Pollinators and Roadsides: Best Management Practices for Managers and Decision Makers

January 2016

U.S. Department of Transportation
Federal Highway Administration

Cover Photo

Courtesy: Xerces Society for Invertebrate Conservation

Photographer: John Anderson, Hedgerow Farms, Inc.

State: California

Description: Showy milkweed (*Asclepias speciosa*) with monarch butterfly (*Danaus plexippus*), honey bee (*Apis mellifera*), and leafcutter bee (*Megachile* spp.). Milkweeds are the required host plants for monarch caterpillars and support a broad diversity of pollinators with their nectar.

Contents

Tables and Figures

Tables **Page**

Figures **Page**

Acronyms

ADOT	Arizona DOT
DNR	Department of Natural Resources
DOTs	Departments of Transportation
ESA	Endangered Species Act
FHWA	Federal Highway Administration
GIS	Geographic information systems
GPS	Global positioning systems
IRVM	Integrated Roadside Vegetation Management
ODOT	Oregon DOT
SMA	Special Management Area
USFWS	U.S. Fish and Wildlife Service
WisDOT	Wisconsin Department of Transportation

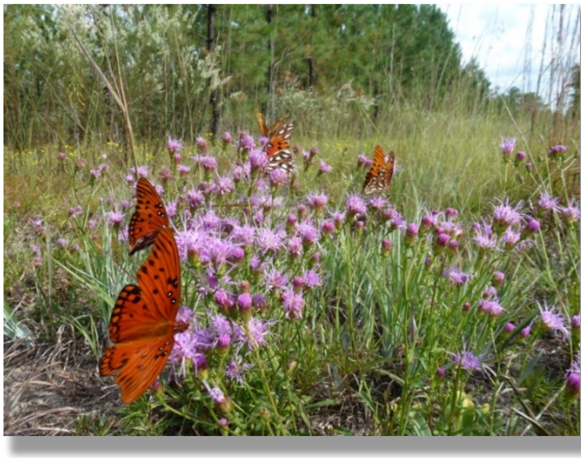
Photo Credits

Photo Number	Photo Title	Courtesy of:
1-1	Roadsides can provide fritillary butterflies and other pollinators with habitat.	Nancy Lee Adamson, The Xerces Society
1-2	Diverse plantings with many flowers, such as this Iowa roadside, support the most pollinators.	Iowa Living Roadway Trust Fund/Maria Urice
1-3	Bumble bees are valuable pollinators of crop plants and wild plants alike. However, many species, including the southern plains bumble bee (*Bombus fraternus*), are in decline.	Jennifer Hopwood, The Xerces Society
2-1	Milkweed plants (*Asclepias* spp.) grow readily in roadsides. They are important as nectar sources for pollinators and as host plants for the monarch butterfly.	Jennifer Hopwood, The Xerces Society
3-1	Honey bees are important crop pollinators.	Nancy Lee Adamson, The Xerces Society
3-2	A flower fly on a coyote brush flower.	Mace Vaughan, The Xerces Society
3-3	Despite their value to ecosystem health and agricultural productions, we know very little about the status of most wild pollinators such as this long-horned bee (*Melissodes* spp.).	Mace Vaughan, The Xerces Society
3-4	Collisions with vehicles are one of several threats to pollinators associated with roads.	iStock.com/dlewis33
3-5	Spring wildflowers bloom along a Texas road, providing nectar and pollen as food sources for pollinators. In addition to providing food and shelter, roadside habitat can help to link other patches of habitat within the landscape.	Anne Stine, The Xerces Society
4-1	Remnant prairie on an Oklahoma roadside.	Jennifer Hopwood, The Xerces Society
4-2	A stand of native asters on a Florida roadside provides late-season nectar and pollen for pollinators.	Jeff Norcini
4-3	Reducing the frequency of mowing of vegetation beyond the clear zone benefits pollinators.	Jeff Norcini
4-4	Milkweed is an attractive component of roadside plantings and supports many pollinators.	MJ Hatfield

Chapter 1
Summary

Pollinators are critical to our food supply as well as to the health of ecosystems. Wild pollinators such as the monarch butterfly and a number of bumble bee species are in decline, and beekeepers in the United States and Europe have reported significant losses of managed European honey bee colonies. Pollinator declines are attributed to loss of habitat, pesticide exposure, diseases, parasites, and effects of introduced species. Roadsides can benefit pollinators by providing foraging habitat, places to breed, nest, and overwinter, and may act as corridors, linking patches of fragmented habitat.

