THREE ESSENTIAL CRITERIA FOR PRELIMINARY SITE ASSESSMENT FOR RESTORATION OF POLLINATOR INSECT HABITAT

by

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ABSTRACT

Insect decline is a global problem primarily caused by human-driven habitat loss. Humans – and the ecosystems around us – are entirely dependent on insects at nearly all trophic levels and for many ecosystem functions, including the pollination of plants grown for crops, textiles, medicines, and other uses. Because human-caused habitat loss is a primary driver of insect decline, humans have the opportunity and responsibility to mitigate some of that habitat loss through habitat restoration. Choosing sites for habitat restoration can be a daunting task in terms of planning, cost, labor, and ecological outcomes. My paper establishes three essential criteria for preliminary assessments of potential pollinator insect habitat restoration sites: site longevity, site connectivity, and site structural complexity. These three criteria are the foundation for a successful site restoration to ensure a site provides suitable, usable habitat for long-term use by pollinator insects. Site longevity ensures the site will be available for long-term use and is an appropriate use of time and money. Site connectivity allows for travel between restoration sites and other patches of suitable habitat. It also relates to how a site is used by pollinator insects and how isolated a population of pollinator insects at that site would be – and therefore, how susceptible to local extinction a population would be. Site structural complexity is the topographical and floral diversity of a site, including the successional stages and vertical structure of the plant communities. Each of these criteria are co-equal in terms of importance: a restoration site cannot succeed unless all three are met.

CHAPTER ONE

INTRODUCTION

Insect Decline

Insect decline is a global ecological problem. The severity of the problem is debated, but there is evidence to show a decline in many pollinator insect populations (Hallmann et al., 2017; Forister et al., 2019; Saunders et al., 2020). For example, 28% of bumble bee (*Bombus*) species in North America are considered threatened, and 155 of 184 assessed butterfly species have declining populations (Hatfield et al., 2015; Forister et al., 2023). Declining insect populations have wide-ranging ecological impacts. Insects are crucial components of nearly every ecosystem on Earth as food sources, pollinators, decomposers, biomass production and nutrient cycling, and more. Their services as pollinators provide the foundation for the continued production of many plants, and therefore the continued function of ecosystems. In particular, humans are dependent on pollinators for food production; while grains such as corn, rice, and wheat are wind pollinated, nearly all cultivated fruits and vegetables rely on insect pollinators (Lautenbach et al., 2012). Pollinators are also responsible for indirect food production: for example, alfalfa is bee-pollinated and used as hay for livestock forage (Abrol, 2012). According to Hansky and Pöyry (2007), human-driven habitat loss is the number one threat to insect populations. Because humans are causing the habitat loss, we also have the opportunity and responsibility to mitigate some of the habitat loss (Jankielsohn, 2023). My paper establishes three essential criteria for evaluating site suitability for pollinator insect habitat restoration: site longevity, site connectivity, and site complexity. These are the first three factors that should be considered when assessing sites for restoration of pollinator insect habitat. With careful planning and an understanding of basic ecological principles, restoring pollinator insect habitat can maximize ecological return for the effort and cost of the restoration to reverse the trend of insect decline.

Ecological Impacts of Insect Decline

Insects are important components of ecosystem function (Mattson, 1977; Wilson, 1987; Frost & Hunter, 2007; Price et al., 2011; Abrol, 2012; Lautenbach et al., 2012). Insects act as herbivores, omnivores, carnivores, and detritivores, participating in and facilitating nutrient cycling throughout the food web and across trophic levels. Insects are involved with ecosystem processes including, but not limited to, converting plant and algal biomass to animal biomass, being food sources for many carnivores (including humans), decomposition of plant and animal matter via mastication and excretion, regulating plant and other insect populations, and pollination (Price et al., 2011). Insects also act as vectors for diseases affecting plants and animals (again, including humans). Declines in overall abundance and species richness disrupts these processes and leaves ecosystems vulnerable to invasive species, disease outbreaks, erosion, nutrient and biomass loss, and other negative impacts (Mattson, 1977; Wilson, 1987; Frost & Hunter, 2007; Price et al., 2011).

Insects play an important role in nutrient cycling. Herbivorous insects affect the nutrient content and decomposition rate of plant litter, sequester nutrients in their body, and add fast-release nutrients via excrement and their dead bodies (Belovsky & Slade, 2000). Insects consume leaves and wood, accelerating the breakdown of lignin (Price et al., 2011). Herbivore effects on nutrient cycling are dynamic; as plant consumption increases, plant abundance decreases, but the increased consumption results in increased nutrient cycling. If the overall effect of increased nutrient cycling outpaces the amount of plant consumption, plant abundance can increase (Belovsky & Slade, 2000). However, when insect populations decline, the nutrient cycling is disrupted, resulting in organic matter buildup on the ground surface and a lack of nutrients available in the soil.

Perhaps most obviously important for humans, animal pollinators are essential for about 90% of flowering plants, including many food crops and other economically important plants (Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services [IPBES], 2016). Globally, pollinators are responsible for approximately $351 billion in annual value for commercial food production (Lautenbach et al., 2012). Adjusting for inflation to 2025 values, that number increases to about $502 billion. Although staple grain crops like rice, corn, and wheat are wind-pollinated, "over a third of crop production does depend on pollinators and about 75% of all crop species profit to varying degrees from animal pollination, including most vegetables, fruits, and spices" (Lautenbach et al., 2012). Without insect pollinators, many commercial food crops could be lost, while others could become more expensive as artificial pollination methods are implemented (Pérez-Méndez et al., 2020). Other anthropocentric benefits of pollinators include fibers for textiles, building materials, medicines, cultural practices such as music and art, and aesthetic uses (Pérez-Méndez et al., 2020). These benefits are major economic drivers, forming the basis for the textile and fashion industries, building and construction industries, biofuel production, pharmaceutical production and medical research, music production, and more (Lautenbach et al., 2012).

