Developing Success Criteria for Ecosystem Restoration and Habitat Management in Central Wisconsin

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Abstract

Before European settlement, one of the dominant ecological communities of Wisconsin was prairie and oak savanna. Overall, savannas encompass a broad group of open, disturbance-mediated cover types. In Central Wisconsin, oak (*Quercus spp.*) and pine (*Pinus spp.*) barrens were the prevalent types of savannas. Barrens have relatively poor nutrient availability but support rare plant species adapted to these conditions and provide important site characteristics for many wildlife species like migratory songbirds and the endangered Karner blue butterfly (KBB; *Lycaeides melissa samuelis*). However, information on how to successfully restore these ecologically important cover types is incomplete, because many barrens that could have functioned as reference ecosystems were converted into production agriculture, pasture, or red pine (*Pinus resinosa*) plantations during early European settlement. The objectives of this study were to (1) describe the flora and avian communities associated with restored barrens and determine if flora, avian richness/diversity has been altered from historic barren communities and (2) to assess fifteen years of active barren management throughout Central Wisconsin to develop success criteria aimed at wildlife site characteristics elements for KBB and migratory songbirds. Twenty sites with extensive restoration history were surveyed. At each site, we performed the Wisconsin Department of Natural Resources KBB occupancy survey, National Ecological Observatory Network bird point count surveys and vegetation sampling to describe the avian and vegetation communities, we compiled a comprehensive list of all observed species, including their occurrence across sites and per hectare estimates for plant species. Through stepwise regression analysis, we identified key predictor variables that influenced KBB abundance and migratory songbird presence.

For KBB, the average lupine percentage positively predicted variation across study sites, while forb diversity negatively influenced it, together explaining 42.5% of the total variation across our study sites for migratory songbirds, both total acres of restoration unit and KBB nectar plant richness positively predicted variation across study sites, together accounting for 33.9%. Among these, total acres stood as the stronger predictor, with KBB nectar plant richness providing a lesser but still positive contribution. Our findings indicate that the flora and avian communities in restored barrens are distinct and diverse, emphasizing the ecological importance of these vegetation cover types for both KBB and migratory songbirds. The identified predictor variables can be used to guide future restoration and management efforts to support these communities. Additionally, this study contributes valuable knowledge to the understanding of the factors that shape barrens and helps inform conservation strategies for maintaining and enhancing the richness and diversity of flora and avian species in central Wisconsin barrens.

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Introduction

Since European settlement disturbance-mediated vegetation cover types have undergone significant changes in structure and function. In many cases, this change has resulted in degradation of these historic ecosystems. Causes of this degradation include agricultural conversion, grazing, introduction of invasive species, inadequate forestry practices, and fire suppression (Gleason 1913; Haney & Apfelbaum 1983). Various ecosystem restoration and vegetation management tools such as prescribed fire, mechanical reduction treatments, chemical applications, and planting native trees/prairie seed have been used to supplement this lack of disturbance through time (Bennion et al. 2020; Nielsen et. all 2003). Yet, studies have shown a history of declining acres in prairie, savanna and barren systems (King 2003; Klenuntjes et al. 2003; Wisconsin Department of Natural Resources 2009). Barrens are generally described as a subset of a savanna ecosystem with a scattered tree canopy (5-50%) that includes a unique understory of forbs and grasses adapted to the dry, low-nutrient soils. Throughout Wisconsin, pine barrens were common in northern and central Wisconsin, while oak barrens were common in southern and western Wisconsin (Curtis 1959; Bray 1960; Wisconsin Department of Natural Resources. 2015). Pre-European settlement, Wisconsin contained 1.8 million acres of oak barrens alone, but due to changes in disturbance regimes, they have become a rarity on the landscape resulting in Wisconsin's Natural Heritage Inventory (NHI) listing it as a G2/S2. G2 is an ecosystem that is imperiled, defined as "at high risk of extinction or elimination due to restricted range, few populations or occurrences, steep declines, severe threats, or other factors" while S2 is an ecosystem that "is imperiled in Wisconsin due to a restricted range, few populations or occurrences, steep declines, severe threats, or other factors" (Epstein 2017).

Due to these changes, which will be called "degradation" from this point forward, the majority of barren systems have undergone severe structural and species compositions changes that caused issues with classification and overall site quality (Wisconsin Department of Natural Resources 2015). Various forms of degradation such as: agricultural conversion, reforestation, invasive species, lack of disturbance (mowing and fire), and infrastructure development are the primary causation of decline and extirpation of many plant and animal communities from the landscape (Apfelbaum & Haney, 1987; D'Antonio & Vitousek, 1992; Pickett & White, 1985). While central to southern Wisconsin was composed of up to two thirds of deciduous savanna when first surveyed in 1850, now savannas only represent less than a single percentage of the landscape (Rhemtulla et al. 2007; Wisconsin Department of Natural Resources. 2015).

Barrens, by definition are open, shrub-dense, sparse in trees, and diverse in ground cover vegetation. This condition creates a mosaic of different ecological components within a site. Such diversity of site characteristics is crucial for various species, including insects, reptiles, amphibians, birds (especially migratory songbirds) and mammals, as they all depend on these elements (Wood et al. 2011; Stewart & Rossi 1981). Many mammalian and bird species need open areas for displaying, feeding, and utilizing edge cover (Bried et al. 2014; Litvaitis 2001; Fuller & DeStefano 2003). Also, due to the low nutrient conditions, many generalist plant species have a difficult time establishing; however, a range of barrens specialist plants are most competitive within these otherwise harsh growing conditions. Specifically, flora that have adapted to live in low-productivity arid soils, where competition is low, and the ability to sustain life even after repeated disturbance events (Leach & Givnish 1999).

Generally, within the northern portion of Wisconsin, pine barrens are more common and the dominate overstory. The overstory consists of scattered jack pine (*Pinus banksiana*) (Haney & Apfelbaum 1993). Where conifers are absent, scrub oaks inhabit that space and are considered oak barren. For oak barrens, the most common species oak species inhabiting these sites are: Black Oak (*Quercus velutina*), White Oak (*Quercus alba*), Bur Oak (*Quercus macrocarpa*), Northern Pin Oak (*Quercus ellipsoidalis*), and Red Oak (*Quercus rubra*) (Radeloff et al. 1998; Curtis 1959). Understory vegetation is predominantly forbs, grass, and shrubs. Quality sites traditionally have a diverse structure of graminoids mainly composed of Little Blue-Stem (*Schizachyrium scoparium)*, Big Blue-Stem (*Andropogon gerardii*), Prairie Dropseed (*Sporobolus heterolepis*), June Grass (*Koeleria macrantha*), Pennsylvania Sedge *(Carex pensylvanica*), Panic Grasses (*Dicanthelium spp*.), Canada Wild-Rye (*Elymus canadensis*) and Sandbur (*Cenchrus longispinus*) (Epstein 2017). Shrub layer can be highly variable but generally incudes: American Hazelnut (*Corylus americana*), Lead-Plant (*Amorpha canescens*), Sweet-Fern (*Comptonia peregrina*), Staghorn Sumac (*Rhus hirta*). In some northern settings, heath species such as Huckleberry (*Gaylussacia baccata*), and Early Low Blueberry (*Vaccinium angustifolium*) persist in these plant communities (Curtis 1959; Bray 1960; Will-Wolf and Stearns 1999). The relative presence of forbs is heavily dependent on previous management actions, and, in some cases, grass species can dominate sites and suppress forbs and legumes. For sites with a more frequent (fire and mowing) disturbance regime as well as supplemental inter-seeding plantings, a range of forbs and legumes may be present on these sites. Some of these species include: Wild Lupine (*Lupinus perennis*), Round-Headed Bush Clover (*Lespedeza capitata*), Flowering Spurge (*Euphorbia corollata*), Common Spiderwort (*Tradescantia ohiensis*), Western Ragweed (*Ambrosia psilostachya*), Prairie Coreopsis (*Coreopsis palmata*), Butterfly-Weed (*Asclepias tuberosa*), Bastard Toadflax (*Comandra umbellata*) and Goat's Rue (*Tephrosia virginiana*) (Will-Wolf and Stearns 1999; Epstein 2017).