Photo 1-1: Roadsides can provide fritillary butterflies and other pollinators with habitat.



Key steps that State Departments of Transportation (DOTs) and other transportation agencies can take to improve the quality of roadside habitat for pollinators include 1) adjusting roadside vegetation management techniques to accommodate pollinator resource needs, and 2) enhancing and restoring native roadside vegetation to include plant materials that improve pollinator habitat.

Pollinator-friendly roadside management practices such as reduced mowing and targeted herbicide use can reduce roadside maintenance costs. Roadsides with pollinator habitat features such as abundant flowering plants can draw tourists, resulting in positive economic benefits to States and local communities. Additionally, farmers and ranchers nearby may benefit economically from roadside habitat because of the ecosystem services such as pollination and pest control the habitat supports.

Roadsides managed with pollinators in mind can achieve multiple goals of stabilizing roadsides, reducing storm water pollution, supporting wildlife, and building public exposure and appreciation for the local landscape.

Ways to adjust roadside vegetation management practices to benefit pollinators:

- Inventory roadside vegetation, using tools such as global positioning systems, geographic information systems, roadside photo imagery, field surveys, and online resources and technology such as smartphone apps to help identify and record vegetation information.
- Protect the habitat that already exists. Identify remnant habitat and prioritize vegetation management in those areas to maintain and expand native vegetation.
- Inventory nonnative, invasive, and exotic vegetation to target them for control.
- Identify areas of high likelihood for successful pollinator-friendly plantings.

- Mow roadside vegetation as little as possible – at most no more than twice per year. Time mowing to minimize disruption to the life cycles of pollinators, especially State-listed, federally-listed, rare, endemic, sensitive, and declining species of pollinators.
- Delay mowing until the fall, preferably after first frost, to benefit a variety of pollinators by allowing flowering plants to bloom uninterrupted throughout the growing season and by reducing the risk of mortality by mower to larval stages of butterflies, moths, flower flies, and other pollinators that reside on vegetation.
- Reduce herbicide use and subsequent impacts of herbicides on pollinators by using selective herbicides, spot-spray applications, and timing applications to the most vulnerable life stage of the weed.
- Provide vegetation maintenance crews with plant identification tools and training to recognize native plants as well as invasive weeds in order to reduce unintended damage to non-target plants during herbicide use.
- If sheep or goats are used to graze invasive weeds on roadsides, take into consideration the timing of the life cycles of rare, endemic, sensitive, and declining species of pollinators.
- If prescribed burns are used, use rotational burning every 3 to 5 years to allow time for pollinator populations and their habitats to recover.
- If biological control agents are used to control weeds, use only those agents that have not demonstrated plant host expansion beyond the target weed.
- If haying occurs in your State, limit it to once a growing season and restrict it in areas that support rare and declining pollinator species.
- Specific conservation measures are needed to protect State- or federally-listed pollinator species, but these measures may also generally benefit pollinators.

Implementation methods and tools:

- Implement pilot projects to test the effectiveness of reduced mowing and/or reduced herbicide strategies.
- Provide education and training about the economic and ecological value of reduced mowing to DOT staff, including administrators, State engineers, resident engineers, and district engineers.
- Identify technologies from other DOTs that have successfully implemented reduced mowing and other pollinator-friendly practices and reach out to roadside managers at those States for information exchanges.
- Provide training to roadside managers about herbicide applications, including the timing of applications and selection of chemicals for particular weeds.
- Provide training for native plant identification and invasive species identification.
- Partner with local botanical experts, State agencies, and/or universities to conduct roadside surveys with maintenance staff and share resources.
- Collaborate with State agencies or local conservation organizations to gain training from experienced land management experts and/or to implement certain technologies such as grazing and prescribed burns.

- Develop strategies for public outreach, especially to adjacent landowners, about the benefits of reduced mowing or other management activities. This may include signage, public service announcements, and written print and electronic materials.

