four oak savanna sites in the Oak Openings Region by surveying vegetation, conducting opportunistic behavioral observations, and analyzing management data from local agencies. We expected sites with greater variation in canopy cover and elevation to have higher nectar plant richness. We also predicted that butterfly species richness would likely be explained by variation in canopy cover and elevation as well as nectar plant density. We expected certain nectar plant species to be preferred because of a greater nectar "reward" (e.g. increased quantity or quality of nectar). We also expected that sites which had been managed more frequently or more recently would have greater lupine and nectar plant densities, greater native nectar plant richness, decreased canopy cover, reduced vegetation heights and densities, and reduced leaf litter depths. Lastly, we predicted nectar plant and butterfly richness would be positively associated with more frequent management.

METHODS

Study sites

Four oak savanna sites within the Oak Openings Region in northwest Ohio were selected and delineated based on the extent of lupine. Patches of lupine <1 m^2 and greater than 10 m from the main area of lupine were excluded from the study site. The perimeter of each site was recorded with a GPS device (Garmin eTrex Vista). Sites 1 ("Mary's Savanna") and 2 ("Reed Road") were located within the Metroparks of the Toledo Area's Oak Openings Preserve (Fig. 2). Site 1 was approximately 0.63 ha in area and site 2 approximately 0.29 ha. These sites were about 1.5 km apart. Since 2007, the Karner blue has been reintroduced annually to Campbell Prairie in Oak Openings Preserve (Fig. 2). This occupied site is approximately 0.63 km from site

1 and 1.7 km from site 2. Sites 1 and 2 were the closest oak savanna sites to Campbell Prairie with large amounts of lupine. Based on dispersal data (Andow et al. 2003), Karner blues from Campbell Prairie could potentially reach sites 1 and 2. In 2008, a Karner blue was observed just west of Campbell Prairie (K. Menard, personal communication). Long term, a corridor has been proposed to facilitate butterfly movement from Campbell Prairie to northern portions of the preserve. The corridor would likely pass by site 2 (K. Menard, personal communication). Sites 3 (“Bowl”) and 4 (“Township”) were located at the Ohio Division of Wildlife’s Meilke Road Savanna Wildlife Area (Fig. 3). The western half of site 4 was located on property owned by Spencer Township. Site 3 was approximately 0.30 ha and site 4 was approximately 0.23 ha and these sites were about 0.16 km apart. The Karner blue was reintroduced into site 3 in July 2010 (the summer after this study took place). Butterflies including the Karner blue can likely move between sites 3 and 4. Sites 3 and 4 were approximately 12.45 km from sites 1 and 2.

Vegetation surveys

Parallel transects were set up running east-west (except site 1 which ran north-south) spaced 10 m apart. A 1 m^2 quadrat frame made of PVC piping was placed every 10 m along the transects. Quadrats falling within 3 m of the edge of the site were not sampled to avoid edge effects. The location of each quadrat was recorded using the GPS device. Because of differences in site size and shape, the number of quadrats sampled varied at each site (site 1-46, site 2-29, site 3-37, site 4-27). Each site was surveyed once between 16 July and 1 August 2009, corresponding to the timing of the Karner blue’s second brood in northwest Ohio (Andow et al. 2003; Ohio Karner Blue Butterfly Recovery Team 2005). Data from local, long-term butterfly monitoring transects suggest butterfly abundance and species richness peak near this time (Schaefer 2009).

Estimates of floral density and richness were taken at each quadrat. Consistent with previous studies (Tolson 1997; Chan & Laurence 2006; Pickens & Root 2009), the number of lupine stems (at each 1 m^2 quadrat) was counted instead of individual plants because it is difficult to determine individuals (Grigore & Tramer 1996; Andow et al. 2003). The number of flowering plant stems was also recorded at each 1 m^2 quadrat. Any plant with a flower was considered a possible nectar source and was counted. The species of each flowering plant stem was noted. Additionally, each site was thoroughly searched for flowering plant species which did not appear in the quadrats. These species were recorded to better estimate richness of the site. Local experts and field guides (Klein 1970; Newcomb 1977; Henn 1998) were used to identify plants either in the field or later using photographs.

To assess the spatial relationship between lupine and potential nectar resources, distance measurements between lupine and flowering plants were recorded. Two lupine plants were selected at diagonally opposite corners of each quadrat. These plants were most often located just outside the quadrat. By anchoring the end of a tape measure near the base of the lupine plant or having an assistant hold the tape measure over the center of the plant, we circled the plant at increasing radii until a flowering plant was located. The distance from the center of each lupine plant to the nearest flowering plant was recorded in meters and the two measurements were averaged (Fig. 4). Because of time limitations, if a flowering plant was not located within 5 m of the lupine plant, the search was terminated and 5 m was recorded as the distance. Occasionally, the nearest distance for both lupine plants was to the same flowering plant.

An estimate of canopy cover was obtained at each quadrat by placing a digital camera (Olympus C-7000 Zoom) with a level at the center of each quadrat and taking photographs of the canopy at heights of 0.5 and 1 m. Photos were then analyzed using ImageJ (Rasband 2009).

Each photo was converted to black and white pixels. Black pixels represented portions of the photo covered by vegetation and white pixels represented the open sky. The percentage of black pixels (number of black pixels divided by the total number of pixels) was calculated for each photo. This percentage was used as an estimate of canopy cover (Klingenbock et al. 2000). Photos that had areas overexposed by the sun required pre-processing before they could be converted to black and white pixels. To do this, the clone stamp tool in Photoshop (Adobe Photoshop 7.0) was used to fill in the overexposed areas with similar looking vegetation.

Other measurements taken at each quadrat included vegetation height and density, percent cover litter and bare ground, leaf litter depth, and elevation. Vegetation height was recorded in meters as the height of the tallest piece of vegetation in the understory within 1 m of the center of the quadrat. A Robel pole was used to determine vegetation density (Robel et al. 1970). The pole was placed at the center of the quadrat and an observer stood 3 m away at an eye-level height of 1.5 m. The lowest observable number on the pole was recorded to the nearest 0.5 dm. Two measurements were taken at each quadrat either in the north-south or east-west (site 2) directions and averaged. Photographs of each quadrat were taken and later analyzed using ImageJ (Rasband 2009) to determine percent cover of litter and bare ground. The freehand selection tool was used to select the area of interest (i.e. litter) and a mask was created converting all pixels to black (selected area of interest) or white (remaining pixels). The percentage of black pixels (number of black pixels divided by the total number of pixels) was calculated for each photo representing percent cover of either litter or bare ground. Leaf litter depth was determined by placing a thin wire into the litter, marking the height of the litter on the wire, and measuring the height with a ruler in centimeters. Two measurements were taken, at diagonally opposite corners of the quadrat and averaged. Lat/Lon to Elevation (Seitz 2009) was used to determine the elevation at each quadrat. The latitude and longitude coordinates taken at each quadrat were uploaded and used by a web service published by the United States Geological Survey to return ground surface elevation (Seitz 2009).

Behavioral observations

While visiting each site for vegetation surveys, opportunistic behavioral observations of butterflies were also performed. If a butterfly was located (any species) it was observed for a period of 15 minutes unless it left the site or was lost. After the first two observation periods, the protocol was changed and butterflies were instead observed for a period of 10 minutes. Behavior was recorded (resting, flying, or feeding) and timed in seconds. When a butterfly was observed feeding, the plant species on which it was feeding was recorded. All observations occurred between 1030 and 1830 EST when the temperature was greater than 17 C° in the shade and there was no precipitation. Butterflies were identified to species using field guides (Daniels 2004) and the help of local experts either in the field or later using photographs. While efforts were made to prevent individual butterflies from being observed twice, this possibility cannot be ruled out especially because sites were surveyed over the course of a few days and butterflies were not marked after observation.

Management history

Management history records were obtained from the Metroparks of the Toledo Area for sites 1 and 2 and from the Ohio Division of Wildlife for sites 3 and 4. Management activities which took place after the vegetation surveys and behavioral observations (i.e. after 1 August 2009) were not utilized. Records consisted of the approximate date and type of management activity at each site. Management activities were then grouped into 15 categories based on the type of management and time period in which the management occurred (i.e. number of burns from 1988-2009, number of mowing events from 2001-2009 etc.).

Statistical analysis

The data were non-normal; therefore, the non-parametric Kruskal-Wallis analysis of variance (ANOVA) test (SAS Institute 2009) was used to determine differences among sites for each of the measured factors. Significant results were followed by pairwise comparisons with Bonferroni correction to determine which sites differed (SAS Institute 2009). Variation in percent canopy cover and elevation was determined using the coefficient of variation ($SD/\bar{x}$). Canonical discriminant analysis (SAS Institute 2009) was also used to assess differences among sites based on the measured factors. Points were classified by the linear discriminate function. Spearman rank correlations (SAS Institute 2009) were used to determine if the measured factors were related to flowering plant or butterfly species richness. Finally, a Poisson regression (SAS Institute 2004) was used to determine if the measured factors could predict lupine stems, flowering plant stems, or the number of flowering plant species per 1 m^2. This type of regression was used because the dependent variables were count data. Based on a regular regression, we added variables and kept those which were significant.

Flowering plant density and the density of each of the flowering plant species in the quadrats were tested with a Kruskal-Wallis ANOVA to determine differences among sites (SAS Institute 2009). Significant results were followed by pairwise comparisons with Bonferroni correction to determine which sites differed (SAS Institute 2009). Sample size was insufficient to test the relationship between flowering plant species density and minutes feeding by butterflies.

Spearman rank correlations (SAS Institute 2009) were used to test for relationships between management and the measured factors and between management and nectar plant and butterfly richness. Each of the 15 management categories was tested with each of the measured factors as well as with both nectar plant and butterfly richness.

RESULTS

(1) How do the measured factors vary across sites? Can these factors be used to predict nectar plant and butterfly richness?