Sciligo et al. (2022) assessed the relationship between native pollinators, native plants, and crop production by evaluating 16 organic farms, including both monoculture and polyculture practices, adjacent natural land cover, and the effects on pollinator abundance and richness. Although strawberries can self-pollinate, self-pollination often results in malformed berries (although strawberries are technically not berries, Sciligo et al. (2022) refer to them as berries and they are colloquially known as berries). Unfortunately – or perhaps fortunately for native pollinators – malformed berries are less marketable and less profitable than better formed berries. They demonstrated that native cover near the strawberry fields increased native pollinator insect abundance and richness, while having little effect on honey bee abundance. This is important because although honey bees are often farmed for commercial pollination services, honey bees are not effective pollinators for strawberries – but native pollinator insects are. Therefore, it is better practice economically and ecologically to support native pollinator insects with patches of native habitat in agricultural areas. Sciligo et al. (2012) found that non-native honey bees did not completely pollinate the achenes, resulting in malformed berries, while native pollinator insects completely pollinated the achenes, resulting in better formed berries – which are, of course, more marketable and therefore more profitable. This finding, that native pollinators are more effective pollinators for fruit production, was also found in a global study of 41 crop systems: "wild insects pollinated crops more effectively; an increase in wild insect visitation enhanced fruit set by twice as much as an equivalent increase in honey bee visitation" (Garibaldi et al., 2013).

Humans are dependent on insect pollinators for the proliferation of food products and for the economic services. Native insect pollinator decline could be catastrophic for our food supply and economies (Pérez-Méndez et al., 2020; Garibaldi et al., 2013). Native insect pollination is as or more effective for crop pollination than non-native insect pollination or artificial pollination (Sciligo et al., 2022; Garibaldi et al., 2013; Carvalheiro et al., 2012. When native bumble bees were excluded from an apple orchard in Argentina, apple production was significantly reduced, even when non-native honeybees are present, and the orchard's profits were reduced by 2.4-fold, demonstrating that declining native insect populations could have significant economic impacts (Pérez-Méndez et al., 2020).

As demonstrated in this section, insects fill a wide variety of ecological niches and provide a multitude of benefits to humans, both directly and indirectly. Because of the depth and breadth of human reliance on insect pollinators, in this paper I will focus primarily on pollinator insects. However, my three criteria described herein also apply to potential habitat restoration sites for non-pollinator species.

Anthropogenic Causes of Insect Decline

Human effects on the environment since the Industrial Revolution are well-documented. Humans have had impacts on every ecosystem type on Earth, ranging from forest clearing to mining to urban development to oceanic trawling to the spread of microplastics across the entire planet (Amoroso et al., 2018; Wohl & Iskin, 2021; Macklin et al., 2023; Farrokhi et al., 2024). Although humans are responsible for the vast majority of habitat loss driving insect declines, humans are also capable of rectifying and mitigating some of the damage by restoring habitat for pollinator insects (Jankielsohn, 2023; Hanski & Pöyry, 2007).

Habitat loss is a significant driver of insect population decline: "… habitat loss is the number one threat to populations of insects and most other organisms, for the reason that smaller area of habitat means smaller and less viable populations" (Hanski & Pöyry, 2007). The U.S. Department of Agriculture states that approximately 53% of land in the U.S. has been converted for agricultural purposes (USDA, 2026). Additionally, urban land use has nearly tripled between 1959 and 2017, and while cropland use has steadily declined since 1959, other types of land development have increased – the declining cropland does not correspond to an increase in natural land cover; instead, those areas are converted to other anthropocentric uses (USDA, 2026). As native vegetative communities are plowed and replaced with large-scale monocrop operations – often sprayed with pesticides that may further disrupt native insect populations – there is less suitable habitat for insects, and less connectivity between areas of suitable habitat (Carvalheiro et al., 2012). Similarly, when native vegetative communities are destroyed to make way for urban and suburban development, those native plants are replaced with asphalt, concrete, and monocultures of turf grasses, resulting in less overall suitable habitat and less connectivity between areas of suitable habitat.

Climate change has had mixed effects on insects, in some ways improving conditions with longer growing seasons, but disrupting insect life cycles in other ways. For example, warming temperatures triggers insect eggs to hatch earlier; however, if the local flora has not also responded to warming temperatures with earlier growth, the newly hatched larvae have no food available (Visser & Holleman, 2001). Warming temperatures can also cause migration dates to shift earlier, resulting in a lack of food if the plants in the region have not started to grow earlier, too (Visser & Both, 2005). If the asynchrony between hatching or migration and food availability becomes too severe, entire generations of insects could be lost. Climate change can also drive range shifts for some species; generalist species with less specific habitat requirements exhibit range shifts, but specialist species with narrow habitat requirements – often dependent on scarce, fragmented habitat due to anthropogenic land disturbance – do not shift their ranges (Warren et al., 2001).