Ways to enhance and restore native vegetation along roadsides to benefit pollinators:

- Prioritize the use of native plants in erosion control and landscape projects.
- Increase the diversity and abundance of native flowers on roadsides, especially flowering plants that benefit pollinators. Seed mixes for erosion control projects are best if they have at least 50% wildflower component, and landscape projects are best with higher than 50% densities of flowering plants.
- Select flowering species that have sequential and overlapping bloom times to provide resources for pollinators throughout the growing season.
- Include plant species known to provide quality forage to pollinators or nesting materials.
- Include butterfly and moth host plants (e.g., milkweeds for monarch butterflies).

Photo 1-2: Diverse plantings with many flowers, such as this Iowa roadside, support the most pollinators.

- Prioritize the use of locally sourced plant material, which can improve establishment and persistence of plantings and have higher value to pollinators.
- Avoid compromising highway safety by maintaining a regularly mown strip of vegetation adjacent to the pavement, avoiding tall plants in high crash zones and within lines of sight, avoiding planting species that are palatable to deer, and installing living snow fences to help reduce drifting snow.
- Prioritize sites for new high quality roadside restorations to maximize restoration success and use resources effectively. Select roadside sites that have low to moderate weed pressure, are wide, are not going to be subject to construction, and will not be impacted by adjacent land use such as pesticide drift.
- By starting with small projects and forming partnerships with restoration experts in State agencies or local conservation organizations, DOTs with limited restoration experience can develop internal expertise and expand by building off of successful projects.

Implementation methods and tools:

- Training in native plant establishment and/or partnerships with experts that can help build internal expertise.
- Increase support within State DOTs for the use of native plants in roadside plantings by providing education about the economic and ecological values of native plants and access to tools for implementing revegetation using native plants.

- Identify funding eligibilities for the use of native plants in roadside plantings.
- Plan ahead to develop restoration plans and seed mixes. Then, reach out to local native seed vendors to communicate future plant material needs in advance.
- Partner with other agencies and organizations to develop and grow a local native seed industry to support DOT plant material needs.
- Establish commitments to purchase and plant State-origin or region-origin seed to help stabilize the native seed market, while also increasing production and reducing costs.
- Maintain eco-regional plant lists of species suitable for roadside plantings that include species that provide nectar, pollen, or act as host plants for pollinators that will establish well under varying conditions, will not become weed problems or disease vectors for adjacent lands, and are of short or moderate stature to allow for sight lines along roadways.
- Communicate the economic and ecological benefits of using native plants to the public, especially to adjacent landowners. Efforts might include signage, public service announcements, written print and electronic materials, or tourism campaigns highlighting showy plantings.
- Form partnerships with public agencies and private organizations to provide education and outreach opportunities to the public.

Photo 1-3: Bumble bees are valuable pollinators of crop plants and wild plants alike. However, many species, including the southern plains bumble bee (*Bombus fraternus*), are in decline.

Chapter 2
Introduction

Report Context

Concerns about the declines of managed honey bees and wild native pollinators, such as monarch butterflies, have focused attention on the importance of habitat restoration and management in the conservation of pollinators and the ecosystem services they provide. Roadsides form one of the most extensive networks of linear habitats on earth, and in the United States, roadside rights-of-way managed by State DOTs cover an estimated 17 million acres (Ament et al. 2014). Roadsides can provide habitat for pollinators, offering food, breeding, or nesting opportunities, and can also aid dispersal of pollinators by linking fragmented habitats. Typically dominated by early-successional plant communities, roadsides can support a diversity of generalist pollinators, including bumble bees, honey bees, and butterflies as well as rare or federally-listed species.

Photo 2-1: Milkweed plants (*Asclepias* spp.) grow readily in roadsides. They are important as nectar sources for pollinators and as host plants for the monarch butterfly.

Not all roadsides are equally beneficial to pollinators. Roadsides that are intensively mown, blanket-sprayed with herbicides, or planted with introduced grasses support far fewer species of pollinators and smaller population densities than roadsides managed for native plants. Roadside vegetation management influences how pollinators use roadsides, and even influences the number of pollinators killed by vehicles driving nearby. Researchers in Europe found that the frequency of mowing was linked to the proportion of butterflies killed on roads because butterflies that had to disperse to find new habitat after roadsides were mowed had a greater likelihood of collisions with vehicles. In contrast, roadsides with more species of plants had fewer butterflies killed by traffic. By reducing the need for pollinators to disperse elsewhere to find food or nesting sites, high quality roadside habitat may reduce the numbers of pollinators killed by vehicles.