Barrens have declined dramatically in Wisconsin, and subsequently wildlife species that are associated with those communities have faced a similar trend (Niemuth & Boyce 1997; Grundel et al. 1998). Similarly, mammalian species have experienced declines, including examples include: Franklin's Ground Squirrel (*Poliocitellus franklinii),* Prairie Deer Mouse (*Peromyscus maniculatus bairdii)*, Prairie Vole (*Microtus ochrogaster)* and various bat species. Additionally, impacted avian species include: Vesper Sparrow (*Pooecetes gramineus),* Sharp-tailed Grouse (*Tympanuchus phasianellus),* Common Nighthawk (*Chordeiles minor),* Lark Sparrow (*Chondestes grammacus),* and Eastern Whip-poor-will (*Antrostomus vociferus)* (Wisconsin Department of Natural Resources. 2015). Sand barren communities house a plethora of threatened and endangered invertebrate species like: Frosted Elfin (*Callophrys irus*) and Persius Duskywing (*Erynnis persius*) (Swengel & Swengel 2018). Yet the focal point of barrens restoration and conservation in Wisconsin is dominated by management for the Karner blue butterfly *(*KBB; *Lycaeides melissa samuelis*; King 2003; Wood 2011; Kleintjes et. all 2003).

The KBB is a federally endangered species that is closely tied to barrens and dry prairie systems due to their host plant, wild lupine, predominantly occurring only in these plant communities (Swengel & Swengel 1996). KBB larvae exclusively use wild lupine as a food source. While the adults also utilize the nectar from this plant, they utilize a wide range of other nectar producing plants as well, such as: wild bergamot *(Monarda fistulosa*), dotted horsemint (*Monarda punctata*) and butterfly-weed. KBB's have a bivoltine lifecycle with two emergences happening in summer, frequently referred to as "flights", where the adults emerge and breed (Swengel & Swengel 1996). Depending on weather and temperature conditions, the first flight tends to occur late May until the end of June (Patterson et al. 2020). Adult KBB tend to live on average 3.5 days but can be highly variable (Knutson et al. 1999). Females will lay eggs on wild lupine at this time which will start the process for the second flight. The second flight will depend on the timing of the first emergence, but normally will happen between late June and early July. (Savignano 1990; Swengel & Swengel 1999). Females also will lay eggs in this stage that will overwinter as eggs for the following year (Grundel et al. 1998b).

Wisconsin is crucial for maintaining KBB population, as it contains some of the largest oak and pine barrens left in the upper Midwest (Anderson & Bowles, 1999). Since the listing of KBB as an endangered species in 1992, federal, state, and private landowners have been restoring barrens, leading to a conservation movement for threatened and endangered species. This effort has placed KBB conservation at the forefront within the state (US Fish and Wildlife Service 1992; Wisconsin Department of Natural Resources 2009; King 2003). The Wisconsin Department of Natural Resources (WIDNR), the Natural Resource Conservation Service (NRCS), and the U.S. Fish and Wildlife Service (UWFWS) have implemented various programs that give incentives for landowners/managers to enhance their properties (Wisconsin Department of Natural

Resources, 2009; US Fish and Wildlife Service, 2005; Natural Resources Conservation Service, 2008). Generally, through providing technical and financial support to assist with site management (Turner & Rylander 1998; USDA NRCS 2007; Nilsson et al. 2008; Kremen & M'Gonigle 2015; Hardman et al. 2016).

Not only do these highlighted entities propose management actions to positively affect KBB, but indirectly improve other wildlife taxa as well. For example, another group of species of high conservation concern is migratory songbirds. (Akresh et al. 2021, Dettmers 2003). Species such as Field Sparrow (*Spizella pusilla*), Clay-Colored Sparrow (*Spizella pallgramineus*) and Grasshopper Sparrow (*Ammodramus savannarum*) are only a few of migratory songbirds that are tied to barrens due to characteristics such as: shrub cover, grass tussock and open canopy (Brawn 2006, Davis et al. 2000, Schlossberg et al. 2010) Species within this group, specifically those that ground nesters or specialize in shrubland and early successional vegetation cover types, are directly impacted by KBB management (Wood et al. 2011; Mossman et al. 1991).Similarly, the decline in this subset of migratory songbirds is a result of widescale degradation and loss of essential selected for site characteristics (Brawn et al., 2001). Previous research has shown that active management for KBB has the ability to improve avian communities on these sites, yet there are no management plans specifically for birds that use barrens in Wisconsin (Wood et. al 2011).

Land management can include a broad range of activities that are aimed to enhance, restore, and/or promote the objectives and goals for a given site (Nielsen et al. 2003). To better understand the effectiveness of these actions, forms of "success criteria" are normally measured, traditionally this criterion is a focal or interest point to the area itself (Kentula 2000; Chan 2004). For instance, State Parks implement management to enhance the aesthetics of walking trails and their success criteria would be the change in public use and or involvement at that given park. In terms of central Wisconsin, KBB are one of the focal points of conservation specifically on both pine and oak barrens (Wood et al. 2011). Management is catered around this species due to it being within the historic range of the species, being one of the only regions that still has and can create suitable barrens, and lastly still currently has large stable populations (Anderson & Bowles, 1999; US Fish and Wildlife Service 1992; Wisconsin Department of Natural Resources 2009). Furthermore, due to the strong correlation that KBB exhibits with higher quality site characteristics and KBB be identified visually makes them an ideal "indicator species" for barrens. (Carignan & Villard 2002). In addition, the life cycle is predictable which makes observing and surveying KBBs relatively easy and incredibly responsive to management (Swengel & Swengel 1999, Pickens 2009). To assess the development of research sites, evaluating the change in occupancy and/or abundance of KBB on a site serves as the ideal criterion.