Reversing Anthropogenic Insect Decline

Ecological restoration and management have become important tools for restoring the damage done by humans. Although pre-colonial plant assemblages are often the goal for habitat restoration, that benchmark is fairly arbitrary and may not be entirely appropriate given "continued invasions of exotic species, disruption of natural processes, and the anticipated impacts from projected climate change" (Thorpe & Stanley, 2011; Harris et al., 2006). However, an understanding of historic plant communities, disturbance regimes, migration pattern disruption, and range changes can help land managers adapt the "precolonial plant assemblage" idea to the actual conditions of a given site to restore ecosystem functions (Thorpe & Stanley, 2011). The assumption is that if the native plant communities are restored, the animal component of the ecosystem can often reestablish naturally – "Field of Dreams" summarized it: "if you build it, they will come." And, as is shown below, they were correct.

Components of Habitat Restoration

Some insect species are generalists – able to subsist on a wide variety of food sources in each of their life stages – and some are specialists – which require specific hosts and one or more stages of their lives. To successfully manage for specialists, their needs must be clearly known and the management plan must account for those needs. When managing for generalists, restoring native plant communities is an effective strategy (Morandin & Kremen, 2013; Tarrant et al., 2013, Barron & Beston, 2022).

Restored native vegetation communities support native pollinator species (Tarrant et al., 2013, Barron & Beston, 2022). Tarrant et al. (2013) found that the restoration communities on reclaimed landfill sites "have the potential to play a role in reversing declining populations of flower-visiting insects by at least partly replacing important pollinator habitats" and noted the importance of having a diverse plant assemblage that provides forage throughout the growing season and overwintering habitat. Barron and Beston (2022) found that restoration prairies in Washington State had similar pollinator abundance as a remnant prairie, and both had higher pollinator abundance than an area invaded by reed canary grass (*Phalaris arundinacea*), highlighting the importance of restored habitat and the control of invasive species to support pollinator insect populations. They also noted the importance of habitat connectivity for pollinator abundance.

In the case of specialist insects, more care is needed for effective management. The specific hosts plants need to be included in restoration seed mixes and/or planted directly into management areas. However, planting massive monocultures of the host plants creates the potential for increased spread of diseases – both within the plant population and within the insect population – and lowers the local biodiversity. It is better to have areas with higher overall diversity, with high species richness of native forbs. This ensures that there are food sources available throughout the growing seasons for a multitude of insects, not only the specialists.

For example, monarch butterflies (*Danaus plexippus*) are generalist nectar-feeders as adults. Their pupal stages are entirely dependent on milkweed (*Asclepias* spp.). Monarch adults lay eggs on milkweed, and the caterpillars feed on the leaves of those milkweed plants. The milkweed sap contains secondary metabolites called cardiac glycosides, which act as herbivory deterrents; they are toxic to most animals other than monarchs and a few other species who specialize in milkweed herbivory (and their predators) (Groen & Whiteman, 2021; National Park Service, 2023). Because of their generalist and specialist life stages, restoring habitat for monarchs directly supports a multitude of other native pollinator insects: milkweed supports the larvae – and many other pollinator insects – and a diversity of other forbs that bloom throughout the growing season support the adults – and many other pollinator insects. Focusing on a single species, such as the monarch, can be an effective strategy to guide site planning, community outreach, and funding opportunities (although the last two are outside the scope of my paper).

The Mid-America Monarch Conservation Strategy is a campaign to restore 1.3 billion milkweed stems within the central and eastern United States to support the migratory population of monarchs. This organization stresses the need for diversity of nectar-producing plants along the migration route, not only the host plant, milkweed. This plan seeks to add about one-fifth of the total restored milkweed in urban areas. In the same vein, this paper will demonstrate that urban habitat can be an important component of habitat restoration for many plants and insects.

Urban Pollinator Habitat

Combined with improved connectivity with rural habitat, urban habitat can restore some of the habitat that was lost during land conversion. Urban habitat is a severely underused source of potential habitat restoration sites. This section will demonstrate that urban habitat is a viable component of landscape-level habitat restoration to bolster native pollinator insect populations.

Previous Studies

Leston and Koper (2016) found an increase in plant diversity from 10 to 80 species in urban rights-of-way (ROW) results in an 85% increase in observed butterfly species. Additionally, in areas that were mowed less frequently and vegetation was allowed to grow 40-cm high, butterfly diversity increased by 112%. Leston and Koper state that their study is "the first to note that if they have a sufficient abundance of 'butterfly plants,' urban transmission lines can also support more butterflies and greater numbers of butterflies." The 'butterfly plants' mentioned include the appropriate host plants for target butterflies and a variety of nectar-producing native plants to support the butterflies throughout their life cycles.

An important note from Leston and Koper (2016) is that the different species of butterflies react differently to the management regimes. It would be easy to assume that areas that are not mowed or sprayed with herbicide for invasive species control would always fare higher in biodiversity metrics than other management strategies; however, these results indicate that there are other factors at work for each butterfly species' success, including the prevalence of appropriate host plants, connectivity to other suitable habitat, and plant diversity. However, as noted in studies described previously, increased forb diversity tends to correlate with increased pollinator diversity (Morandin & Kremen, 2013; Tarrant et al., 2013, Barron & Beston, 2022).

Brown at al. (2023) found an increase in bee species richness and abundance, and butterfly species abundance, in response to planting native forbs, grasses, and shrubs along roadways. Their results support the idea that ROWs and other urban spaces have the potential to "support biodiversity comparable to nearby (semi) natural habitats and that management interventions can increase local biodiversity (Brown et al., 2023). They demonstrated that bee richness and abundance, and butterfly abundance, increased significantly in response to biodiversity plantings in road ROWs.