There are two fundamental approaches to improving the quality of roadside habitat for pollinators: 1) adjusting vegetation management to accommodate pollinator resource needs, and 2) enhancing and restoring native vegetation along roadsides. Here we provide best management practices for managing roadside vegetation to reduce impacts to pollinators. This includes implementing roadside plantings that provide functions, including erosion control and motorist safety, while also benefiting pollinators. We also outline challenges to implementation identified by State DOTs and roadside restoration experts, and discuss potential opportunities to overcome these challenges. Additionally, we include case studies from across the United States.

Report Development

The Xerces Society for Invertebrate Conservation and ICF International staff performed a thorough literature review of peer-reviewed and technical material and conducted interviews with State DOTs and roadside restoration experts who work with DOTs. The literature review included a comprehensive treatment of the status of pollinators, causes of decline, potential mitigation efforts, habitat restoration and management for pollinators, and applications to highway rights-of-way. The interviews provided documentation of existing roadside vegetation management practices, including information on the current State of the practice in roadside vegetation management as relates to pollinators. The interviews also provided feedback about the feasibility of implementing roadside vegetation management strategies that can benefit pollinators, highlighting both successes and challenges in improving pollinator habitat. This report is based on information identified in the literature review and obtained through the interviews.

Report Organization

These best management practices are intended as a starting point for State DOTs looking to make roadsides more pollinator-friendly. This report is organized around the key findings of the literature review and the interview report. Chapter 3, *A Primer on Pollinators and Pollinator Use of Roadside Habitat*, provides background information on pollinators, their biology, their decline, and threats to pollinators, as well as how pollinators use roadsides and the potential contributions of roadside management and restoration to pollinator conservation. Chapter 4, *Roadside Vegetation Management and Pollinators*, outlines best management practices for managing roadside vegetation to reduce harm to pollinators. Chapter 5, *Using Native Plants to Restore Roadsides for Pollinators*, outlines best management practices for roadside plantings that support pollinators. Chapter 6, *Overcoming Obstacles to Implementing Pollinator-Friendly Practices*, outlines obstacles to implementation of pollinator-friendly practices, along with tools and resources to mitigate challenges to implementation. Chapter 7, *Resources for Roadside Management for Pollinators*, provides resources; Chapter 8, *Contributors*, provides details about the authors of this report; and Chapter 9, *References Cited*, provides a comprehensive list of references.

Chapter 3

A Primer on Pollinators and Pollinator Use of Roadside Habitat

Importance of Pollinators

The ecosystem services provided by pollinators are essential to human wellbeing, agricultural production, and ecosystem health. An estimated 85% of the world's flowering plants depend on animals—mostly insects—for pollination (Ollerton et al. 2011). Pollinators sustain wildland plant communities that provide food and shelter for myriad other wildlife. Pollinators are an indispensable component of a healthy environment.

Photo 3-1: Honey bees are important crop pollinators.

Pollinators are also crucial to agriculture and to our diet. More than two-thirds of crop species are dependent upon pollinators, including crops that produce fruits, vegetables, spices, nuts, seeds, and livestock forage (Klein et al. 2006). From the coffee you drink in the morning to the apple pie you have for dessert, an estimated one-in-three mouthfuls of food and drink that you consume come from a pollinator-dependent crop (McGregor 1976; Klein et al. 2006). In fact, the most nutritious parts of our diet, the fruits and vegetables, are the products that are most dependent upon insect pollination. The majority of minerals, vitamins, and nutrients we need to maintain our health (such as vitamin C, calcium, and folic acid) come from crop plants that depend partially or fully on animal pollinators (Eilers et al. 2011). The value of insect crop pollination is estimated to be up to $27 billion in the U.S. (Morse and Calderone 2000; Losey and Vaughan 2006).