Our first objective is to provide an updated description of the flora and avian communities in restored barrens of Central Wisconsin and assess if these communities have changed compared to their historical composition. This information may be invaluable for land managers and conservationists working to restore and preserve these unique cover types. By understanding the current ecological communities and comparing them to historical records, we aim to contribute to the development of more effective conservation and restoration practices that maintain and enhance the richness and diversity of flora and avian species in Central Wisconsin barrens. Our second objective is to assess fifteen years of active barrens management throughout Central Wisconsin to develop success criteria aimed at wildlife ecological components for karner blue butterflies and migratory songbirds in barren systems. We predict: (a) Sites with more time (years) in management will be an important predictor variable for wildlife populations on sites and (b) site vegetation composition will show a strong positive association with wildlife populations on site.

Methods

Study Area

The area of study includes twenty sites in the morainal sands portion of Central Wisconsin. The study was limited to 5 different counties: Portage, Waupaca, Waushara, Adams and Marquette (Figure 1). These parcels were selected due to the history of involvement with the U.S. Fish and Wildlife Service – Partners for Fish and Wildlife Program and continuity of KBB data. These sites cover a range of years of management and involvement from 3-15 years. Each site is enrolled in the Partners Program when restoration efforts were initially started and follow management was conducted. All property management was focused on the creation of suitable KBB environment and landowner's personal goals and objectives.

Experimental Design

Flora characterization

To assess plant species occupancy, we implemented a time constraint survey, where each site was surveyed within the restoration area boundaries for one hour during summer 2020. The sites were walked with a timed meander method with the effort to cover as much of the site as possible (Hlina et al. 2014). Each species detected was grouped into 3 different categories dependent on abundance, 1) One to three individuals, 2) three to one-hundred individuals and 3) one hundred plus individuals. Individuals were defined as one genet, for example one hundred ramets of goldenrod (Solidago spp.) was counted as a singular plant. This approach was taken due to having a high probability of detecting lower frequency plant species that would generally not be detected doing a transect or plot-based survey.

Additionally, we implemented a plot-based survey to better understand the composition of our study sites (Sorrells & Glenn 1991). Twenty 1x1 meter plots were established in 2022 using an initial random starting point then overlaying as grid system using ArcMap to establish the other nineteen sampling locations within the restoration boundary, also known as systematic random sampling. Individuals were defined same as the previous vegetation survey and graminoids were recorded on a one to three scale based on percent cover within the plot: 1) single stem up to ten percent, 2) ten to twenty percent and 3) over twenty percent. For borderline calls on percentages, a 20-drop pin test was used to give a more precise estimate of the percent cover (Bonham 1989; Herrick et al. 2005). Lastly, at each point, basal area and a visual estimation of percent wild lupine was also recorded using photographic scoring cards developed during 2020 using photographs of measured sites.

Avian Characterization

To ensure accurate occupancy and population data we entered sites at prime bird activity times between thirty minutes before sunrise and five hours after (Robbins 1981). For comparability of data between projects being implemented at the University of Wisconsin-Stevens Point, we used The National Ecological Observatory Network (NEON) protocol for point count surveys. This entailed "One or more observers going to pre-established points and recording all the birds heard and/or seen during a set period of time. Point counts are six minutes long, with each minute tracked by the observer, following a two-minute settling-in period. All birds were recorded to species and sex, whenever possible, and the distance to each individual or flock shall be measured with a laser rangefinder" (National Ecological Observatory Network 2019). To avoid double-counting individual birds, once a bird of a particular species was identified at a point during the count, it was not recounted during that same session. However, newly detected birds of the same species were counted as separate individuals. Due to the site being smaller in acreage compared to traditional NEON surveying sites, we randomly distributed 5 points across each site that was surveyed. Those points were 250m apart and 125m away from any property boundary when possible. These points were located using Avenza Maps application. Each site was surveyed twice, with the initial survey between May 27th and June 23rd and the 2nd surveys between June 23rd and June 30th. All data were recorded on a pre-made data sheet specifically made for this survey and input into Microsoft Excel.

Karner Blue Occupancy

We followed the Wisconsin Department of Natural Resources occupancy surveying protocol to determine relative KBB population on each site (Chan 2004; WIDNR protocol citation). We implemented a time constraint search limited to one hour to standardize survey time across our sites and recorded the number of individual KBB observations and distance traveled. This relative population estimate was converted to an estimate of KBB observations per mile of transect. To record acres covered and distance traveled, a georeferenced map was prepared for each site and the Record Tracks function was used in Avenza Maps app. This was done in 2020, 2021 and 2022 to better represent KBB populations and account for yearly variation within the populations.

Additional Site Data Collection

For each site, other variables were obtained from external sources. Soil information was gathered using the Web Soil Survey (Natural Resources Conservation Service, n.d.), while the U.S. Fish and Wildlife Service provided precise dates, management actions related to initial site restoration, and the total acreage of the restored area.

Data Analysis

Site Characterization – Flora Community

We compared the plant species identified in our occupancy data to the documented forbs and legumes that KBB is known to select for nectar foraging, as indicated by Grundel et al., (2000) and Kleintjes et al., (2003). Then, a comprehensive table of all species with the proportion of sites that they occurred on (n=20) was created with KBB plants highlighted. Also, richness values for: total forb species, document KBB plants, non-KBB plants, invasive species, graminoids, and general nectar plants per site was calculated for further analysis (Wisconsin Department of Natural Resources, n.d.).

For our flora composition data, similar to the migratory songbird methods, we created a complete list of all species surveyed with the proportion of sites on which they occurred. Additionally, each species was extrapolated to an individuals per hectare basis. To describe flora diversity across sites, we calculated a Shannon-Weiner diversity index per study area for all plants and for only nectar producing species to compare for further analyses (Shannon & Weaver, 1949). The formula used for the Shannon-Weiner diversity index is:

$H' = - \Sigma(p_i * \ln(p_i))$

where:

H' is the Shannon-Weiner diversity index

Σ is the sum of

p_i is the relative abundance of the ith species

$\ln(p_i)$ is the natural logarithm of the relative abundance of the ith species

Site Characterization – Avian Community

Similar to the plant occupancy data, a comprehensive list of all species of migratory songbirds observed was created. From this list, bird species of conservation concern were identified; that includes birds that are threatened, endangered or with population in steep decline (Wisconsin Department of Natural Resources, 2021; U.S. Fish & Wildlife Service, 2022).

After compiling the list of migratory songbird species observed at each site, we calculated the Shannon-Weiner diversity index to assess the overall diversity of songbird communities across each study area.

Success criterion

To identify important site variables for both KBB and migratory songbirds, we conducted separate stepwise linear regression using the "ols_step_both_p" function from the "olsrr" package in R (R Core Team, 2021; Hebbali, 2020), with an alpha of 0.1, for both to investigate the relationship between their abundance and a set of environmental covariates that were collected previously. The covariates included: non KBB plants richness, graminoid richness, acres, average percent lupine, invasive species richness, average basal area, KBB nectar plants richness, general nectar plants richness, general nectar plant diversity, total forb diversity, and plant species richness. Additionally, for KBB we added total miles walked from surveying effort, bird diversity and bird richness, and for migratory songbirds we added total KBB count per site; we included all covariates as potential predictors. To assess the strength and direction of the relationships between each predictor variable and the abundance of each dependent variable (KBB or migratory songbirds), we calculated the regression coefficients and corresponding standard errors, p-values, and R-squared values for each model using the "lm" function in R.