Sites differed greatly with respect to the measured factors. Each of the measured factors was significantly different among sites except for percent cover bare ground and leaf litter depth (Kruskal-Wallis ANOVA). Average lupine density (stems/1 m^2) was greatest at site 2 ($\bar{x}$ =27.97) followed by sites 3 ($\bar{x}$ =12.05); 4 ($\bar{x}$ =9.19); and 1 ($\bar{x}$ =7.07) (H =17.13, p =0.0007) (Fig. 5). Average flowering plant density (stems/1 m^2) was greatest at site 3 ($\bar{x}$ =0.65), followed by sites 2 ($\bar{x}$ =0.07); 4 ($\bar{x}$ =0.04); and 1 ($\bar{x}$ =0) (H =19.19, p =0.0002) (Fig. 6). Site 3 had the lowest average lupine-flowering plant distance (m) ($\bar{x}$ =1.07) followed by sites 2 ($\bar{x}$ =2.90); 4 ($\bar{x}$ =3.09); and 1 ($\bar{x}$ =4.06) (H =68.27, p <0.0001) (Fig. 7).

The smallest average percent canopy cover at a height of 1 m was at site 3 ($\bar{x}$ =29.48) followed by sites 2 ($\bar{x}$ =33.39); 4 ($\bar{x}$ =44.40); and 1 ($\bar{x}$ =50.41) (H =13.13, p =0.0044) (Fig. 8). Site 3 had the greatest variation in canopy cover (1.217), represented by the coefficient of variation, followed by sites 2 (1.073); 4 (0.595); and 1 (0.244). Similar percent cover and variation were observed at 0.5 m height.

The greatest average maximum vegetation height (m) was seen at site 1 ($\bar{x}$ =1.24) followed by sites 3 ($\bar{x}$ =0.95); 2 ($\bar{x}$ =0.84); and 4 ($\bar{x}$ =0.81) (H =21.88, p <0.0001) (Fig. 9). Average vegetation density (dm) was greatest at sites 1 ($\bar{x}$ =2.15) and 3 ($\bar{x}$ =2.11) followed by sites 4 ($\bar{x}$ =1.26) and 2 ($\bar{x}$ =0.76) (H =30.01, p <0.0001) (Fig. 10). Average percent cover of litter (per 1 m^2) was greatest at site 4 ($\bar{x}$ =21.54) followed by sites 2 ($\bar{x}$ =12.52); 1 ($\bar{x}$ =11.67); and 3 ($\bar{x}$ =10.97) (H =22.99, p <0.0001) (Fig. 11). Average percent cover of bare ground (per 1 m^2) was not significantly different among sites. Site 3 ($\bar{x}$ =14.84) had the highest percent cover of bare ground followed by sites 2 ($\bar{x}$ =5.68); 1 ($\bar{x}$ =2.58); and 4 ($\bar{x}$ =1.49) (Fig. 12). Average leaf litter depth (cm) also did not differ significantly among sites. Site 3 had the greatest average leaf litter depth ($\bar{x}$ =2.61) followed by sites 4 ($\bar{x}$ =2.52); 1 ($\bar{x}$ =2.40); and 2 ($\bar{x}$ =1.73) (Fig. 13). Average elevation (m) differed significantly among sites (H =68.22, p <0.0001) (Fig. 14). The greatest variation in elevation (represented by the coefficient of variation) was seen at site 3 (0.003) followed by sites 1 (0.002); 2 (0.001); and 4 (0.001).

In summary, site 1 had the lowest average lupine and flowering plant densities and the largest average lupine-flowering plant distance. This site also had the highest average percent canopy cover and the smallest average elevation. Site 2 had the highest average lupine density. Site 3 had the highest average flowering plant density, lowest average lupine-flowering plant distance, and the smallest average percent canopy cover. It also had the greatest variation in percent canopy cover and elevation. Lastly, site 4 had the highest average percent cover of litter.

The canonical plot from the canonical discriminant analysis provided a visual representation of the variation among sites based on the measured factors (Fig. 15). Twenty of the 139 points were misclassified by the linear discriminate function. Based on this analysis, sites 2 and 4 were most similar.

Site 4 had the highest flowering plant richness (9) followed by sites 3 (8); 2 (7); and 1 (6) (Table 1). Site 4 also had the greatest butterfly richness (7) followed by sites 2 (6); 3 (5); and 1 (4) (Table 1). Spearman rank correlations did not demonstrate a relationship between any of the measured factors and flowering plant richness. However, butterfly richness was negatively correlated with average maximum vegetation height (r =-1) and positively correlated with average elevation (r =1). While *p* values were <0.0001, they are suspect because of the small sample size (N =4).

The final Poisson regression model for lupine stems (i.e. lupine density) contained seven variables (measured factors) including elevation, lupine-flowering plant distance, percent cover of litter, percent cover of bare ground, vegetation density, flowering plant richness, and leaf litter depth (Table 2). The models for flowering plant stems and flowering plant richness both contained only one variable (lupine-flowering plant distance) (Table 2).

(2) What is the density and species composition of nectar resources in late summer? Is there a preference for certain nectar species?

Average flowering plant density (stems/1 m^2) was significantly different among sites (Kruskal-Wallis ANOVA, H =19.19, *p* =0.0002). Density was greatest at site 3 ($\bar{x}$ =0.65), followed by sites 2 ($\bar{x}$ =0.07); 4 ($\bar{x}$ =0.04); and 1 ($\bar{x}$ =0) (Fig. 6). Seventeen total species were recorded across all sites including one state potentially threatened, three state threatened, and two non-native species (Table 1). Flowering spurge (*Euphorbia corollata*) was the only species present at all four sites. In addition, the average density (stems/1 m^2) of only one species, woodland sunflower (*Helianthus divaricatus*), was significantly different among sites, ranging from 0 at sites 1 and 2 to 0.46 at site 3 (Kruskal-Wallis ANOVA, H =16.67, *p* =0.0008).

Fifteen of the 17 species recorded are either listed as a nectar source in the Karner Blue Butterfly Federal Recovery Plan (Andow et al. 2003) or were observed as nectar sources in a local study (Pickens 2006). Hairy hawkweed (*Hieracium gronovii*) and scaly blazing star (*Liatris squarrosa*) were the two species not documented as nectar sources however; very similar species such as orange hawkweed (*Hieracium aurantiacum*), mouse ear hawkweed (*Hieracium pilosella*), rough blazing star (*Liatris aspera*), and dwarf blazing star (*Liatris cylindracea*) are listed in the federal recovery plan.

Thirty-five behavioral observations were conducted across sites totaling approximately 238 minutes. Eleven observations included feeding for a total of 54 minutes (23% of total minutes observed). Butterflies were observed feeding from three species: flowering spurge, scaly blazing star, and butterfly weed (*Asclepias tuberosa*) (Table 3). Fourteen to 16 butterfly species were represented in the behavioral observations (two individuals could not be identified to the species level) with five to six species observed feeding (Table 4). Site 4 had the greatest butterfly species richness (7) followed by sites 2 (6); 3 (5); and 1 (4).

A preference for certain nectar species may exist because butterflies frequently fed on species that had lower densities than other available flowering plants. No feeding was observed at site 1. At site 2, orange sulfur (*Colias eurytheme*) was observed feeding from flowering spurge for 4.45 minutes and orange sulfur, wild indigo duskywing (*Erynnis baptisiae*), and spicebush swallowtail (*Papilio troilus*) were observed feeding from scaly blazing star for a total of 20.88 minutes. Because neither of these two flowering plant species was recorded within the quadrats during the vegetation surveys, they are presumed to have a very low density (Table 3). At site 3, monarch (*Danaus plexippus*), spicebush swallowtail, and great spangled fritillary (*Speyeria cybele*) were observed feeding from butterfly weed for a total of 16.78 minutes. At this site, butterfly weed and early goldenrod (*Solidago juncea*) had the lowest densities ($\bar{x}$ =0.05 stems/1 m^2) of the four total species recorded in the quadrats (Table 3). At site 4, butterflies (orange sulfur or clouded sulfur (*Colias philodice*) and great spangled fritillary) fed from butterfly weed, which had a very low density (not sampled in quadrats), for a total of 12 minutes.

Across sites, different butterfly species fed from the same flowering plant species most notably butterfly weed and scaly blazing star (Table 4). Butterfly weed was available at site 2 (presumably at a very low density) but was not fed upon.

(3) How does management influence the measured factors? How does management influence nectar plant and butterfly richness?

Each of the four study sites was actively managed (Table 5). Site 1 had been managed for the longest period of time (since 1988). Prescribed fire played a dominant role at this site especially in the early years of management. In the past decade, seeding of native plants and woody species removal (i.e. mechanical and/or chemical methods used to remove woody plants) became more frequent. Site 1 had been mowed once. Site 2 had been managed since 2001. Seeding of native plants as well as woody species removal were the most common management practices. This site was also mowed once. Management records obtained for sites 3 and 4 were not spatially detailed enough to separate the data between the two sites. Sites 3 and 4 had been managed since 1996. Management consisted primarily of woody species removal and more recently, prescribed fire. Two burns had occurred, one in 2006 and one in 2007. No significant relationships were found between management and the measured factors or between management and nectar plant and butterfly richness (Spearman rank correlations).

DISCUSSION

Based on our knowledge of quality butterfly habitat, site 3 was the most suitable site overall followed closely by site 2. Site 4 was the next best site followed by site 1. Site 3 had the highest flowering plant density and the second highest lupine density. Based on previous studies, all sites had moderate to high lupine densities but flowering plant densities were low (Tolson 1997; Chan & Laurence 2006). Site 3 also had the greatest variation in canopy cover and elevation. Overall, sites with a more heterogeneous canopy (and sites with a more open canopy) had a higher density of both lupine and flowering plants. At site 3, lupine and flowering plants were found across a sun-shade gradient which is important for the Karner blue and other butterflies (Grundel et al. 1998; Lane & Andow 2003; Albanese et al. 2008). Site 3 may have had the highest quality lupine based on a study by Pickens and Root (2008), which demonstrated that lupine quality during the Karner blue's second brood was primarily explained by herbaceous vegetation density. On average, the sites in this study had similar (or slightly higher) vegetation densities compared to the occupied Karner sites in the study by Pickens and Root (2008). Lupine and flowering plant densities at site 3 may have been reduced by an illegal off-road vehicle trail which ran though the site.