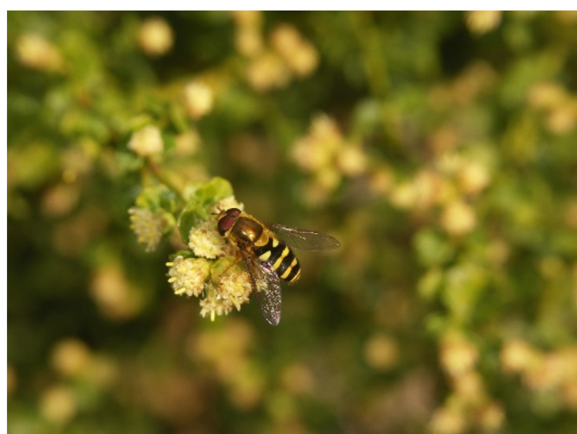
Pollinator Biology

Pollination is a mutually beneficial interaction between plants and pollinators. Animals visit flowers seeking sustenance, and in the process transfer pollen grains which allow flowering plants to reproduce. Sugary nectar and/or protein-packed pollen grains are food resources for pollinators (see Table 3-1). The great majority of pollinators are insects, including bees, wasps, flies, beetles, butterflies, and moths (Allen-Wardell et al. 1998; Kevan 1999; Kearns 2001), but many bird and bat species pollinate as well (Grant 1994; Valiente-Banuet et al. 2004). Bees are considered the most important group of pollinators for agricultural crops (Morse and Calderone 2000; Garibaldi et al. 2013) as well as for wild plants in temperate climates (Michener 2007). Bees are the most important pollinators because 1) they collect both pollen and nectar (most insects just visit flowers to drink nectar), 2) they forage in and around a nest 3) they make more trips to flowers as they are foraging to collect provisions for a nest and 4) they have more flower constancy, i.e., once they find a good forage source they visit that type of flower over and over.

The domesticated European honey bee (*Apis mellifera L.*) is the most well-known of all bees. This bee has been managed for honey production for hundreds of years and has also become widely managed for crop pollination. Honey bees contribute more than $15 billion in crop production annually in the United States (Morse and Calderone 2000). There are also approximately 4,000 species of wild, native bees in North America (Michener 2007), and many are also important crop pollinators (Tepedino 1981; Bosch and Kemp 2001; Javorek et al. 2002; Winfree et al. 2008; Garibaldi et al. 2013). Native bees are important in the production of an estimated $3 billion worth of crops annually to the United States economy (Losey and Vaughan 2006; Calderone 2012), and emerging research shows that this is likely an underestimate of their total economic contributions (Chaplin-Kramer et al. 2011). A recent analysis of 41 crop systems worldwide found that managed honey bees do not replace the pollination services provided by a diverse community of native bees (Garibaldi et al. 2013). Additionally, native bees are often more efficient than honey bees on an individual bee basis at pollinating particular crops, such as squash, berries, and tree fruits (Tepedino 1981; Bosch and Kemp 2001; Javorek et al. 2002; Garibaldi et al. 2013).

Of the other orders of pollinating insects, flies (Diptera) also provide substantial pollination services (Speight 1978; Kearns 2001; Larson et al. 2001), especially in alpine areas and tundra. Other insects such as beetles (Coleoptera) and wasps (Hymenoptera) provide pollination services, though to a lesser extent (Frankie et al. 1990; Irvine and Armstrong 1990; Kevan 1999). The contribution of most butterfly and moth species (Lepidoptera) to pollination services is unknown (Jennersten 1988; Frankie et al. 1990; Allen-Wardell et al. 1998; Westerkamp and Gottsberger 2000), but there are instances where butterflies have been documented pollinating wild plant species, including some flowering plants specially adapted for butterfly pollination (e.g., Russelia, Phlox, and Lantana; Fallon et al. 2014). Many butterfly species take long flights between flowers and may carry pollen for a long time, and they may be effective as dispersers of pollen.

Photo 3-2: A flower fly on a coyote brush flower.



In addition to insect pollinators, there are two groups of nectar-feeding vertebrates that play an important role in pollination: hummingbirds and bats. There are 12 species of nectar-feeding bats that are known pollinators in North America and Mexico (National Research Council 2007). The known ranges for these bats corresponds closely with the distribution of columnar cacti (e.g., saguaro [*Carnegiea gigantea*], *Pachycereus* spp., *Stenocereus* spp., *Lophocereus* spp.) and agaves (*Agave* spp.), the main species they are known to pollinate (Valiente-Banuet et al. 2004), primarily in the deserts of Arizona, California, Nevada, New Mexico, and Texas. Hummingbirds, which pollinate about 130 native plant species with flowers adapted for hummingbird pollination, make long migratory journeys in North America and depend on nectar corridors to meet the energy demands they undergo to sustain their long-distance movements (Nabhan et al. 2004).