Additionally, to assess the relationships between our covariates, we calculated Pearson correlation coefficients using the "cor" function in R. This allowed us to identify any significant correlations and potential multicollinearity issues among the predictor variables.

Results

Flora and avian community descriptions

Among the twenty research sites that were surveyed for KBB, vegetation, and avian communities, a total of 123 plant species and 45 migratory songbird species were identified. Of these, 35 plant species were documented to be used by KBB for nectar foraging and 6 bird species were identified with conservation concern status.

The occurrence of each plant and bird species was assessed across all study sites, with the results displayed in Table 1 for the plants and Table 2 for the migratory songbirds. Both tables show the proportion of sites that each species occurred on, with the highest occurring species for the flora community being flowering spurge and for the avian community Mourning Dove (*Zenaida macroura*). The remainder of the tables provide an updated characterization of both communities for barrens and delineate what species occupy these systems.

Flora community composition

We also estimated the per hectare abundance of each plant species using our systematic random sampling method. The results of these estimates are displayed in Table 3, which include the percentage of sites each species occurred on, per hectare estimate, along with the 90% lower and upper confidence intervals. The highest estimated per hectare abundance was observed for Wild Bergamot at 32,750 plants per hectare with a confidence interval of 19,165-46,335. Other notable species Wild Lupine at 24,925 plants per hectare and Butter and Eggs (*Linaria vulgaris*) an invasive species at 30,850 plants per hectare.

Success criterion

The results of the correlation analysis showed significant correlations between a multitude of plant richness and plant diversity values. Other significant correlations include: average percent lupine and total KBB counts ($r = 0.492$, $p < 0.05$) and between average basal area and invasive species richness ($r = -0.479$, $p < 0.05$). The full correlation matrix can be found in figure 2.

For KBB, the stepwise regression analysis identified two predictor variables that were significant to butterfly abundance, which together explained 42.5% of the variation across our study sites. The final model included average lupine percentage and forb diversity, with average lupine percentage being the strongest positive effect on abundance and forb diversity being the strongest negative effect. Model summary and coefficients can be found in Table 4 and Table 5.

Similarly, for migratory songbirds the stepwise regression identified two predictor variables as well. Both predictors explained 33.9% of the variation across study areas. The final model included acres of restoration area and KBB nectar plants richness, with acres being the strongest positive predictor and KBB nectar plants richness being a lesser positive predictor. The model summary and coefficients can be found in Table 6 and Table 7.

Discussion

In our study, the restored barrens in Central Wisconsin hosted a diverse flora community, with a total of 123 plant species identified across the 20 research sites. This diversity emphasizes the ecological richness of barrens and contributes to our understanding of the plant species composition in the region. Additionally, Curtis J (1959) reported a similar set of dominant species, emphasizing restoration efforts are keeping the historic identity and unique characteristics of barrens.

Among the plant species identified, 35 are known to be selected by KBB for nectar foraging (Grundel et al., 2000; Kleintjes et al., 2003) with a total of 118 species of nectar producing plants. The presence of these species in the restored barrens is particularly significant as it indicates the potential for these sites to support a high abundance of the endangered KBB population as well as a collection of other pollinator species. Furthermore, high abundance of Wild Lupine estimated at 24,925 plants per hectare provides an essential food source for KBB larvae, the abundance and diversity of documented plant species validates the efforts for recovery, and conservation of this federally endangered butterfly.

The most commonly occurring species in our study was Flowering Spurge, while Wild Bergamot had the highest estimated per hectare abundance. The abundance and distribution of these species within the restored barrens could be influenced by a variety of factors, such as soil type, nutrient availability, and the specific management actions implemented at each site. Management actions like prescribed burning, woody encroachment removal, initial seed mix planting, and invasive species control on restoration areas likely significantly shaped the observed flora community composition in our study. By removing competition and promoting the growth of preferred species, these management actions can create a more favorable environment for the development of flora communities that support KBB and other wildlife species (Swengel 1998).

Our study identified a total of 45 migratory bird species inhabiting the study areas during our survey periods, six of which are listed as conservation concern status. Mourning Dove was the most commonly occurring species in the avian community. These findings give us a better understanding of the bird community associated with these sites and give valuable insight into the importance of conservation and restoration of barrens for species in addition to KBB. Comparing findings with other studies in the region, such as Wood et al. (2011), reveals similarities in bird community composition on barrens. For instance, Wood et al. (2011) reported a similar group of species occupying their study sites, albeit with different dominant bird species and nearly identical species richness. These findings demonstrate the diverse avian community composition in our study area, further emphasizing the importance of barrens for bird conservation.

Among the identified bird species, six have been listed as of conservation concern. These include the Brewer's Blackbird *(Euphagus cyanocephalus*), Wood Thrush (*Hylocichla mustelina*), Vesper Sparrow, Grasshopper Sparrow, Eastern Whip-Poor-Will, and Common Nighthawk. The presence of these species in the restored barrens is particularly important because it indicates that these areas can provide crucial resources for the conservation of these vulnerable bird populations. Furthermore, the results highlight the essential ecological components within barrens that encourage the presence of these species. These attributes could be crucial for formulating effective conservation strategies and management actions.

Similar to KBB, the abundance and distribution of bird species within the restoration area could be influenced by other factors such as vegetation structure, food availability, predations pressure, and management actions that were highlighted previously. A combination of all these likely played a significant role in shaping the avian community composition (Johnson, 2007; Marzluff & Ewing, 2001.) Furthermore, depending on the management strategies implemented, resources such as nesting cover and food availability may have been affected, altering the composition. It's important to note that these effects could lead to either improvement or deterioration in these resources, contingent upon the specific management actions taken or not taken. By promoting a diverse heterogeneous vegetation structure, the composition of species occurring on these sites could change (Wiens & Rotenberry, 1981).

Considering the results from the correlation and the stepwise regression analyses, we can better our understanding of the factors influencing the success of restoration efforts for KBB and migratory songbirds. The following discussion will focus on the relationships between variables and the abundance of KBB and migratory songbirds.

The stepwise regression analysis identified two significant predictor variables for KBB abundance, which together explained 42.5% of the variation across study sites: average lupine percentage and forb diversity. Average lupine percentage had the strongest positive effect on KBB abundance, which is consistent with the importance of wild lupine as a host plant for KBB larvae. In contrast, forb diversity had the strongest negative effect on KBB abundance. While this seems counter intuitive, the likely origin of this effect is that forb diversity was non-significantly negatively correlated with average lupine percentage. While forb diversity is likely beneficial to KBB, it appears that the factors that produce high lupine percentages may be related to or even cause lower forb diversity. Among all 20 research sites, the minimum number of observed nectar-producing species known to be utilized by KBB was 13. This relatively high minimum number of nectar-producing species may represent a minimum threshold for KBB nectar foraging species beyond which additional species diversity provides limited benefits. As a result, it is crucial to strike a balance between promoting lupine percentage, which is essential for KBB survival, and maintaining a reasonable level of forb diversity to support their foraging needs.