While sites 3 and 2 were the most suitable based on the measured factors, they did not correspond to the greatest butterfly or flowering plant species richness. Both sites were lower in richness than site 4 (which had the highest butterfly and flowering plant richness) but higher than site 1. Our analysis suggested butterfly richness was negatively correlated with vegetation height. Tall grasses may restrict the occupation of a site by forbs. Elevation was positively correlated with butterfly richness and was important in predicting the number of lupine stems/1 m^2. Butterfly richness has been positively related to nectar plant richness (Kumar et al. 2009) and our findings loosely follow that trend (Table 1). Sites 2 and 4 had the most similar butterfly species composition among sites. These two sites were also the most similar based on the measured factors (Fig. 15) indicating a possible link between the measured factors and species composition.

The measured factors varied (often significantly) across sites. While some factors such as flowering plant density should be improved, as long as factors are within favorable ranges, this type of heterogeneity creates important microclimates for butterflies. Butterflies are highly sensitive to both daily and seasonal changes in climate; therefore, their ability to move to more favorable sites greatly increases their chance for success (Oliver et al. 2010). In northwest Ohio, it is often difficult to determine exactly what a restored oak savanna site should resemble. Variation among sites should be maintained because it likely benefits not only butterflies but biodiversity as a whole. Variation in the type of habitat can also create microclimates. As a result of more extreme changes in climate, oak savanna butterflies may seek out different habitat types altogether. Because the Oak Openings Region is a mosaic of different habitat types it may be particularly well suited to buffer these changes resulting in more stable butterfly populations (Oliver et al. 2010).

In order for oak savanna butterflies to seek out more favorable conditions at other sites, they must be able to reach the sites. In the Oak Openings Region it is critical to consider how suitable butterfly habitat is connected within and between protected areas. In human-dominated landscapes (such as the Oak Openings) the inclusion of residential, commercial, industrial, and agricultural land in land restoration and management may be necessary to ensure links between protected areas (Van Dyck et al. 2009). Because the region is highly fragmented, increasing the area of existing protected areas is not always possible. Providing connections between protected areas may be the best way to increase the amount of available oak savanna habitat.

Sufficient nectar resources may not have been available at these four sites in late summer. Average flowering plant density (stems/1 m^2) ranged from 0 to 0.65 and differed significantly among sites. Site 3 had the greatest density ($\bar{x}$ =0.65) followed by sites 2 ($\bar{x}$ =0.07); 4 ($\bar{x}$ =0.04); and 1 ($\bar{x}$ =0) (Fig. 6). These values were low compared to a previous study by Tolson (1997) which was conducted to evaluate potential reintroduction sites for the Karner blue in northwest

Ohio (Fig. 16). In Tolson's study, each of the three sites surveyed at the donor location (Allegan State Game Area, Allegan, Michigan) had reproducing populations of the Karner blue. The average density of flowering plants at these sites ranged from 0.07 to 0.98 stems/1 m^2. The five potential reintroduction sites surveyed in the Oak Openings Region (Kitty Todd Nature Preserve) had average densities ranging from 0.27 to 3.00 stems/1 m^2. One site had formerly supported populations of the Karner blue and two supported populations of the frosted elfin and Persius duskywing (at the time of the study). The average flowering plant densities at these sites were 0.70; 0.27; and 2.42 stems/1 m^2 respectively. Based on Tolson's study, site 3 may have been the only site with sufficient nectar resources during the time of the Karner blue's second brood. These findings support the decision to reintroduce the Karner blue to site 3 in July 2010 (the summer after this study took place).

Nectar resources are dynamic and vary across time and space as well as within and across years. Global climate change may also be starting to alter the distribution of nectar resources. However, this study did demonstrate the importance of scaly blazing star and butterfly weed for many butterfly species in late summer. While butterflies are somewhat opportunistic in their feeding behaviors, declines in these two species without a corresponding increase in other species with similar nectar rewards may result in a decrease in butterfly abundance. Measurements of nectar volume, composition, and concentration etc. are also important to better understand preference. In addition, flower morphology plays a role in limiting butterfly foraging from certain nectar species. Smaller butterflies, such as the Karner blue, generally have shorter tongues and may not be able to access nectar from flowers with deep corollas (Corbet 2000; Tiple et al. 2009).

Previous studies have suggested that butterfly weed may be an important nectar source for the Karner blue. Grundel and Pavlovic (2000) concluded that Karner blues most frequently chose a suite of nectar species including lyre-leaved rock-cress (*Arabis lyrata*), lanceleaf coreopsis (*Coreopsis lanceolata*), flowering spurge, white sweet clover (*Melilotus alba*), spotted bee balm (*Monarda punctata*), common cinquefoil (*Potentilla simplex*), *Rubus* spp., showy goldenrod (*Solidago speciosa*), and possibly butterfly weed and woodland sunflower. While numerous studies have identified nectar species that are visited frequently by the Karner blue, frequency of use may not indicate a preference. Butterflies may simply be utilizing certain resources more often because they are abundant. In order to quantify preference, the density of each nectar species must be measured. A study by Savanick (2005) in Wisconsin took into account both the number of butterfly feeding visits and flower species abundance and found that second brood Karner blues exhibited a preference for butterfly weed, leadplant (*Amorpha canescens*), whorled milkweed (*Asclepias verticillata*), western sunflower (*Helianthus occidentalis*), and spotted bee balm. Of the species listed above, flowering spurge, butterfly weed, and woodland sunflower were the only species observed (in flower) at our four sites, however, all of the species except for leadplant are found in the Oak Openings Region (The Nature Conservancy 2008; ODNR Division of Wildlife 2009).

Behavioral studies such as those identifying preferred nectar species are critically important to improve butterfly conservation efforts. Behavioral studies provide insight into important species specific information including possible preferences as well as basic resource requirements (Dennis et al. 2006). Turlure et al. (2009) found that two co-occurring glacial relict butterfly species which share the same biotope and host plant have different ecological requirements related to differences in life history and behavioral traits such as egg-laying strategies. While much attention is often given to the Karner blue, it is also important to learn more about the specific requirements of other oak savanna butterflies in order to successfully conserve the biodiversity of this unique community.

Few conclusions can be made about how management influenced the vegetation or the butterflies themselves. This can partially be attributed to the small sample size (four total sites) but may also be the result of the lack of spatial detail in the management records. A prescribed fire may have been recorded for a site but the fire may not have moved through the entire site (fires can be patchy). Or, if woody species removal occurred, it was hard to determine from the records whether removal was in a certain area of the site or uniformly across the site. This information would help us better understand how management influences vegetation and the general ecology and population trends of butterflies (Schultz et al. 2008).

Kuntz (2009) found a positive correlation between burns and proportion of closed canopy and a negative correlation between mowing and proportion of closed canopy. This suggests burns may promote woody growth while mowing reduces canopy cover. It may also suggest that burns are used at sites with high canopy cover and mowing is used at sites with less canopy cover. Number of burns has also been positively correlated with the number of oak saplings (Plenzler 2008). Negative correlations between total number of management events and litter depth and between number of burns and litter depth have also been found (Plenzler 2008).

Based on previous studies, different management practices result in compositionally different butterfly communities and different practices benefit different species (Smallidge & Leopold 1997; Swengel & Swengel 2001; Vogel et al. 2007). Butterfly richness and abundance have been shown to decrease with recent burning (Kwilosz & Knutson 1999; Swengel & Swengel 2001; Vogel et al. 2010). Fewer Karner blues were present in recently burned areas compared to unburned areas; however, burned areas were recolonized quickly (Kwilosz & Knutson 1999; Pickens & Root 2009). Karner blue abundance has also been negatively correlated with the number of years since last management activity (Smallidge et al. 1996) and Karner blue females have been shown to avoid reproduction in management units unburned for more than four years (Pickens & Root 2009). As a result, assessing the effects of management on butterflies is critical and may be especially important for at risk species (Schultz et al. 2008).

To better understand possible nectar preferences, future studies should include more butterfly observations. The location of each observation should also be recorded with a GPS device. This spatial information will allow us to better understand how butterflies are interacting with their environment and how behavior relates to the other measured factors used to characterize a site. Estimates of butterfly abundance may also be helpful to understand how the measured factors affect butterfly populations. If flowering plant densities are low, more frequent vegetation sampling (i.e. every 5 m along the transect instead of every 10) may be necessary to better capture the density of each species. Lastly, if possible, more sites should be evaluated.

CONSERVATION RECOMMENDATIONS

To improve butterfly conservation efforts, managers should continue to work to increase nectar plant densities during late summer at each of the four sites. Other oak savanna sites should be evaluated to determine if sufficient nectar resources are available. These nectar resources are especially important for the Karner blue during the second brood when foraging increases. Managing for a more open, heterogeneous canopy may increase both nectar plant and lupine densities. Increasing densities of scaly blazing star and butterfly weed through seeding or plantings may especially benefit butterfly populations and is a relatively simple management practice to implement. Including preferred nectar species in site assessments and monitoring may also be beneficial. Additional behavioral studies are needed to further investigate which nectar species are preferred and how different butterfly species interact with their environment. Vegetation surveys are also important to link butterfly species to particular habitat characteristics and to assess the effects of management and climate change on butterflies.

In order to better assess the effects of management on butterflies and their habitat, management records should be improved through the use of precise GPS devices. Using a GPS device, the area within a site that received a treatment can be recorded and then viewed in ArcMap (or a similar GIS program). With an easily accessible spatial record of management, both managers and researchers can determine if their study plots, transects, location of behavioral studies etc. actually received a recorded management treatment. This information will help us better understand the outcome of our management practices and will allow us to make adjustments as necessary.

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Vogel, J. A., R. R. Koford, and D. M. Debinski. 2010. Direct and indirect responses of tallgrass prairie butterflies to prescribed burning. Journal of Insect Conservation **14:**663-677.