Table 3-1. Pollinator Habitat Needs

Pollinators	Food	Shelter
Bumble bees	Nectar for adults; nectar and pollen collected as provisions for larvae	Nest in small cavities, underground in abandoned rodent nests, under clumps of grass, or in hollow trees, bird nests, or walls
Ground-nesting bees	Nectar for adults; nectar and pollen collected as provisions for larvae	Nest in bare or partially vegetated, well-drained soil
Tunnel-nesting bees	Nectar for adults; nectar and pollen collected as provisions for larvae	Nest in narrow tunnels in dead standing trees, or excavate nests in pith of stems and twigs. Some construct domed nests of mud, plant resins, saps, or gums on the surface of rocks or trees
Beetles	Pollen and nectar as adults; vegetation as larvae or prey such as aphids, slugs, insect eggs	Larvae overwinter in loose soil or leaf litter Adults shelter under rocks, logs, brush
Butterflies and moths	Vegetation of larval host plants; nectar; some males obtain nutrients, minerals, and salt from rotting fruit, tree sap, animal dung and urine, carrion, clay deposits, and mud puddles	Host plants; protected site such as a tree, bush, tall grass, or a pile of leaves, sticks, or rocks
Flies	Nectar and sometimes pollen as adults; insect prey such as aphids, scales, mites, thrips as larvae	Larvae found on plants near prey Pupae and adults overwinter in soil or leaf litter
Wasps	Nectar as adults; insect prey such as caterpillars, aphids, grasshoppers, planthoppers, and true bugs as larvae	Many nest in the ground; others nest in tunnel nests in wood or cavities in mud or resin
Bats	Nectar, pollen, fruit	Caves and mine shafts, trees, and various structures including bridges
Hummingbirds	Nectar, insects, tree sap, spiders, caterpillars, aphids, insect eggs, and willow catkins	Trees, shrubs, and vines near suitable foraging habitat

Adapted in part from Marks 2006; Mader et al. 2014

Pollinator Decline

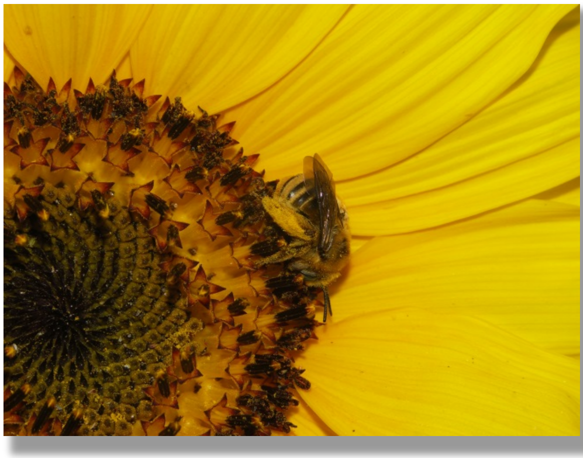
Globally, pollinators are in decline (Biesmeijer et al. 2006; National Research Council 2007; Potts et al. 2010). Pollinator declines are attributed to the loss, degradation, and fragmentation of habitat (Kremen et al. 2002; Potts et al. 2010); introduced species (Memmott and Wasser 2002; Tallamy and Shropshire 2009); the use of pesticides (Kevan 1975; Pisa et al. 2015); habitat disruption from grazing, mowing, and fire (Potts et al. 2005; Johst et al. 2006; Hatfield and LeBuhn 2007); and diseases and parasites (Altizer and Oberhauser 1999; Colla et al. 2006; Cameron et al. 2011).

In the U.S., the number of honey bee colonies has been in decline over the past half-century because of disease, parasites, lack of floral resources, insecticides, and other factors (National Research Council 2007). Since 2006, beekeepers have experienced record high annual hive losses of 29% or more (Bee Informed Partnership 2014).