For migratory songbirds, the stepwise regression identified two significant predictor variables, explaining 33.9% of the variation across study sites: size of restoration unit and KBB nectar plant richness. The size of the restoration unit had the strongest positive predictor effect, suggesting that larger restoration areas may provide more resources for these bird species. KBB nectar plant richness also had a positive predictor effect, indicating that the presence of nectar plants, which support KBB, may also benefit songbird populations. This may be in part due to having more high-quality nectar producing forbs that could increase insect populations, therefore creating higher quality foraging for grassland birds.

Conclusion

Our research revealed a total of 123 plant species and 45 migratory songbird species across the twenty surveyed sites. The presence of a minimum of 13 observed nectar-producing species known to be utilized by KBB and six bird species of conservation concern supports that the restored barrens provide crucial resources for both KBB and migratory songbirds. The high abundance of lupine, the larval host plant for KBB, further highlights the significance of these environments in KBB conservation.

The stepwise regression analyses identified significant predictor variables for KBB and migratory songbird abundance. For KBB, the strongest positive predictor was the average lupine percentage across a site, emphasizing the critical role of wild lupine in KBB conservation. In contrast, forb diversity had the strongest negative effect on KBB abundance. However, it is important to consider that the minimum observed number of nectar-producing species known to be utilized by KBB across the study sites was 13, which could potentially be a threshold for maintaining optimal site suitability. For migratory songbirds, larger restoration areas and the presence of KBB nectar plants emerged as significant positive predictors, highlighting the importance of prioritizing larger barren areas and promoting the growth of nectar plants.

Based on these findings, we recommend future management actions and restoration efforts in Central Wisconsin's restored barrens to focus on several key objectives. First, promote the growth of wild lupine, which is essential for the survival of KBB larvae, and aim to increase the average lupine coverage across restoration sites. Second, maintain an optimal level of plant diversity, ensuring that a sufficient variety of nectar-producing species known to be utilized by KBB are present without negatively impacting lupine abundance. Third, conserve and restore larger barren areas, as they have been shown to support higher migratory songbird abundance. Lastly, encourage the growth of KBB nectar plants, which provide essential resources for both KBB and migratory songbirds. By refining management actions according to these insights, we can enhance the effectiveness of restoration efforts in promoting the recovery and conservation of vulnerable KBB and migratory songbird populations in Central Wisconsin's restored barrens.

In conclusion, our study demonstrates the importance of restored barrens in Central Wisconsin for the conservation of Karner blue butterflies and migratory songbirds. By refining management actions based on our research, we can continue to promote the recovery and conservation of these vulnerable species and ensure the long-term success of restoration efforts in Central Wisconsin's unique barrens ecosystem.

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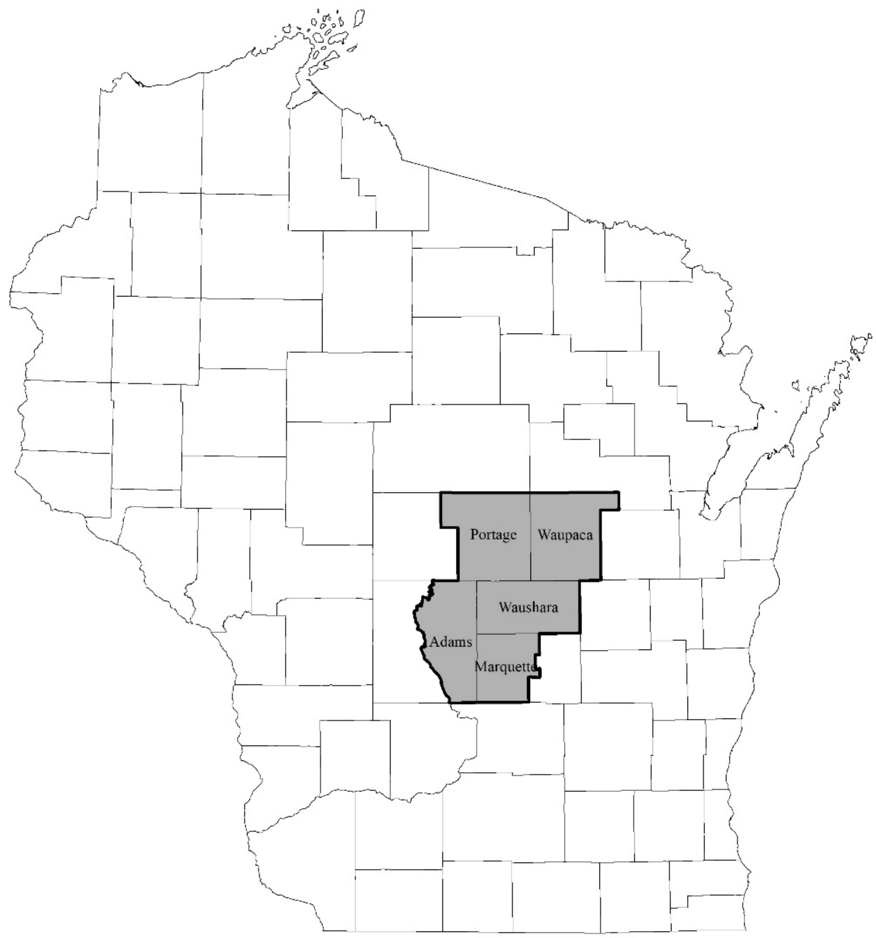

Figure 1. State map showing the counties in WI surveyed.