FIGURES

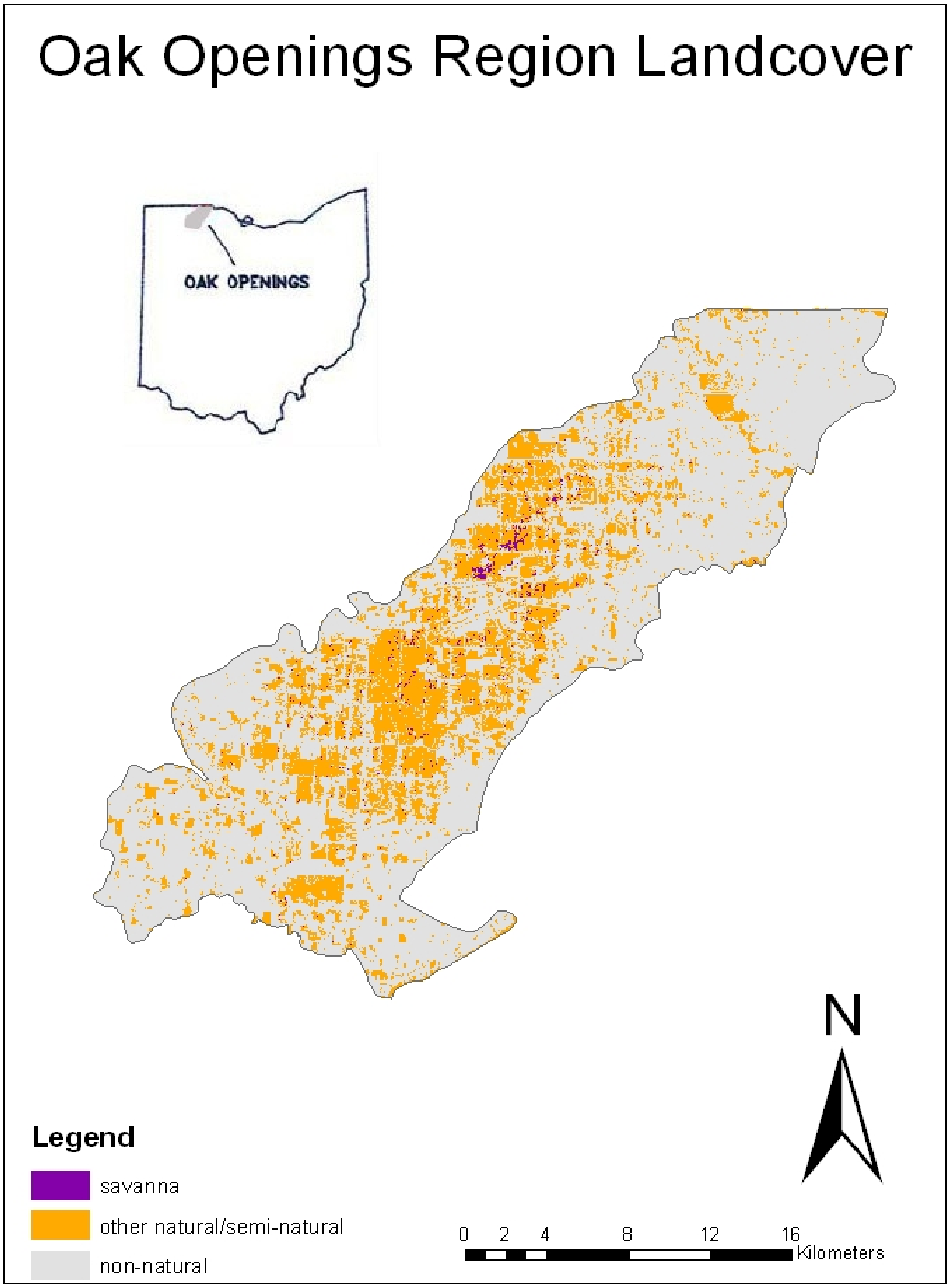

Figure 1. Map of northwest Ohio's Oak Openings Region landcover (Schetter & Root 2011). Natural and semi-natural areas including oak savanna make up approximately 25% of the region. Oak savanna was historically dominant but now covers <2 km^2 as a result of fire suppression and changes in land use.

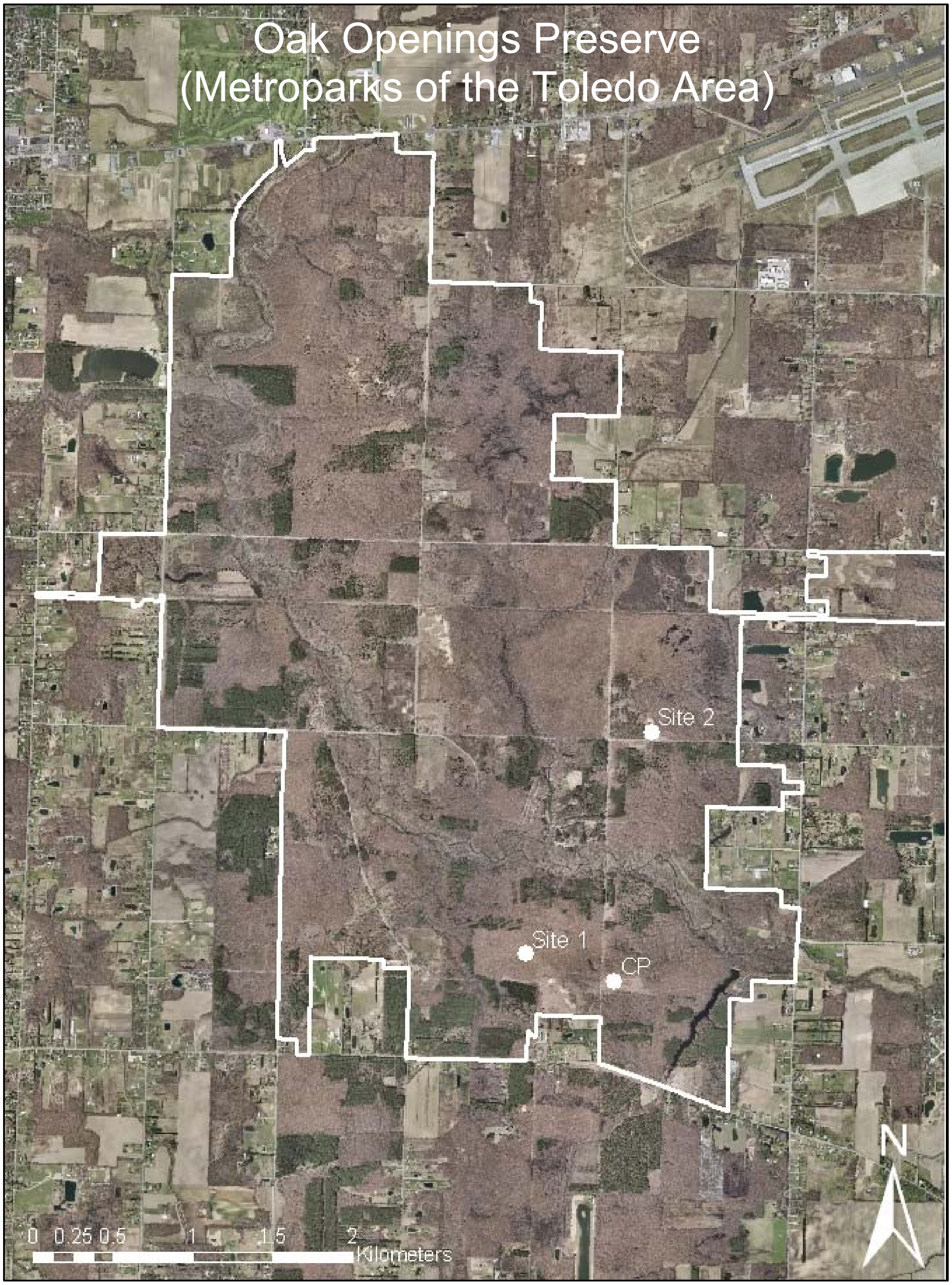

Figure 2. Metroparks of the Toledo Area's Oak Openings Preserve (outlined in white). Study sites 1 and 2 are indicated on map. Campbell Prairie ("CP") a site currently occupied by Karner blue butterflies is also noted.

Figure 3. Ohio Division of Wildlife's Meilke Road Savanna Wildlife Area (outlined in white). Study sites 3 and 4 are indicated on map. Karner blue butterflies were reintroduced into site 3 in July 2010 (the summer after this study took place).

Figure 4. Photo illustrating lupine-nectar distance measurement methodology. To assess the spatial relationship between lupine and potential nectar sources a tape measure was anchored near the base of a lupine plant at the corner of the quadrat. We then circled the plant at increasing radii until a flowering plant was located. The distance from the lupine plant to the flowering plant was recorded in meters.