Though little is known about the status of most of North America's pollinators, what data does exist suggests that numerous species are experiencing declines similar to or more severe than the declines seen in honey bees. One-quarter of North America's bumble bees have experienced significant declines (Hatfield et al. 2014), including declines in species that were formerly some of the most common species (Evans et al. 2008; Grixti et al. 2009; Cameron et al. 2011).

Monarch butterflies (*Danaus plexippus*) in North America are vulnerable to extinction, according to a recently completed assessment funded by the U.S. Forest Service and undertaken by NatureServe and the Xerces Society for Invertebrate Conservation (Jepsen et al 2015). Monarch butterfly populations have dropped by 90% east of the Rocky Mountains (Rendón-Salinas and Tavera-Alonso 2014) and by 50% west of the Rockies (Monroe et al. 2014). Three factors appear most important to explain the decline of eastern monarchs: loss of milkweed breeding habitat due to increased use of herbicides on genetically modified herbicide-resistant cropland and land conversion, logging at overwintering sites, and an increase in extreme weather events (Jepsen et al 2015). The loss of milkweeds, the monarch's required larval host plants, has been significant, particularly within agricultural fields (Hartzler 2010; Pleasants and Oberhauser 2012).

Photo 3-3: Despite their value to ecosystem health and agricultural productions, we know very little about the status of most wild pollinators such as this long-horned bee (*Melissodes* spp.).



Other butterfly species have also seen significant declines. NatureServe (a primary source for species conservation data, status, and trends in the United States) has assessed all 800 butterfly species in the United States and has found that 141 (17%) are at risk of extinction (NatureServe 2014). Twenty-six species of butterflies are listed as threatened or endangered under the Federal Endangered Species Act (U.S. Fish and Wildlife Service 2014). Some studies are also showing regional declines in butterfly species (Forister et al. 2011).

The populations of both hummingbirds and nectar-feeding bats throughout the southwestern United States have also experienced declines (National Research Council 2007). Hummingbirds face disruption of migratory routes and loss of habitat (Calder 2004), while nectar-feeding bats face disturbance of their roost sites and removal of foraging habitat and nectar sources (U.S. Fish and Wildlife Service 2006).

The loss of pollinators negatively affects plant reproduction and plant community diversity (Bawa 1990; Fontaine et al. 2005; Brosi and Briggs 2013). Threats to pollinators may have profound consequences for ecosystem health as well as our food systems (Kearns et al. 1998; Spira 2001; Steffan-Dewenter and Westphal 2008).

Roadsides and Pollinator Conservation

Concerns about pollinator decline and its repercussions have led to increased efforts to reduce threats to pollinators. Managing existing habitat for pollinators and restoring additional habitat has been demonstrated to increase pollinator abundance and diversity (Fiedler et al. 2012; Klein et al. 2012; Morandin and Kremen 2013), and roadsides are a conservation opportunity to increase pollinator habitat. Roadsides provide several ecological functions for pollinators, including serving as foraging habitat, providing breeding or nesting opportunities, and aiding dispersal of pollinators by linking fragmented habitats.

Pollinator Food Sources

Flowering plants in roadsides are important sources of nectar and pollen for pollinators that reside within the roadside habitat (Munguira and Thomas 1992) as well as those that use the roadside as a partial habitat and reproduce or overwinter elsewhere (Ouin et al. 2004). Roadsides have the potential to provide resources needed for all life stages (e.g., host plants, nectar plants, and overwintering habitat for butterflies). For example, roadsides can wholly support butterfly and moth populations if nectar and host plants are sufficiently abundant (Munguira and Thomas 1992; Saarinen et al. 2005). Roadsides can also provide food for managed honey bees. Honey bee colonies require diverse sources of pollen and nectar, and a lack of forage is frequently cited as a primary contributing factor to declines in honey bee health (National Research Council 2007).

The availability of floral resources influences the abundance and diversity of butterflies (Saarinen et al. 2005) and bees (Hopwood 2008) found on roadsides. A diversity of flowers with a succession of bloom throughout the growing season benefits wild pollinators such as solitary bees and monarch butterflies, as well as managed honey bees, which benefit from a diversity of pollen sources to maintain a healthy immune system (Alaux et al. 2010; Di Pasquale et al. 2013).