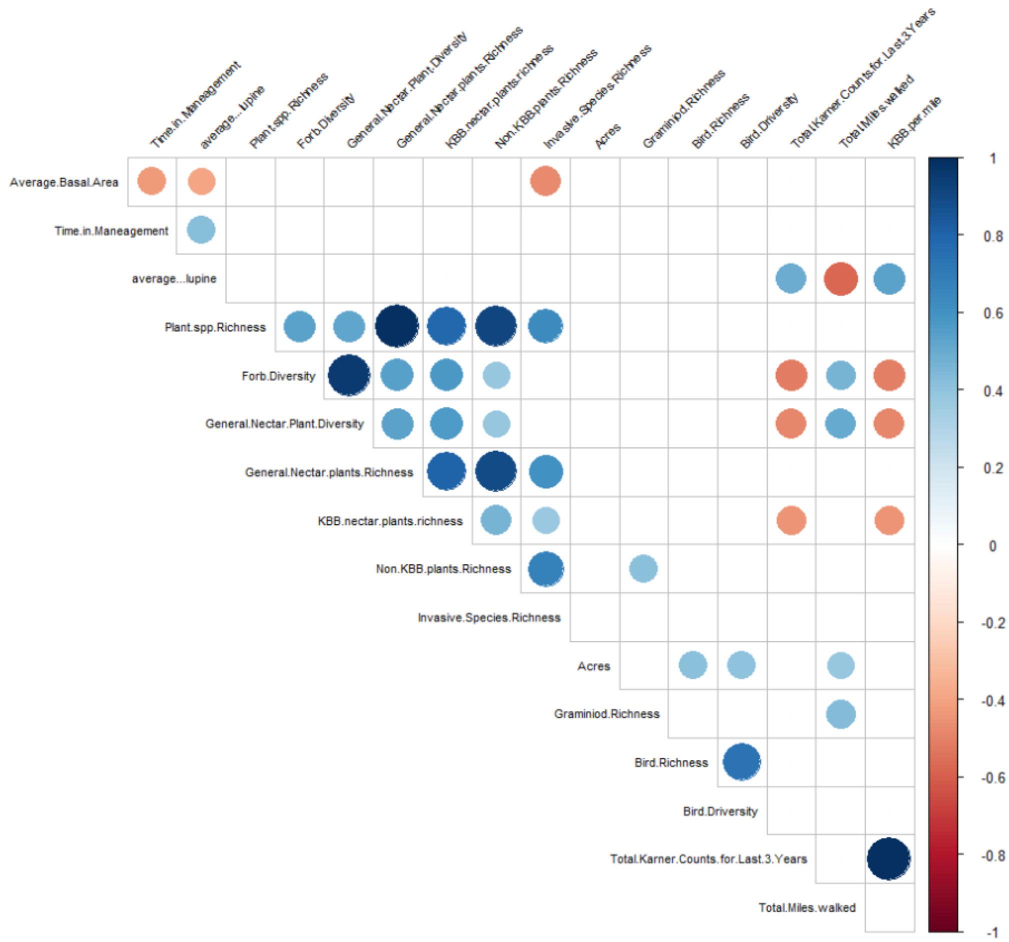

Figure 2. Visualization of significant correlations among variables in the restored barrens of Central Wisconsin across 20 study sites. This analysis was conducted using a significance level of 0.1. The circle size and color intensity represent the strength of correlation, with larger, darker circles indicating stronger correlations.

Table 1. Comprehensive list of all vegetation species observed across 20 study sites on restored barrens in Central Wisconsin during the 2020 field season. The table includes the percentage of sites each species was found on, with species that are important for the Karner Blue Butterfly highlighted.

Species	Percent of Sites Occupied
Euphorbia corollata (flowering spurge)	100%
Asclepias syriaca (common milkweed)	95%
Lespedeza capitata (round headed bush clover)	95%
Hypericum perforatum (St. john's wort)	95%
Lupinus perennis (wild lupine)	95%
Berteroa incana (hoary alyssum)	90%
Rudbeckia hirta (black eyed susan)	90%
Erigeron annuus (daisy fleabane)	90%
Achillea millefolium (yarrow)	90%
Monarda punctata (dotted horsemint)	85%
Solidago spp. (goldenrods)	80%
Verbascum thapsus (common mullien)	80%
Asclepias tuberosa (butterfly-weed)	80%
Asclepias verticillata (whorled milkweed)	75%
Monarda fistulosa (wild bergamot)	75%
Linaria vulgaris (butter and eggs)	70%
Tradescantia ohiensis (Ohio spiderwort)	70%
Centaurea stoebe (spotted knapweed)	70%
Amorpha canescens (leadplant)	70%
Solidago speciosa (showy goldenrod)	70%
Verbesina virginica (frostweed)	65%
Liatris spp. (blazing Star)	65%
Rosa (rose spp.)	65%
Verbena officinalis (vervain)	60%
Cinquefoil other	60%
Artemisia frigida (sagewort)	60%
Asclepias amplexicaulis (clasping milkweed)	60%
Coreopsis palmata (prairie coreopsis)	60%
Symphyotrichum ericoides (heath aster)	55%
Trifolium pratense (red clover)	50%
Aster other	50%
Hieracium (hawkweed spp.)	50%
Trifolium repens (white clover)	50%
Dalea purpurea (purple prairie clover)	50%
Vicia cracca (blue vetch)	50%

Oenothera biennis (evening primrose)	45%
Symphyotrichum oolentangiense (sky blue aster)	45%
Melilotus officinalis (sweet clover)	45%
Silphium integrifolium (rosinweed)	45%
False indigo (baptisia australis)	40%
Fragaria vesca (wild strawberry)	40%
Desmodium canadense (showy tick-trefoil)	40%
Silene latifolia subsp. Alba (white cockle)	40%
Helianthus occidentalis (western sunflower)	35%
Zizia aurea (golden alexander)	35%
Helinium spp. (sneezeweeds)	35%
Antennaria spp. (pussy-toes)	30%
Pseudognaphalium obtusifolium (sweet everlasting)	30%
Echinacea paradoxa (yellow coneflower)	30%
Astragalus canadensis (milk vetch)	30%
Lithospermum caroliniense (hairy puccoon)	30%
Lactuca virosa (wild lettuce)	25%
Anemone virginiana (tall thimbleweed)	25%
Cirsium vulgare (bull thistle)	25%
Trifolium hybridum (alsike)	25%
Tephrosia virginiana (goat's rue)	25%
Krigia biflora (two-flower dwarf dandelion)	25%
Drymocallis arguta (prairie cinquefoil)	25%
Leucanthemum vulgare (ox eye daisy)	25%
Erigeron canadensis (horseweed)	20%
Erigeron canadensis (marestail)	20%
Saponaria spp. (soapworts)	15%
Monarda citriodora (annual monarda)	15%
Physalis (ground cherry spp.)	15%
Campanula rotundifolia (harebell)	15%
Geum aleppicum (yellow avens)	15%
Hieracium gronovii (hairy hawkweed)	15%
Ceanothus americanus (New Jersey tea)	10%
Arnoglossum atriplicifolium (pale Indian plantain)	10%
Coreopsis lanceolata (lance-leaf coreopsis)	10%
Pycnanthemum muticum (mountain mint)	10%
Veronica (speedwells)	10%
Heliopsis helianthoides (ox eye sunflower)	10%
Medicago sativa (alfalfa)	10%
Cirsium arvense (Canada thistle)	10%

Apocynum androsaemifolium (spreading dogbane)	10%
Helianthus divaricatus (rough sunflower)	10%
Echinacea (coneflower spp.)	10%
Trifolium campestre (yellow hop clover)	5%
Chamaecrista fasciculata (partridge pea)	5%
Persicaria sagittata (American tear thumb)	5%
Phlox divaricata (woodland phlox)	5%
Aruncus dioicus (goatsbeard)	5%
Dianthus spp. (pinks)	5%
Nepeta cataria (catnip)	5%
Silphium terebinthinaceum (prairie dock)	5%
Scrophularia (figwort spp.)	5%
Lotus corniculatus (bird's-foot trefoil)	5%
Helianthus annuus (common sunflower)	5%
Daucus carota (Queen Anne’s lace)	5%
Agrimonia eupatoria (agrimony)	5%
Gaillardia pulchella (blanket flower)	5%
Lithospermum canescens (hoary puccoon)	5%
Heuchera americana (alumroot)	5%
Tanacetum vulgare (Tansy)	5%
Asclepias viridis (green milkweed)	5%
Prunella vulgaris (heal-all)	5%
Salvia officinalis (common sage)	5%
Galium (bedstraw spp.)	5%
Amorphous fruiticosa (desert false indigo)	5%
Doellingeria umbellata (flat top aster)	5%
Arabidopsis arenosa (sand cress)	5%
Asclepias vestita (woolley milkweed)	5%
Heliopsis helianthoides (smooth sunflower)	5%
Cypress spurge (Euphorbia cyparissias)	5%
Mallow spp.	5%
Pastinaca sativa (wild parsnip)	5%
Convolvulus arvensis (field bindweed)	5%