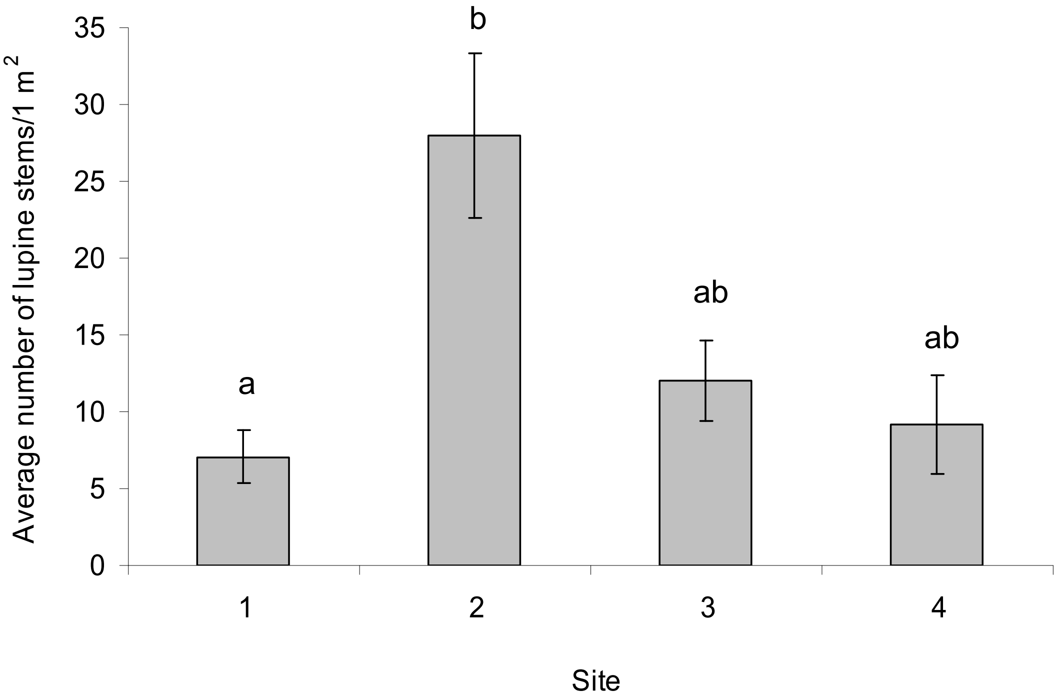

Figure 5. Average number of lupine stems/1 m^2 at each site. Error bars represent SE. Sites are significantly different (Kruskal-Wallis ANOVA, H =17.13, *p* =0.0007). Letters indicate homogenous groups determined by follow-up pairwise comparisons (*p* <0.0001).

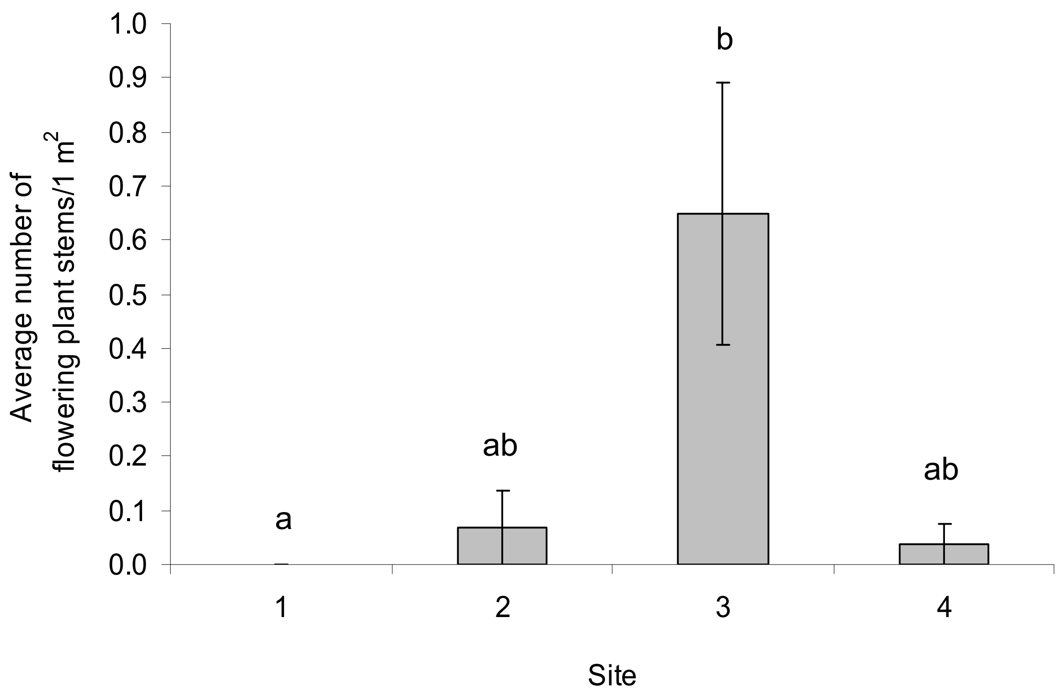

Figure 6. Average number of flowering plant stems/1 m^2 at each site. Error bars represent SE. Sites are significantly different (Kruskal-Wallis ANOVA, H =19.19, *p* =0.0002). Letters indicate homogenous groups determined by follow-up pairwise comparisons (*p* <0.05).

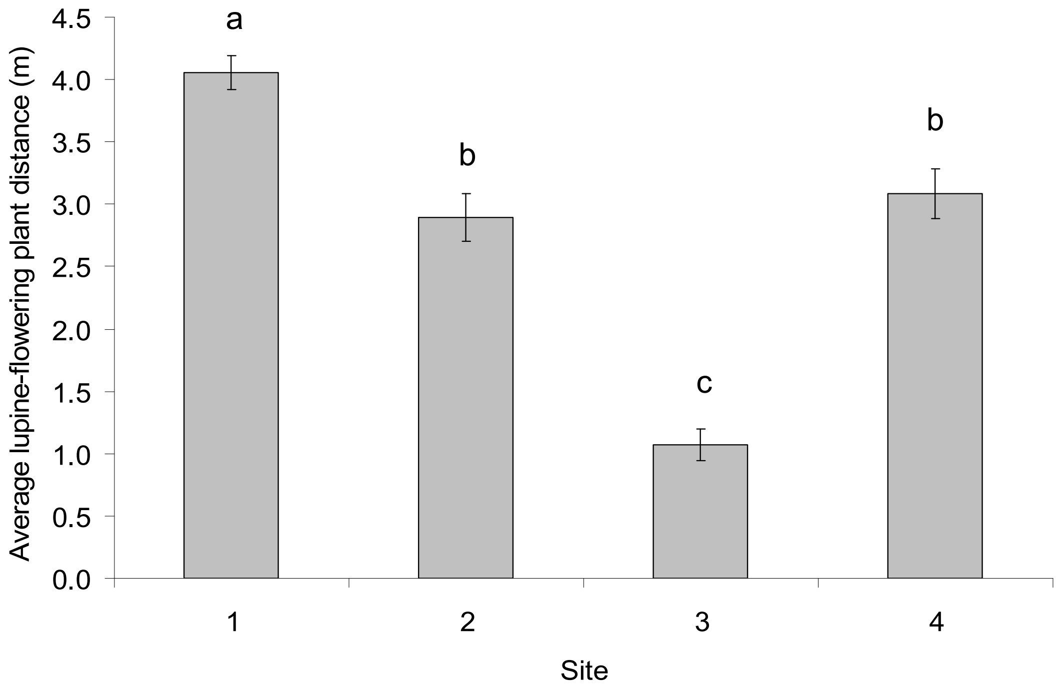

Figure 7. Average lupine-flowering plant distance (m) at each site. Error bars represent SE. Sites are significantly different (Kruskal-Wallis ANOVA, H =68.27, p <0.0001). Letters indicate homogenous groups determined by follow-up pairwise comparisons (p <0.05).

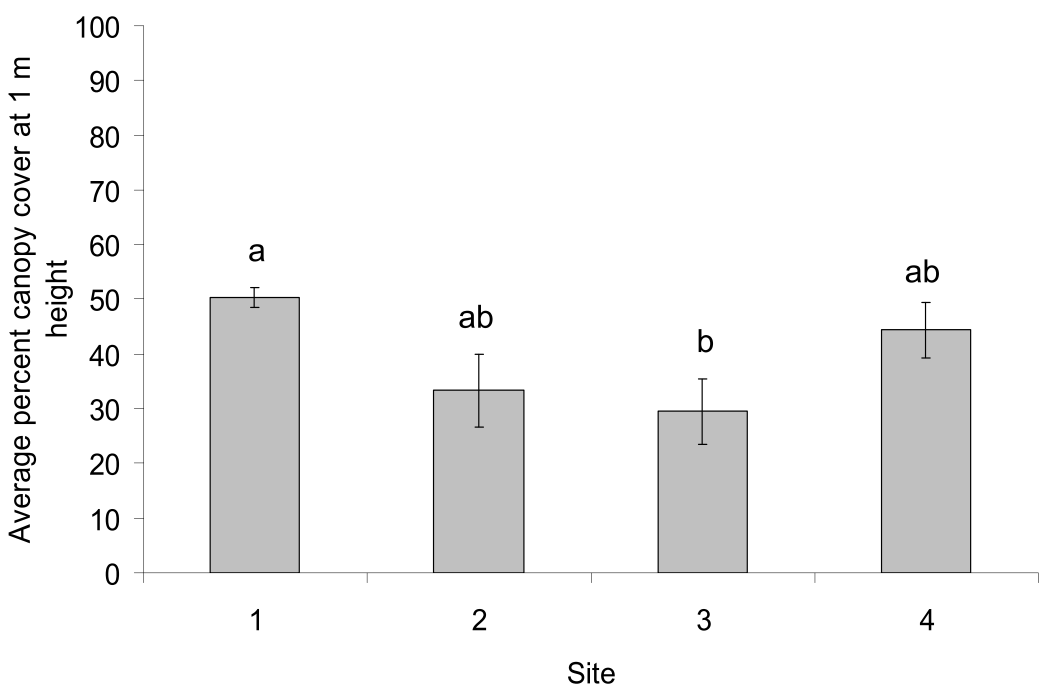

Figure 8. Average percent canopy cover at 1 m height at each site. Error bars represent SE. Sites are significantly different (Kruskal-Wallis ANOVA, H =13.13, p =0.0044). Letters indicate homogenous groups determined by follow-up pairwise comparisons (p <0.05).