Klinger et al. (2024) targeted a single species, the monarch butterfly, and found that residential gardens in urban areas "have the potential to provide significant habitat for monarch butterflies." They examined urban habitat patches ranging from 0.012 m^2 to 4,738 m^2 and analyzed the number of monarch butterfly eggs observed within each patch. Their results indicate the most important characteristics of urban habitat for monarch butterflies is the abundance of milkweed plants, the presence of common milkweed (*Asclepias syriaca*), the diversity of nectar-producing plants in the patch, and the age of the patch (note: the authors recognize that patch age and abundance of milkweed are closely related). They conclude that even very small (<1 m^2) urban habitat patches can provide suitable habitat for monarch butterflies.

Coleman and Wait (2022) compared insect pollinator visits to urban and rural prairies in Missouri. The urban prairies varied from <0.01 hectare to 4 hectares, while the rural prairies ranged from approximately 4 hectares to 16 hectares. The urban and rural prairies had significantly different dominant forb species, but the urban prairies had more insect pollinator visits than the rural prairies. Coleman and Wait (2022) had two important takeaways. First, they demonstrated that urban habitat can, and does, support pollinator insects, even if the plant community does not reflect the typical or historic prairie community composition. Second, their data support the idea that connectivity is crucial for insect pollinator movement and foraging. The authors suppose that the rural prairies had fewer visits because they were surrounded by agricultural land with inadequate foraging, which prevents insect pollinators with shorter travel distances from accessing those prairies.

On roadsides in Kansas, Hopwood (2008) found a significant difference in pollinator abundance and richness between restored roadsides and weedy roadsides. The restored roadsides had been planted with a mix of native prairie species, and the weedy roadsides were unimproved and dominated by weedy non-native species. Hopwood (2008) found that increased native forb richness was associated with higher native pollinator richness and abundance, while also highlighting the importance of bare ground for native insects – many native bees are ground-nesting, and bare ground is a critical component of their habitat.

These studies show that urban habitat is an underused resource for habitat restoration. These areas are prime candidates for increasing connectivity and the overall amount of habitat for pollinator insects. However, each potential site needs to be evaluated for its restoration suitability based on longevity, connectivity, and structural complexity.

CHAPTER 2

STRATEGIC APPROACH

Establishing Habitat Components

The studies described in Chapter 1 demonstrate the ecological consequences of unchecked insect population decline and illustrate the need for habitat restoration to support pollinator insect populations. To best support native pollinators, the increased restored habitat must include rural, agricultural, urban, and corridor components to maximize the amount and connectivity of native pollinator habitat. Connectivity is the overarching consideration that links the habitat components under the umbrella of the preliminary evaluation criteria, and will be discussed further in Chapter 3. Coleman & Wait (2022) demonstrated that connectivity is crucial: if an insect cannot reach a patch of high-quality habitat, that habitat does not directly benefit the insect. Ensuring adequate connectivity between habitat patches allows insects to travel between areas of suitable habitat. Furthermore, habitat connectivity has a significant effect on habitat occupancy and species abundance (Hanski & Pöyry, 2007). This chapter will define and explain rural, agricultural, and urban habitat components, drawing on the literature described in Chapter 1 and existing programs that support native pollinators to develop a set of criteria for prioritizing areas for habitat restoration. Rural, agricultural, and urban areas each offer distinct opportunities and challenges for pollinator insect habitat restoration. The following sections will explain the opportunities and challenges for each, while outlining why these components are equally important for supporting pollinator insect populations.

Rural Areas

Rural areas, for the purpose of this definition, include everything not included in urban, agricultural, industrial, or other human-developed land. These areas include relic natural areas, Federal- or State-owned land (wildlife refuges, natural areas, and parks), restored natural areas, and other generally undisturbed land. These areas can offer large areas of land with multiple habitat types (site complexity) and are often protected long-term (site longevity). Rural areas already provide some habitat value for pollinator insects; identifying the management actions needed to improve that habitat quality or connectivity are more effective than a complete overhaul. Site connectivity will likely be the limiting criteria for rural habitat restoration.

Rural areas already in some sort of natural land use are prime candidates for habitat improvement. Targeted removal of invasive plant species allows for the improvement of the native vegetative communities, especially when paired with overseeding with native species (Flory & Clay, 2009; Cutting & Hough-Goldstein, 2012). In areas with dense populations of invasive species, overseeding with native species can improve the diversity of native plant species (Cardarelli et al., 2020).

Agricultural Areas

Agricultural areas are ripe with opportunities to support native pollinators. As described in Chapter 1, agricultural outcomes – in terms of yield, marketability, and profit – and pollinator outcomes are improved by increasing native forb diversity within agricultural areas. Increasing connectivity between crop land and patches of native vegetation for native pollinator insects has a measurable benefit on farmed crops and native pollinator insect populations by facilitating movement between crops and areas of native vegetation with blooms throughout the growing season (Garibaldi et al., 2013; Morandin & Kremin, 2013; M'Gonigle et al., 2015; Sciligo et al., 2022). Several avenues for this already exist in the U.S. Perhaps the most prolific is the Conservation Reserve Program (CRP), which is a voluntary program funded by the U.S. Department of Agriculture (USDA) to incentivize farmers to convert cropland and pasture to native vegetation. Another facet of the program facilitates the planting of Filter Strips and Prairie Strips. The functions of these strips are to improve water quality by filtering surface water runoff from agricultural land, control soil erosion, and improve wildlife habitat (USDA Farm Service Agency [FSA], no date). This practice supports insect populations by providing diverse foraging habitat and some connectivity to other habitat.