Table 2. Comprehensive List of all migratory songbird species observed across 20 study sites of restored barrens in Central Wisconsin during the 2022 field season. The bird surveys were conducted following the NEON bird point count survey methods. The table includes the percentage of sites each species was observed on, the total number of observations for each species, and highlights the species of conservation concern.

Species	% of Sites Occurred on	Total Number Obs.
Zenaida macroura (mourning dove)	100%	61
Spizella pusilla (field sparrow)	95%	141
Troglodytes aedon (house wren)	95%	58
Contopus virens (eastern wood-pewee)	90%	56
Dumetella carolinensis (gray catbird)	90%	58
Melospiza melodia (song sparrow)	90%	100
Molothrus ater (brown-headed cowbird)	90%	76
Spizella passerina (chipping sparrow)	90%	79
Turdus migratorius (American robin)	90%	104
Pheucticus ludovicianus (rose-breasted grosbeak)	85%	56
Passerina cyanea (indigo bunting)	80%	63
Seiurus aurocapilla (ovenbird)	75%	64
Tachycineta bicolor (tree swallow)	65%	42
Geothlypis trichas (common yellowthroat)	60%	50
Icterus galbula (Baltimore oriole)	60%	23
Vireo olivaceus (red-eyed vireo)	60%	22
Tyrannus tyrannus (eastern kingbird)	55%	33
Setophaga petechia (yellow warbler)	50%	14
Myiarchus crinitus (great crested flycatcher)	45%	11
Spinus tristis (American goldfinch)	45%	20
Vermivora cyanoptera (blue-winged warbler)	45%	16
Agelaius phoeniceus (red-winged blackbird)	40%	28
Geothlypis philadelphia (mourning warbler)	40%	16
Vireo flavifrons (yellow-throated vireo)	40%	16
Piranga olivacea (scarlet tanager)	35%	8
Spizella pallida (clay-colored sparrow)	30%	38
Charadrius vociferus (killdeer)	25%	5
Sialia sialis (eastern bluebird)	25%	8
Vireo gilvus (warbling vireo)	25%	7

Archilochus colubris (ruby-throated hummingbird)	20%	5
Bombycilla cedrorum (cedar waxwing)	20%	6
Euphagus cyanocephalus (brewer's blackbird)	20%	10
Hylocichla mustelina (wood thrush)	20%	4
Pooecetes gramineus (vesper sparrow)	20%	8
Sayornis phoebe (eastern phoebe)	20%	5
Setophaga pensylvanica (chestnut-sided warbler)	20%	10
Ammodramus savannarum (grasshopper sparrow)	15%	8
Hirundo rustica (Barn Swallow)	10%	5
Mniotilta varia (black-and-white warbler)	10%	3
Setophaga ruticilla (American redstart)	10%	2
Antrostomus vociferus (eastern whip-poor-will)	5%	1
Catharus fuscescens (veery)	5%	1
Chordeiles minor (common nighthawk)	5%	2
Icterus spurius (orchard oriole)	5%	1
Leiothlypis ruficapilla (Nashville warbler)	5%	2
Grand Total		**1346**

Table 3. Detailed vegetation composition of restored barrens in Central Wisconsin, as observed in 2022. The data were gathered using a 1x1 meter plot-based survey method across various sites. The table lists all plant species identified, their occurrence on different sites as a percentage, and provides per hectare estimates along with their 90% confidence intervals.

Species	% of Sites Occurred on	Average # per Hectare	Lower CI per Hectare	Upper CI per Hectare
Lupinus perennis (wild lupine)	100%	24925	18373	31477
Lespedeza capitata (round headed bush clover)	90%	7250	4422	10078
Monarda fistulosa (wild bergamot)	90%	32750	19165	46335
Euphorbia corollata (flowering spurge)	75%	18350	6182	30518
Achillea millefolium (yarrow)	75%	17775	7680	27870
Linaria vulgaris (butter and eggs)	75%	30850	15135	46565
Hieracium aurantiacum (orange hawkweed)	75%	18450	8657	28243
Rudbeckia hirta (black eyed susan)	70%	8975	2275	15675
Asclepias verticillata (whorled milkweed)	70%	13400	6257	20543
Berteroa incana (hoary alyssum)	70%	6275	1719	10831
Centaurea stoebe (spotted knapweed)	65%	13075	3569	22581
Hypericum perforatum (st. john's wort)	65%	4175	1850	6500
Tradescantia ohiensis (Ohio spiderwort)	65%	2300	803	3797
Erigeron annuus (daisy fleabane)	65%	3975	0	8273
Verbesina virginica (frostweed)	65%	8600	4538	12662
Asclepias syriaca (common milkweed)	65%	2675	682	4668
Symphyotrichum laeve (smooth blue aster)	60%	4375	1375	7375
Solidago speciosa (showy goldenrod)	55%	4250	1705	6795
Euthamia graminifolia (grassleaf goldenrod)	55%	1150	511	1789

Amorpha canescens (leadplant)	55%	1125	373	1877
Rubus caesius (dewberry)	50%	2700	220	5180
Solidago altissima (late goldenrod)	45%	7625	760	14490
Artemisia frigida (sagewort)	45%	1000	350	1650
Symphyotrichum ericoides (heath aster)	45%	6500	1693	11307
Monarda punctata (dotted horsemint)	40%	8800	1813	15787
Liatris aspera (rough blazing star)	40%	725	214	1236
Helianthus occidentalis (western sunflower)	40%	13375	0	32021
Silene latifolia subsp. Alba (white cockle)	40%	1000	204	1796
Solidago canadensis (Canada goldenrod)	40%	2925	0	6804
Solidago juncea (early goldenrod)	40%	1100	169	2031
Conyza canadensis (horseweed)	40%	7375	1681	13069
Other cinquefoil	40%	1275	106	2444
Verbena stricta (hoary vervain)	40%	1350	196	2504
Solidago rigida (stiff goldenrod)	35%	2975	0	6001
Zizia aurea (golden alexander)	35%	900	318	1482
Symphyotrichum oolentangiense (sky blue aster)	35%	1225	162	2288
Rubus idaeus (red raspberry)	35%	2550	0	5243
Asclepias tuberosa (butterfly-weed)	30%	550	96	1004
Fallopia scandens (climbing false buckwheat)	30%	300	37	563
Rosa (rose spp.)	30%	1425	0	2983
Hieracium caespitosum (yellow hawkweed)	30%	6575	0	15269
Physalis (ground cherry spp.)	25%	450	18	882