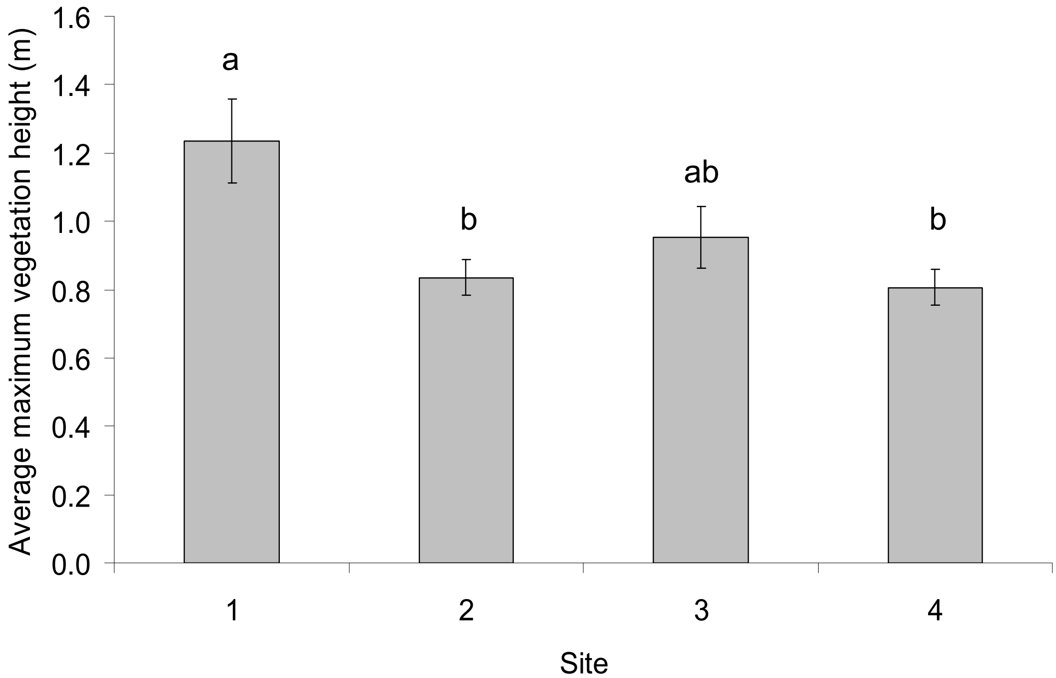

Figure 9. Average maximum vegetation height (m) at each site. Error bars represent SE. Sites are significantly different (Kruskal-Wallis ANOVA, H =21.88, p <0.0001). Letters indicate homogenous groups determined by follow-up pairwise comparisons (p <0.0001).

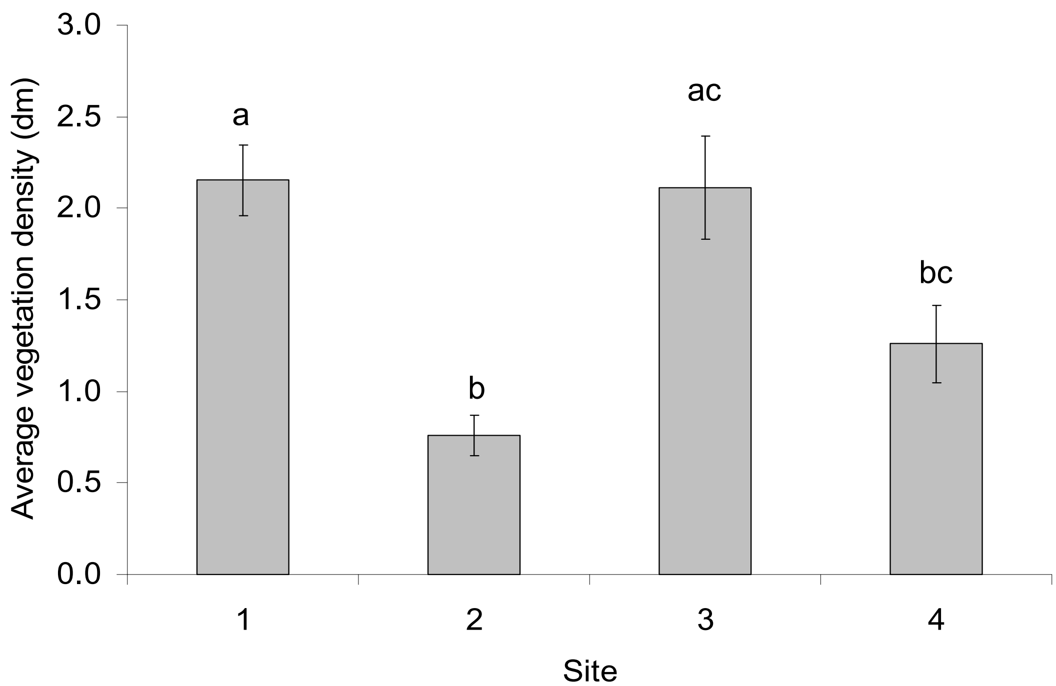

Figure 10. Average vegetation density (dm) at each site. Error bars represent SE. Sites are significantly different (Kruskal-Wallis ANOVA, H =30.01, p <0.0001). Letters indicate homogenous groups determined by follow-up pairwise comparisons (p <0.05).

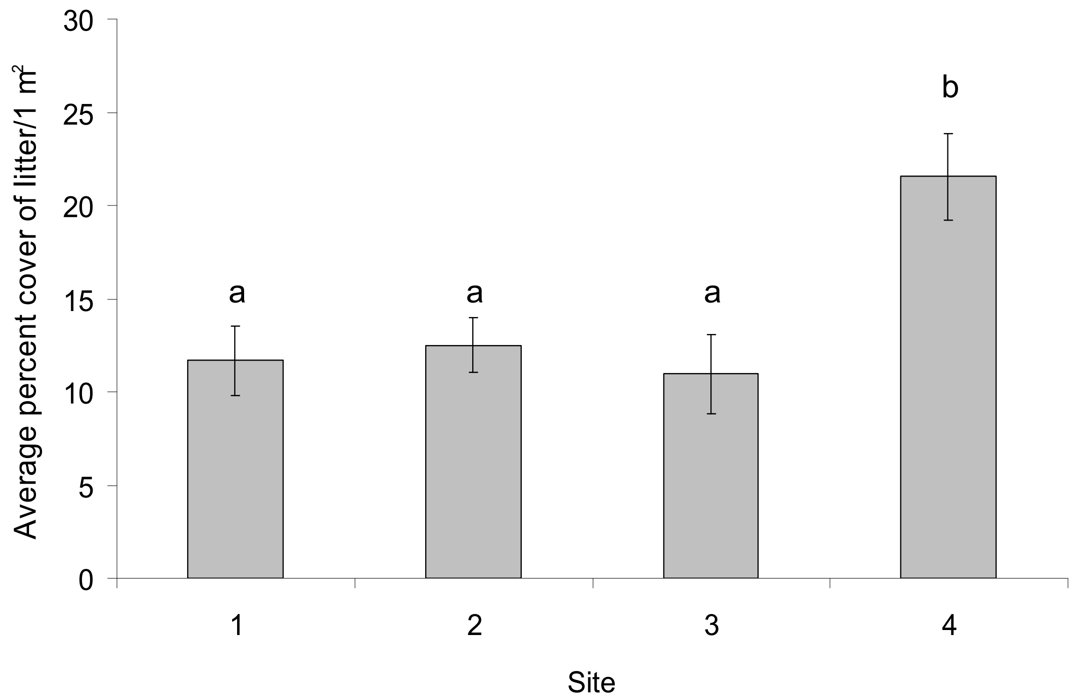

Figure 11. Average percent cover of litter/1 m^2 at each site. Error bars represent SE. Sites are significantly different (Kruskal-Wallis ANOVA, H =22.99, p <0.0001). Letters indicate homogenous groups determined by follow-up pairwise comparisons (p <0.05).

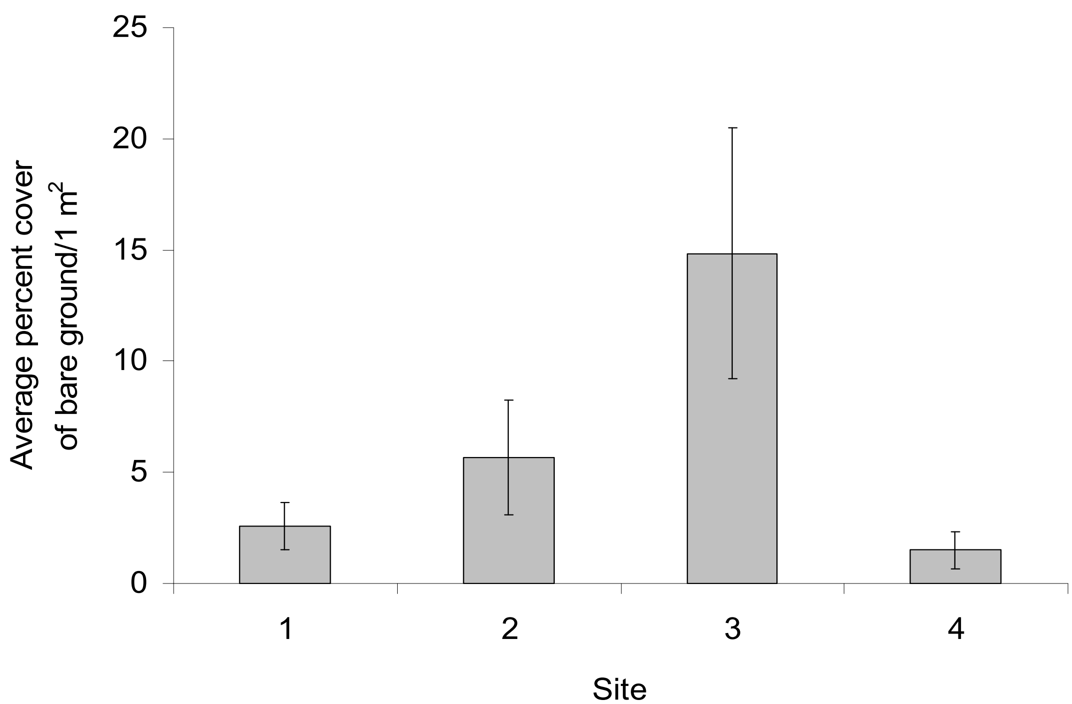

Figure 12. Average percent cover of bare ground/1 m^2 at each site. Error bars represent SE.