Even if land does not qualify for CRP funding, these areas can still be useful for pollinators and economically viable for landowners. Especially for smaller-scale farms growing fruit and vegetable crops, these plantings could have substantial economic returns as increased native pollinator populations improve the crop pollination to increase the amount and quality of the yield. Even if the areas are lower-quality semi-natural cover, they still have a positive effect on insect species abundance and diversity and contribute to landscape-level species persistence (Hendrickx et al., 2007; Duflot et al., 2015). Lower-quality habitat that does not align with historic plant community composition still supports native pollinator insects (Coleman & Wait, 2022).

Similarly, patches of native vegetation within larger monoculture farms can increase fruit production by supporting increased native pollinator populations in the area (Carvalheiro et al., 2012). As demand for food rises with the increasing global human population, more land is converted to agriculture, reducing the amount of native vegetation. This conversion reduces overall habitat for pollinator insects while also increasing the distance between areas of suitable habitat. Therefore, establishing patches of native vegetation provides forage as well as connectivity to the agricultural crops. The patches of native vegetation resulted in “enhanced abundance and diversity of mango flower visitors" which "were associated with significantly higher mango production yields" (Carvalheiro et al., 2012). This strategy benefits the farmers by increasing yield and benefits native pollinator insects by providing native vegetation with food sources throughout the growing season and connectivity between patches of native vegetation and crop land.

Agricultural Land Conversion

Another option is to fully convert farmland back to native vegetation. This is partially supported by CRP, but large-scale restorations may be better conducted by local organizations that can purchase the land (or accept it as a trust or donation) and manage the restoration long-term.

Some farmers are leasing their cropland to solar energy companies on 30- to 50-year leases. Once the solar panels are installed, that land is excellent for planting low-growing native vegetation. Prescribed fire is not used in solar arrays, so management of the vegetation is typically spot-treating invasive species and periodic mowing and mulching to reduce plant residue build-up. A solar array in Michigan is experimenting with sheep grazing, which would manage vegetation and fertilize the soil (Newstex, 2022). Regardless of management, using solar array land as an opportunity to plant native vegetation will support native pollinators.

Urban Areas

Urban areas are a mostly untapped wellspring of opportunity for pollinator insect habitat restoration. Urban areas are generally quite stable in the long-term in terms of layout, so restoring habitat within urban areas can create permanent (on a human scale) patches of habitat of varying sizes. Roads and recreational trails running in and out of the urban areas can be used as connections between patches within the urban area and to larger patches in rural or agricultural areas. Essentially, any urban areas with turf grass could have part or all of that grass replaced by native plants. Parks, yards, and business properties could convert parts of their maintained grass to native vegetation. In addition to providing habitat for pollinators, this would reduce the amount of time, money, and resources used to maintain that grass. However, it should be noted that the highly fragmented nature of urban habitat is not suitable for all species, and urban habitat cannot be a substitute, on its own, for large-scale habitat restoration outside of urban areas. In addition to its fragmented nature, urban habitat comes with a slew of risks for pollinator insects including vehicle collisions, nest removal or damage by humans, and exposure to pollutants such as light, noise, chemicals, and heat (Collins et al., 2024).

Another avenue of pollinator habitat restoration is to improve the vegetation around existing stormwater management infrastructure and the streams within cities, which are often channelized to some degree and bordered by vegetation. In addition to increasing overall habitat, restoring habitat around streams would create continuous corridors between other areas of habitat. These plantings would be a component of blue-green infrastructure designed to mitigate flood risks from climate-change-induced increases in high-volume precipitation events. Vegetated stream banks and stormwater retention ponds, in addition to providing pollinator insect habitat, have many benefits including phytoremediation, increase hydraulic conductivity, improved soil microorganism communities, and air cooling via transpiration (Corduan & Kühn, 2024). Forbs planted in these areas provide habitat for insect pollinators aboveground and contribute to water infiltration through the soil.

Corridors for Connectivity

Habitat connectivity is a crucial component of restoration (Coleman & Wait, 2022; Carvalheiro et al., 2012). Connectivity facilitates insect travel and promotes genetic diversity between insect and plant populations (USFWS, 2003). One of the most underutilized opportunities for habitat connectivity is using established, maintained utility rights-of-way as insect habitat. This has already been used to great effect in central Wisconsin along an oil pipeline right-of-way. The pipeline traverses the critical habitat for Karner blue butterfly (*Lycaeides melissa samuelis*), whose life cycle is entirely dependent on wild lupine (*Lupine perennis*). As part of a habitat conservation plan (HCP) between the Wisconsin Department of Natural Resources and the pipeline company, the right-of-way was intentionally seeded with wild lupine in support of the Karner blue. Although Karner blue recovery has been slower than initially hoped, increased efforts to restore habitat in Wisconsin have had major benefits (Hess & Hess, 2015). Across the Midwest, Karner blue populations increased between 2010 and 2012, then crashed in 2013; Wisconsin reported a population decline of 54% while the surrounding states reported declines of 80% to 100%. This difference has been attributed to aggressive restoration work in Wisconsin in the preceding years (Hess & Hess, 2015). The USFWS Karner Blue Recovery Plan suggests that corridors with habitat patches less than 300 m apart can facilitate dispersal and the maintenance of subpopulations (USFWS, 2003). This same concept can be applied to other pollinators: connectivity between habitat patches facilitates the dispersal of insects and maintenance of their populations (Baguette et al., 2012).