Coreopsis lanceolata (lance-leaf coreopsis)	25%	975	0	2312
Coreopsis palmata (prairie coreopsis)	25%	6025	0	13564
Verbascum thapsus (common mullien)	25%	250	0	540
Asclepias amplexicaulis (clasping milkweed)	25%	200	25	375
Drymocallis arguta (prairie cinquefoil)	25%	200	25	375
Rubus occidentalis (black rasberry)	25%	350	24	676
Taraxacum spp. (dandelion)	25%	325	0	680
Rubus allegheniensis (blackberry)	25%	1000	0	2253
Chrysopsis mariana (golden aster)	20%	525	0	1381
Lactuca virosa (wild lettuce)	20%	100	12	188
Fragaria vesca (strawberry)	20%	5525	0	11606
Dalea purpurea (purple prairie clover)	20%	625	0	1424
Astragalus canadensis (milk vetch)	20%	250	0	548
Trifolium pratense (red clover)	20%	675	0	1608
Heliopsis helianthoides (smooth sunflower)	20%	1475	0	3187
Hieracium gronovii (hairy hawkweed)	20%	400	0	878
Erigeron canadensis (marestail)	20%	825	0	2026
Rumex acetosella (red sorrel)	20%	14900	0	32479
Vicia cracca (blue vetch)	20%	175	0	374
Helianthus divaricatus (rough sunflower)	15%	525	0	1103
Lysimachia quadrifolia (whorled loosestrife)	15%	600	0	1648
Persicaria sagittata (American tearthumb)	15%	525	0	1237
Antennaria spp. (pussy-toes)	15%	3050	0	6426

Solidago nemoralis (oldfield goldenrod)	15%	500	0	1032
Lithospermum caroliniense (hairy puccoon)	15%	450	0	1212
Silphium integrifolium (rosinweed)	15%	1275	0	3247
Desmodium canadense (showy tick trefoil)	15%	225	0	460
Silphium terebinthinaceum (prairie dock)	10%	275	0	676
Echinacea paradoxa (yellow coneflower)	10%	150	0	347
Ratibida columnifera (long-headed coneflower)	10%	325	0	898
Veronica spp. (speedwells)	10%	700	0	1710
Baptisia alba (white wild indigo)	10%	75	0	180
Tephrosia virginiana (goat's rue)	10%	50	0	116
Helinium spp. (sneezeweeds)	10%	75	0	180
Anemone virginiana (tall thimbleweed)	10%	75	0	180
Antennaria plantaginifolia (plantain leaf tpussytoes)	10%	700	0	1940
Saponaria spp. (soapworts)	5%	150	0	437
Medicago sativa (alfalfa)	5%	125	0	364
Apocynum androsaemifolium (spreading dogbane)	5%	75	0	218
Desmodium canescens (woodland tick trefoil)	5%	25	0	73
Pennstemon spp. (beardtongues)	5%	25	0	73
Pseudognaphalium obtusifolium (sweet everlasting)	5%	25	0	73
Trifolium hybridum (alsike)	5%	25	0	73
Ceanothus americanus (New Jersey tea)	5%	25	0	73

Echinacea purpurea (purple coneflower)	5%	75	0	218
Eurybia macrophylla (largeleaf aster)	5%	50	0	146
Leucanthemum vulgare (ox eye daisy)	5%	50	0	146
Dalea ornata (western prairie clover)	5%	375	0	1091
Symphyotrichum sericeum (silky aster)	5%	125	0	364
Salvia officinalis (common sage)	5%	25	0	73
Heliopsis helianthoides (ox eye sunflower)	5%	75	0	218
Arnoglossum atriplicifolium (pale Indian plantain)	5%	25	0	73

Table 4. Table 4: Stepwise selection summary for the linear regression analysis conducted on the density of Karner Blue Butterfly (KBB) per mile. Data were collected from 2020 to 2022 across 20 restored barren study sites in Central Wisconsin. The alpha threshold was set at 0.1 for statistical significance. The table details the variable selection process and their impact on KBB density, with statistics shown as: C(p) (Mallows' Cp), AIC (Akaike Information Criterion) and RMSE (Root Mean Square Error).

Step	Variable	Added/ Removed	R-Square	Adj. R-Square	C(p)	AIC	RMSE
1	Average Percent Lupine	Addition	0.287	0.247	6.6540	171.4562	15.9610
2	Forb Diversity	Addition	0.425	0.358	4.2430	169.1249	14.7382

Table 5. Detailed summary of the linear regression analysis results examining the density of Karner Blue Butterfly (KBB) per mile. The data, collected from 20 restored barren study sites in Central Wisconsin from 2020 to 2022, were analyzed with a p-value threshold of 0.1 for statistical significance. The table presents each term used in the model, the unstandardized and standardized coefficients, standard errors, t-values, p-values, and the lower and upper bounds of the 90% confidence intervals.

Term	Unstandardized	Std. Error	t	p	Lower 90	Upper 90	Standardized
(Intercept)	69.376213	37.4629103	1.851864	0.08149354	4.205482	134.546944	NA
Average lupine	1.048998	0.4700013	2.231904	0.03936825	0.231380	1.866615	0.4272095
Forb Diversity	-28.106086	13.8624805	-2.027493	0.05858631	-52.221350	-3.990821	-0.3880832

Table 6: Summary of the stepwise selection process for the linear regression analysis conducted on migratory songbird diversity on restored barrens in Central Wisconsin. Data were collected in 2022 from 20 study sites. The alpha threshold was set at 0.1 for statistical significance. The table details the variable selection process and their impact on songbird diversity, with statistics shown as: C(p) (Mallows' Cp), AIC (Akaike Information Criterion), and RMSE (Root Mean Square Error)

Step	Variable	Added/ Removed	R-Square	Adj. R-Square	C(p)	AIC	RMSE
1	Acres	Addition	0.163	0.117	0.5640	-21.2453	0.1291
2	KBB Nectar Plants Richness	Addition	0.345	0.268	-1.0330	-24.1419	0.1175

Table 6. Detailed summary of the linear regression analysis results conducted on migratory songbird diversity in the restored barrens of Central Wisconsin. The data was collected in 2022 from 20 study sites. The table presents each term used in the model, the unstandardized and standardized coefficients, standard errors, t-values, p-values, and the lower and upper bounds of the 90% confidence intervals.

Term	Unstandardized	Std. Error	t	p	Lower 90	Upper 90	Standardized
(Intercept)	2.399573666	0.162680085	14.750261	4.040138e-11	2.116574296	2.68257304	NA
Acres	0.006474904	0.002582332	2.507386	2.260337e-02	0.001982661	0.01096715	0.5062606
KBB Nectar Plant Richness	0.016740152	0.007708664	2.171602	4.432797e-02	0.003330108	0.03015020	0.4384632