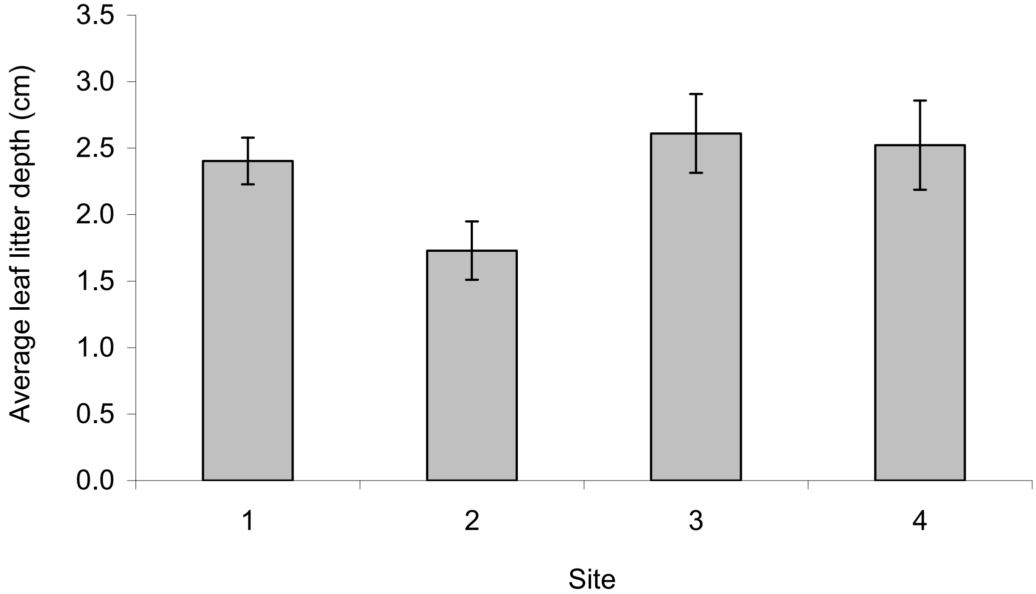

Figure 13. Average leaf litter depth (cm) at each site. Error bars represent SE.

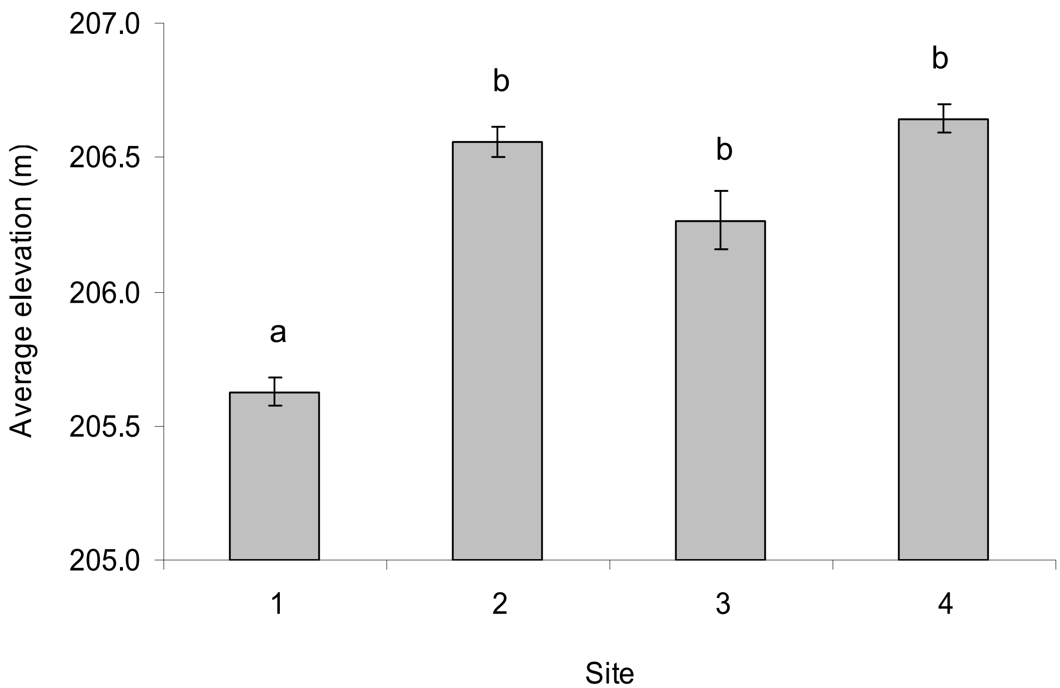

Figure 14. Average elevation (m) at each site. Error bars represent SE. Sites are significantly different (Kruskal-Wallis ANOVA, H =68.22, p <0.0001). Letters indicate homogenous groups determined by follow-up pairwise comparisons (p <0.0001).

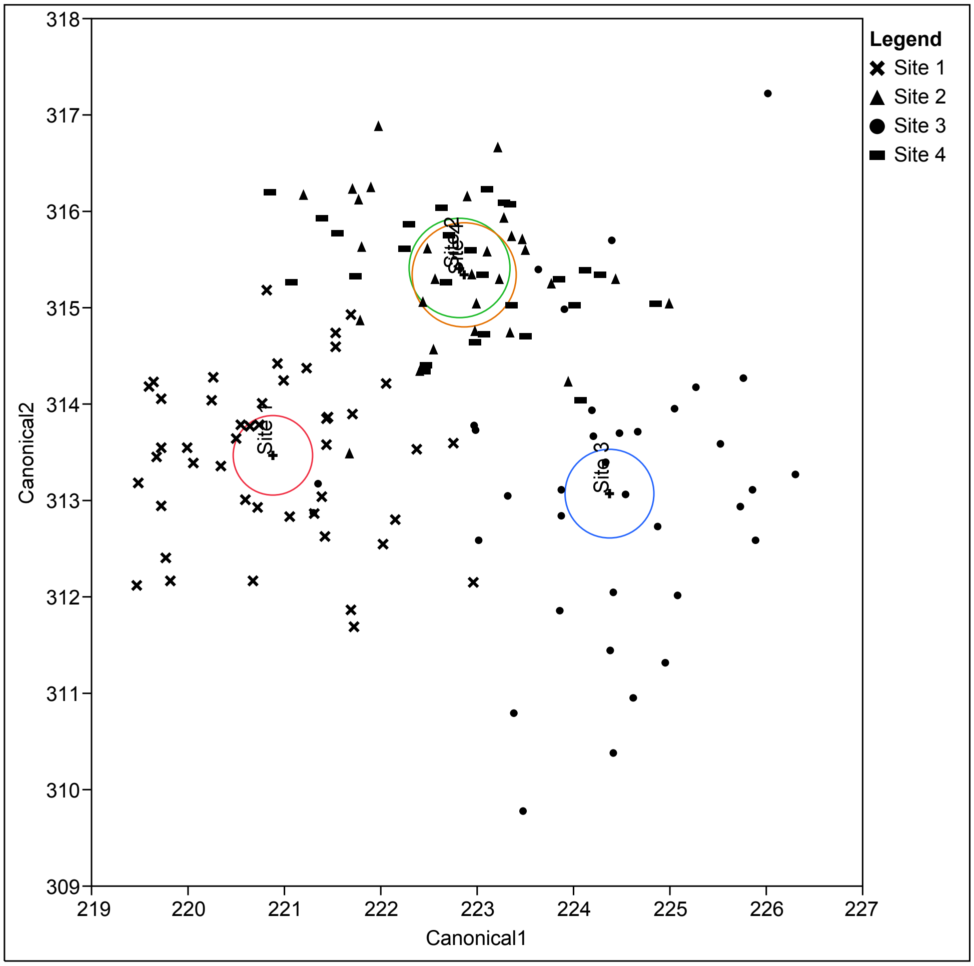

Figure 15. Canonical plot summarizing variation among sites based on the measured factors at each 1 m^2 quadrat. Measured factors include number of lupine stems, number of flowering plant stems, flowering plant richness, lupine-flowering plant distance (m), percent canopy cover at 0.5 and 1 m heights, vegetation height (m), vegetation density (dm), percent cover of litter, percent cover of bare ground, leaf litter depth (cm), and elevation (m). Each multivariate mean is surrounded by a 95% confidence circle. Twenty of the 139 points were misclassified by the linear discriminate function.

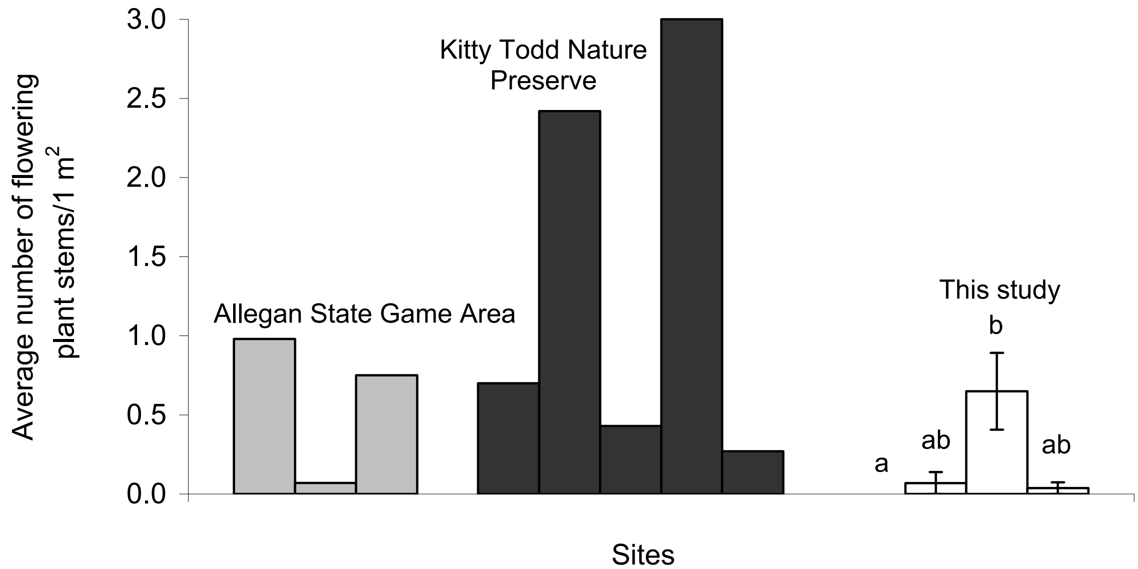

Figure 16. Average number of flowering plant stems/1 m^2 at several sites. Data from the Allegan State Game Area in Allegan, Michigan and the Kitty Todd Nature Preserve in the Oak Openings Region were collected to evaluate potential reintroduction sites for the Karner blue butterfly in northwest Ohio (Tolson 1997). For this study, error bars represent SE. Sites are significantly different (Kruskal-Wallis ANOVA, H =19.19, p =0.0002). Letters indicate homogenous groups determined by follow-up pairwise comparisons (p <0.05).