The U.S. is crisscrossed by utility ROWs that have to be maintained free of woody vegetation, offering the perfect opportunity to restore native herbaceous plant communities. Utility ROWs can provide patches of varying native plant community types, ranging from seral-stage to later-successional, which provides reliable food resources and supports similar insect biodiversity to other suitable habitats (Oki et al., 2021). Utility rights-of-ways can both provide suitable insect habitat and act as corridors between other areas of suitable insect habitat.

As mentioned in the discussion of urban areas, corridors can also include road rights-of-way and the areas around recreational trails. Decommissioned railways are often converted into bike trails – what better scenery along these paths than native vegetation filled with colorful flowers, fluttering butterflies, and buzzing bees?

Habitat Restoration Considerations

Large-scale habitat restoration is a daunting task. However, with careful planning and an understanding of basic ecological principles, habitat restoration can maximize ecological return for the effort and cost of the restoration. Having clear, measurable goals can also guide the planning process. This section will describe three preliminary criteria for assessing site suitability for pollinator insect habitat restoration.

Location Selection

Location is the primary concern for this paper in terms of choosing areas for restoration. Because habitat restoration should be a long-term investment, site stability is an important component. As described in Chapter 1, habitat connectivity is critical for supporting pollinator insects. Therefore, location selection is driven by the three criteria of site longevity, site connectivity, and site complexity. This will be discussed in further detail in the next chapter.

Species Focus

Although the evaluation criteria established in my paper are for general use, there are opportunities to target particular species for habitat restoration in support of larger species protection efforts. Choosing a target species should be guided by a few principles (Bried et al., 2014; Shuey, 2013; Miller & Hobbs, 2007). First, the species should be native to the area. Second, the species should offer some tangible (pollination) or aesthetic (contribute to a beautiful landscape) benefit, or be endangered/threatened, in order to earn grant funding and garner social or political support. Third, site complexity should be considered; for example, Karner blues are unlikely to persist in an urban environment due to its heavily fragmented condition, so planting lupine in urban areas specifically for Karner blues would not be ecologically sound. Finally, habitat connectivity, as it relates to the target species, must be considered. For example, it might be possible to establish a large area of suitable habitat for Karner blues, but without connectivity, that area may not be used by Karner blues – or, if the Karner blues are brought to the site, the population would be an isolated sub-population susceptible to local extinction. Karner blues have short flight durations and often do not travel far from their hatching site (USFWS, 2003). Therefore, Karner blues have narrow parameters for habitat connectivity, especially compared to a migratory insect like the monarch butterfly.

The monarch butterfly is proposed threatened due to habitat loss (USFWS, 2024). In urban areas, planting milkweed to support monarchs provides educational opportunities for children who can easily identify the iconic orange butterflies. Studies described in Chapter 1 indicated that monarchs benefit even from very small milkweed plantings, so sprinkling small pockets of milkweed throughout a city creates substantial habitat for monarchs. The Mid-America Monarch Conservation Strategy believes that urban milkweed plantings could add up to 21% of their goal to restore 1.3 billion stems of milkweed along the monarch migration route (Midwest Association of Fish and Wildlife Agencies, 2023). This shows that urban components of habitat restoration can be an important component of a species restoration effort, in addition to providing habitat for non-threatened species.

A species focus can guide location assessment or seed mix decisions, and can help with community engagement with insect habitat restoration. The idea that “a rising tide lifts all ships” is true in the case of habitat restoration: a restored native plant community benefits all native animal species, especially the pollinator insects who rely on native plants for food, protection, and a place to live.

Community Outreach

Community outreach is particularly important in urban and agricultural areas. Many people are unaware of the importance of functioning ecosystems and the critical roles plants and insects play in those functions. Davis and Stoyko (2022), while examining barriers to urban pollinator habitat, found that people had aversions to native plants because the plants are not appealing visually, would be too high-maintenance to take care of, people do not know how to care for them, there are not enough flowers, and it would not help wildlife, among other reasons. These concerns could easily be alleviated by community outreach in the form of free seminars, mailings, billboards, and online postings (reels, videos, social media posts, etc.) as they are misconceptions.

Although the concern that the plants would not be visually appealing was the most common response in the survey, that would be easily corrected by showing images of native landscaping and native prairies. Because so many common garden plants are cultivars of native plants or close relatives of native plants, there are native plant substitutes for many garden favorites. And, as time goes on, the native plants would become the cultural norm and be accepted as beautiful garden plants.

Other common concerns were that native plants would be too high-maintenance and that people do not know how to care for them (Davis & Stoyko, 2022). However, native plants are adapted to local soil and climate conditions, and would require less maintenance and upkeep than a grass lawn. Occasional weeding – or perhaps more frequent weeding the first couple years while the native plants establish – is the only considerable labor. There is no need to mow, although some people might like to clear the previous year's stalks and dead flower heads in the spring. Caring for the native plants is quite easy: plant them in a suitable place and let them grow. Planting directions can be shared in brochures, on seed packets, and in videos.

In agricultural areas, one of the easiest ways to communicate with people about pollinator habitat is through the CRP programs and non-profit organizations like Pheasants Forever, which work directly with farmers to install CRP fields and strips. These organizations are more likely to promote the benefits to the farmer, such as monetary benefits of CRP and topsoil loss reduction, but these plantings directly increase habitat for native pollinators. One major area for improvement is the seed mixes used in the plantings to increase the diversity of forbs and to ensure the species used are native to the area.