TABLES

Table 1. Flowering plant and butterfly species richness at each site.

Site	*Flowering plant*		*Butterfly*	
	Scientific name	Common name	Scientific name	Common name
1	*Baptisia tinctoria*	wild indigo	*Danaus plexippus*	monarch
	Euphorbia corollata	flowering spurge	*Everes comyntas*	eastern tailed-blue
	Helianthus divaricatus	woodland sunflower	*Megisto cymela*	little wood satyr
	Hieracium gronovii	hairy hawkweed	*Satyrium liparops*	striped hairstreak
	Lithospermum caroliniense[a]	hairy puccoon	total species 4	
	Tephrosia virginiana	goat's rue		
	total species 6			
2	*Achillea millefolium*	common yarrow	*Colias eurytheme*	orange sulfur
	Asclepias tuberosa	butterfly weed	*Erynnis baptisiae*	wild indigo duskywing
	Erigeron strigosus	lesser daisy fleabane	*Lycaena phlaeas*	American copper
	Euphorbia corollata	flowering spurge	*Megisto cymela*	little wood satyr
	Krigia virginica[a]	dwarf dandelion	*Papilio troilus*	spicebush swallowtail
	Liatris squarrosa[b]	scaly blazing star	*Vanessa virginiensis*	American lady
	Polygala polygama[a]	racemed milkwort	total species 6	
	total species 7			
3	*Asclepias tuberosa*	butterfly weed	*Danaus plexippus*	monarch
	Baptisia tinctoria	wild indigo	*Erynnis horatius* or *Erynnis baptisiae*	Horace's or wild indigo duskywing
	Coreopsis tripteris	tall coreopsis	*Papilio cresphontes*	giant swallowtail
	Erigeron strigosus	lesser daisy fleabane	*Papilio troilus*	spicebush swallowtail
	Euphorbia corollata	flowering spurge	*Speyeria cybele*	great spangled fritillary
	Helianthus divaricatus	woodland sunflower	total species 5	
	Saponaria officinalis[c]	soapwort		
	Solidago juncea	early goldenrod		
	total species 8			
4	*Asclepias tuberosa*	butterfly weed	*Celastrina neglecta*	summer azure
	Erigeron strigosus	lesser daisy fleabane	*Colias eurytheme* or *Colias philodice*	orange or clouded sulfur
	Euphorbia corollata	flowering spurge	*Erynnis baptisiae*	wild indigo duskywing
	Helianthus divaricatus	woodland sunflower	*Megisto cymela*	little wood satyr
	Hieracium gronovii	hairy hawkweed	*Satyrium titus*	coral hairstreak
	Hypericum perforatum[c]	St. John's wort	*Skipper* sp.	—
	Polygala polygama[a]	racemed milkwort	*Speyeria cybele*	great spangled fritillary
	Rosa carolina	pasture rose	total species 7	
	Solidago juncea	early goldenrod		
	total species 9			

[a]*State threatened (Ohio)*, [b]*Potentially threatened (Ohio)*, [c]*Non-native*

Table 2. Summary of explanatory variables' influence on lupine stems (lupine stems/1 m^2), flowering plant stems (flowering plant stems/1 m^2), and flowering plant richness (number of flowering plant species/1 m^2) resulting from a Poisson regression analysis. Significant variables are elevation (m), lupine-flowering plant distance (m) (distance), percent cover of litter (cover litter), percent cover of bare ground (cover bare), vegetation density (dm) (veg density), and leaf litter depth (litter depth). e^b is a multiplicative factor by which the presence of the variable increases lupine stems, flowering plant stems, or flowering plant richness. For example, for each unit increase in elevation, number of lupine stems is multiplied by $e^{0.4137}$ or 1.512.

Variable	*b*	*SE*	*df*	*Wald* X^2	*p*
Lupine stems					
elevation	0.4137	0.042	1	97.23	<0.0001
distance	-0.1958	0.018	1	118.36	<0.0001
cover litter	0.0076	0.0021	1	13.14	0.0003
cover bare	-0.0448	0.005	1	80.03	<0.0001
veg density	-0.1205	0.0229	1	27.62	<0.0001
flowering plant richness	-0.2622	0.0673	1	15.18	<0.0001
litter depth	-0.0736	0.0176	1	17.51	<0.0001
Flowering plant stems					
distance	-4.1188	0.7322	1	31.65	<0.0001
Flowering plant richness					
distance	-3.4138	0.8335	1	16.78	<0.0001

Table 3. Butterfly feeding at each site by flowering plant species. A dash (—) indicates the species was found within the site but was never sampled in a quadrat therefore density cannot be reported.

Site	*Flowering plant species*		*Minutes feeding*	*% total feeding*	*Density (stems/1 m^2)*
	Scientific name	Common name			
1	*Baptisia tinctoria*	wild indigo	0		—
	Euphorbia corollata	flowering spurge	0		—
	Helianthus divaricatus	woodland sunflower	0		—
	Hieracium gronovii	hairy hawkweed	0		—
	Lithospermum caroliniense[a]	hairy puccoon	0		—
	Tephrosia virginiana	goat's rue	0		—
	total species 6				
2	*Achillea millefolium*	common yarrow	0		—
	Asclepias tuberosa	butterfly weed	0		—
	Erigeron strigosus	lesser daisy fleabane	0		—
	Euphorbia corollata	flowering spurge	4.45	17.57	—
	Krigia virginica[a]	dwarf dandelion	0		$\bar{x}$ =0.07 SE=0.07
	Liatris squarrosa[b]	scaly blazing star	20.88	82.43	—
	Polygala polygama[a]	racemed milkwort	0		—
	total species 7				
3	*Asclepias tuberosa*	butterfly weed	16.78	100	$\bar{x}$ =0.05 SE=0.04
	Baptisia tinctoria	wild indigo	0		—
	Coreopsis tripteris	tall coreopsis	0		—
	Erigeron strigosus	lesser daisy fleabane	0		—
	Euphorbia corollata	flowering spurge	0		$\bar{x}$ =0.08 SE=0.05
	Helianthus divaricatus	woodland sunflower	0		$\bar{x}$ =0.46 SE=0.19
	Saponaria officinalis[c]	soapwort	0		—
	Solidago juncea	early goldenrod	0		$\bar{x}$ =0.05 SE=0.05
	total species 8				
4	*Asclepias tuberosa*	butterfly weed	12	100	—
	Erigeron strigosus	lesser daisy fleabane	0		—
	Euphorbia corollata	flowering spurge	0		—
	Helianthus divaricatus	woodland sunflower	0		$\bar{x}$ =0.04 SE=0.04
	Hieracium gronovii	hairy hawkweed	0		—
	Hypericum perforatum[c]	St. John's wort	0		—
	Polygala polygama[a]	racemed milkwort	0		—
	Rosa carolina	pasture rose	0		—
	Solidago juncea	early goldenrod	0		—
	total species 9				

[a]*State threatened (Ohio)*, [b]*Potentially threatened (Ohio)*, [c]*Non-native*

Table 4. Feeding at each site by butterfly species.

Site	*Butterfly species* Scientific name	Common name	*Minutes feeding*	*Flowering plant species*
1	*Danaus plexippus*	monarch	0	
	Everes comyntas	eastern tailed-blue	0	
	Megisto cymela	little wood satyr	0	
	Satyrium liparops	striped hairstreak	0	
	total species 4			
2	*Colias eurytheme*	orange sulfur	10	flowering spurge, scaly blazing star
	Erynnis baptisiae	wild indigo duskywing	11	scaly blazing star
	Lycaena phlaeas	American copper	0	
	Megisto cymela	little wood satyr	0	
	Papilio troilus	spicebush swallowtail	4.33	scaly blazing star
	Vanessa virginiensis	American lady	0	
	total species 6			
3	*Danaus plexippus*	monarch	3.50	butterfly weed
	Erynnis horatius or *Erynnis baptisiae*	Horace's or wild indigo duskywing	0	
	Papilio cresphontes	giant swallowtail	0	
	Papilio troilus	spicebush swallowtail	12.28	butterfly weed
	Speyeria cybele	great spangled fritillary	1	butterfly weed
	total species 5			
4	*Celastrina neglecta*	summer azure	0	
	Colias eurytheme or *Colias philodice*	orange or clouded sulfur	2	butterfly weed
	Erynnis baptisiae	wild indigo duskywing	0	
	Megisto cymela	little wood satyr	0	
	Satyrium titus	coral hairstreak	0	
	Skipper sp.	—	0	
	Speyeria cybele	great spangled fritillary	10	butterfly weed
	total species 7			

Table 5. Management activities at each site during three time frames. Management began in 1988 at site 1, 1996 at sites 3 and 4, and 2001 at site 2. The first time frame (1988-2009) therefore, includes all recorded management activities. The second time frame (2001-2009) represents management in the last 8.7 years and the last time frame (2006-2009) represents the most recent management activities. Seeding events refer to the distribution of native plant seed into a site. Woody species removal includes both mechanical and chemical methods to remove woody plants. Total is the sum of all management activity.

Time frame	*Site(s)*	*# of burns*	*# of mowing events*	*# of seeding events*	*# of years with woody species removal*	*Total*
*1988-2009**	1	11	1	6	7	25
	2	0	1	5	4	10
	3 and 4	2	0	0	10	12
*2001-2009**	1	3	1	4	5	13
	2	0	1	5	4	10
	3 and 4	2	0	0	5	7
*2006-2009**	1	1	0	2	2	5
	2	0	1	1	1	3
	3 and 4	2	0	0	3	5

**Through 1 August 2009*