CHAPTER 3

CRITERIA FOR PRIORITIZING AREAS OF HABITAT RESTORATION

The three preliminary criteria for evaluating site suitability for pollinator habitat restoration are based in the research discussed in Chapter 2, which described the different types of areas for potential habitat restoration and some considerations associated with habitat restoration. This section will distill the information into a set of three criteria for prioritizing areas of habitat restoration in support of pollinator insects: site longevity, site connectivity, and site structural complexity. These criteria are the most important considerations for assessing site suitability for pollinator insect habitat restoration. Additionally, these three criteria form the foundation necessary for a successful habitat restoration project; just as fire requires oxygen, fuel, and heat to burn, a potential habitat restoration site must provide longevity, connectivity, and structural complexity.

Site Longevity

Site longevity is the first of the essential criteria to consider when assessing a potential restoration site, simply because the other two are irrelevant if the site is not available long-term. Sites with high connectivity and structural complexity are not useful for long-term pollinator insect population restoration if they are only available for one or two growing seasons; it can take several growing seasons for structural complexity to develop, and many native perennial forbs do not bloom in their first year (Lindborg & Eriksson, 2004; Prigge et al., 2024). Older restoration sites become more structurally similar to natural habitats, resulting in greater species abundance and richness (Grimbacher & Catterall, 2007). The longer a site can provide habitat for native pollinator insects, the better.

In many cases, habitat can be restored and protected in perpetuity via land trusts or ownership by conservation organizations. Programs like CRP offer semi-permanence through renewable 10- to 15-year contracts (USDA, no date). Municipal, county, and state land can be protected in perpetuity or for long stretches of time: parks, wildlife areas, recreation areas, and the lawns around government buildings can offer long-term habitat restoration sites. In addition to the HCP and CRP programs, the federal government offers other conservation agreements including safe harbor plans and candidate conservation agreements (with or without assurances). Safe harbor plans range in length from 5 to 100 years depending on the species being conserved, CRP contracts are typically for 10 to15 years, and mitigation measures defined in HCPs can extend in perpetuity with permanent protection and habitat management. This indicates that even shorter-lived sites (5 to 15 years) can benefit pollinator insects. However, given the assumption that supporting insect pollinators in perpetuity is a net benefit to humans (as discussed in Chapter 1), the longer a site can be in habitat restoration, the better. A common refrain in native plant restoration is *year 1 it sleeps, year 2 it creeps, and year 3 it leaps* – meaning that native plants take 3 growing seasons to establish, and may not flower during their first 2 years of growth (Wisconsin Department of Agriculture, Trade, and Consumer Protection, 2025). Simply from a plant establishment perspective, sites available for fewer than 3 years are not a good investment ecologically (or financially). However, site longevity ranging from 3 years to perpetuity provides habitat for pollinator insects.

Site longevity is connected to site ownership. If the owners are not committed to long-term habitat restoration, there is a risk of the land being developed or sold to developers, destroying any restoration efforts. If land cannot be outright owned by conservation organizations, it should be protected by legal contracts to prevent damage or development. These long-term sites become valuable sources of seed for new restoration sites, and lessons learned during the establishment of the long-term sites can be applied from a new restoration's beginning. More importantly, long-term sites provide consistent habitat for pollinator insects. Sites available for fewer than 3 years should not be considered; sites available for more than 3 years should be given increasing priority as length of availability increases.

When sites cannot be protected indefinitely, the question becomes less about ecology and more about practicality of ecological benefit versus cost and labor. Simply from a practicality standpoint, sites with fewer than 3 years longevity – such as sites in urban areas with future redevelopment plans – should be given lower priority than sites with higher longevity, whereas sites that can be permanently (human timescale) restored to pollinator insect habitat should be given top priority. Although plants may establish during shorter periods, the tradeoff between cost/labor and the duration of habitat is simply not a good use of resources when other, longer-term sites are available.

Site Connectivity

Connectivity clearly is a critical component of pollinator insect habitat. Site connectivity is complex; it includes not only the size of the patch and the distance between patches, but also the probability of occurrence of an insect population, the average migration distance of insect species, and the immigration and emigration rates of species with regard to patch size (Hanski & Pöyry, 2007). These factors come together to describe the expected rate of immigration to a given patch per unit of time (Hanski & Pöyry, 2007). However, given the complexity of some of these parameters and the dearth of readily available data for many insect species, for the purposes of my paper, site connectivity will focus on structural connectivity (the spatial configuration of habitat patches) rather than functional connectivity, which includes the behavior of an organism within the landscape structure (Baguette & Van Dyck, 2007). Sites with the potential for greater connectivity should be given priority over sites with lower connectivity potential.

Site structural connectivity is highly dependent on the restoration goals. For example, if a restoration effort is targeting a particular species, the structural connectivity must align with that species' needs. For example, Karner blues on average travel 35 to 209 m per day, although they will travel as many as 500 m between patches (USFWS, 2003). Because Karner blue butterflies, as adults, only live for about 5 days, their ability to travel between patches is quite limited. At the other extreme, bumble bees' daily foraging distances vary by species, but typically range from about 200 to 600 m, with some individuals traveling over 2,000 m (Osborne et al., 1999; Redhead et al., 2016). Therefore, it is useful to know which pollinator insect species are native to the area to tailor the site connectivity minimum distance to the native species' ability. If a restoration project is focusing on a particular species (like monarchs or Karner blues), the distance between patches should be tailored to match the average flight distances of the targeted species to ensure the patches are usable by the species. When a species has an average flight distance with a wide range, patch distance should fall on the lower end of the range to ensure the highest potential for use. If a site is designed for use by more than one species, the connectivity should correspond to the lowest average travel distances to ensure all target species are able to access the site.

Because small patches are often enough to provide the needed connectivity within urban areas, there are ample opportunities for larger-scale connections. For example, if all agricultural fields along waterbodies (including drainage ditches) had a 6-m buffer strip of native vegetation between the cultivated area and the waterbody, that would add thousands of hectares of habitat with continuous or near-continuous connectivity. CRP would not apply in all cases, so this would need to be incentivized, or it could become the cultural expectation that farmers be responsible stewards of the land they own by establishing a robust buffer of native vegetation between their fields and any waterbodies. Similarly, road and utility rights-of-way and recreational trails offer enormous stretches of connected land ripe for native habitat restoration

In addition to distance, site connectivity should consider the plants at the site. If the plants at the site are not suitable for foraging, the site offers a resting place but no food. This means that each restoration patch or site should be planted/seeded with a high diversity of native forbs that offer nectar and pollen. Although native bunchgrasses offer resting and nesting places, they do not offer food for pollinator insects. Additionally, if a restoration project is focusing on a particular species, each patch should include that species' host plant (if applicable) to maximize suitability.

Site Structural Complexity

As discussed in Chapter 1, the size of the patches is not particularly important (Klinger et al., 2024; Coleman & Wait, 2022). Klinger et al. (2024) indicate that if patches contain suitable vegetation, patches can be very small, even less than 1 m^2. Although Klinger et al. (2024) specifically studied monarch butterflies, the results indicate that even narrow strips along paths or field edges, or small- to medium-sized patches in parks or yards could be used as habitat by a wider array of pollinator insects. Although it might be nice to restore the entire 84-km corridor of the Glacial Drumlin State Trail, it may be more practical to restore smaller areas with open canopies and fewer invasive plant species to manage. Similarly, it would be an ecological goldmine to convert all the existing utility rights-of-way into high-diversity native plant communities, but the time, labor, and cost of that venture are unrealistic – not to mention the challenges and ecological disturbance of getting crews and equipment into remote, difficult terrain for ongoing restoration and management activities. Instead, identifying particular areas for restoration is key to getting the most bang for our buck. More importantly, there is no compelling ecological imperative to restore

100% of potential areas or attain 100% continuity. Large numbers of small patches covering a wide range of geologic and landscape types in a region may maximize diversity native vegetation in suitable abundance and diversity growing in patches of suitable size and connectivity can provide enough habitat to support pollinator insects at sustainable populations (Tscharntke et al., 2002). Many smaller patches can include more habitat types and support more species than a single large patch; multiple small fragments support more butterfly species than the same total area in fewer fragments (Tscharntke et al., 2002).

That is to say, there is no need to convert every square foot of turf grass to native vegetation, or to convert every hay field or pasture to native vegetation. Rather, the focus should be on which areas can support native vegetation, which areas can offer the most habitat diversity, which areas offer the most connectivity, and which are the most reasonable in terms of the cost and labor to install them versus the ecological and economic return (Valeri et al., 2025; Tscharntke et al., 2002). Habitat complexity has a positive relationship with species richness (St. Pierre & Kovalenko, 2014; Pianka, 2000; Ritchie & Olff, 1999; Chesson, 2011; Harpole & Tilman, 2007; Narwani et al., 2013). Assessing whether a site can support diverse vegetation and multiple habitat types is crucial for selecting restoration sites that will support the largest abundance of pollinator insects. Additionally, implementing management practices to mimic natural disturbance regimes can increase site complexity by creating successional community differences, whether by tree felling, mowing, or prescribed fire (Carey, 2003; Braschler et al., 2009; Severson & Rinne, 1988).

Likewise, although it may be appealing to plan a restoration to match the exact historic vegetative diversity of a region, it is more realistic to focus on plant species that serve the greatest number of pollinator insects and plant species that serve imperiled pollinator insects. Higher plant diversity and flower abundance contribute to overall insect abundance and diversity, even in lower-quality habitat (Kleijn & van Lengevelde, 2006). In restoration, perfection is the enemy of good. More native plants on the landscape is a good thing, as long as those patches of native vegetation are planted with consideration for overall landscape connectivity.

CHAPTER 4

CONCLUSION

The purpose of my paper was to demonstrate the need for habitat protections for pollinator insects and outline criteria for how to evaluate potential sites for restoration in urban, rural, and agricultural areas. Because humans are dependent on pollinator insects for the proliferation of nearly all non-grain plants we consume, pollinator insects are not only critical to human health, but also to our agriculture and economic systems. It is our responsibility, and in our best interest, to mitigate some of the habitat loss to support sustainable populations of pollinator insects.

Habitat restoration can be overwhelming to plan. The first step is to identify a suitable site. The first three criteria for evaluating and prioritizing potential habitat restoration sites are:

1. Site longevity – how long is this site available to be used as habitat?
    a. Sites with fewer than 3 years of availability should not be considered
    b. Sites with longer availability should be prioritized
2. Site connectivity – does this site have connectivity to other areas of suitable habitat, or can a connecting corridor be established?
    a. Average flight distances of pollinator insects vary widely
        i. Consider the capability of the target pollinator species, if applicable
        ii. Closer is better to serve a larger number of insects
    b. Areas with non-native grasses or other non-preferred plant species still offer rest sites for pollinators between patches
3. Site structural complexity – does this site support multiple habitat types?
    a. Variation in plant communities, both in terms of species richness and structural variation in height

b. Topographic differences to support different types of communities

c. Manage for different successional stages or disturbances

Based on these criteria, sites can be identified and evaluated for habitat restoration. Sites that meet these criteria are more likely to provide long-term habitat with ecologically suitable vegetation and high connectivity to other areas of pollinator insect habitat. If we build it correctly, they will come.

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