Shelter and Nest Sites

Roadsides can also provide shelter, sites for nesting or egg-laying, or overwintering habitat. Bees provide for their young by constructing nests in which their offspring develop. Many ground-nesting bees prefer to nest in sunny, bare patches of soil (Linsley 1958). Such patches can be found around the bases of native bunch grasses such as little bluestem (*Schizachyrium scoparium*) that tend to grow in dense bundles, leaving small areas of bare ground exposed between plants. Hopwood (2008) found that ground-nesting bees in Kansas were more common in roadsides with native plantings. In contrast, roadsides with a tight sod of brome or other nonnative cool season grasses had fewer ground-nesting bees.

Roadside vegetation can also provide habitat for tunnel-nesting bees, which nest in hollow or pithy stems or other small cavities. Bumble bees require a small, insulated cavity, such as underneath grass clumps (Svennson et al. 2000) or under the thatch of bunch grasses (Hatfield et al. 2012).

The breeding and overwintering habitat needs are less understood for other groups of pollinators, but Schaffers et al. (2012) has recorded syrphid fly species and soldier beetles overwintering in roadside soil or litter. Butterflies and moths may also utilize roadsides as overwintering habitat (Schaffers et al. 2012) or shelter (Saarinen et al. 2005).

Landscape Connectivity

Landscape connectivity is important for the populations of many species, but due to urbanization, agricultural intensification, and other human activities, habitat is becoming increasingly fragmented (Saunders et al. 1991). Roadsides extend across a variety of landscapes, often contain greater plant diversity than adjacent lands, and are generally excluded from further development and major disturbances. In developed landscapes, such as intensively managed agricultural lands, roadsides may provide areas of refuge for pollinators in an otherwise inhospitable environment. The linear shape and connectivity of roadsides may help pollinators move through the landscape, either for daily foraging or for dispersal to larger habitat patches (Dirig and Cryan 1991; Ries et al. 2001; Hopwood et al. 2010).

Threats to Pollinators from Roadsides and Roadside Management

Photo 3-4: Collisions with vehicles are one of several threats to pollinators associated with roads.

Roads can pose specific threats to pollinators. Roadside vegetation management can be harmful to pollinators (Johst et al. 2006). Roads can be a source of mortality for pollinators due to collisions with vehicles (Munguira and Thomas 1992). Roads fragment and degrade habitat (Trombulak and Frissell 2000). Roads may act as barriers to pollinator movement (Valtonen and Saarinen 2005). The prevalence of invasive and nonnative species on roadsides reduces pollinator abundance and diversity (Hopwood 2008). Finally, roadsides are exposed to pesticide drift from adjacent land (Krupke et al. 2012) and to pollution from vehicles (Jablonski et al. 1995). Despite these threats, roadsides provide an opportunity to increase pollinator habitat and contribute to pollinator health. The roadside management practices outlined in this document lessen the negative impacts of many of these threats.

Future Conservation Opportunities in Roadside Management

Roadside habitat restoration and modification of roadside vegetation management practices can mitigate the threats to pollinators that are associated with roads. For example, managing roadsides to maximize plant diversity through the judicious use of mowing and spot-spraying of herbicides can promote pollinators. Roadsides with remnant or restored vegetation can lessen the effects of habitat fragmentation by functioning as corridors and connecting larger habitat patches (Forman et al. 2003; Huijser and Clevenger 2006). Additionally, if roadside restorations contain floral resources, pollinators will be less likely to seek habitat elsewhere, reducing their risk of being killed by vehicles (Ries et al. 2001; Skórka et al. 2013). The removal of invasive species increases pollinator abundance and diversity (Hanula and Horn 2011; Fiedler et al. 2012), and roadside restorations that replace invasive plants with native vegetation improve pollinator habitat.

Roadsides can provide quality habitat for a diverse community of pollinators if managed with care. Managing roadsides with pollinators in mind can also benefit other insects that contribute to crop pest control as well as songbirds and game birds. As patches of refuge for pollinators in otherwise inhospitable landscapes, roadside habitat can contribute to the maintenance of healthy ecosystems and provision of ecological services such as crop pollination.

Photo 3-5: Spring wildflowers bloom along a Texas road, providing nectar and pollen as food sources for pollinators. In addition to providing food and shelter, roadside habitat can help to link other patches of habitat within the landscape.

This page intentionally left blank.

Chapter 4
Roadside Vegetation Management and Pollinators

Overview

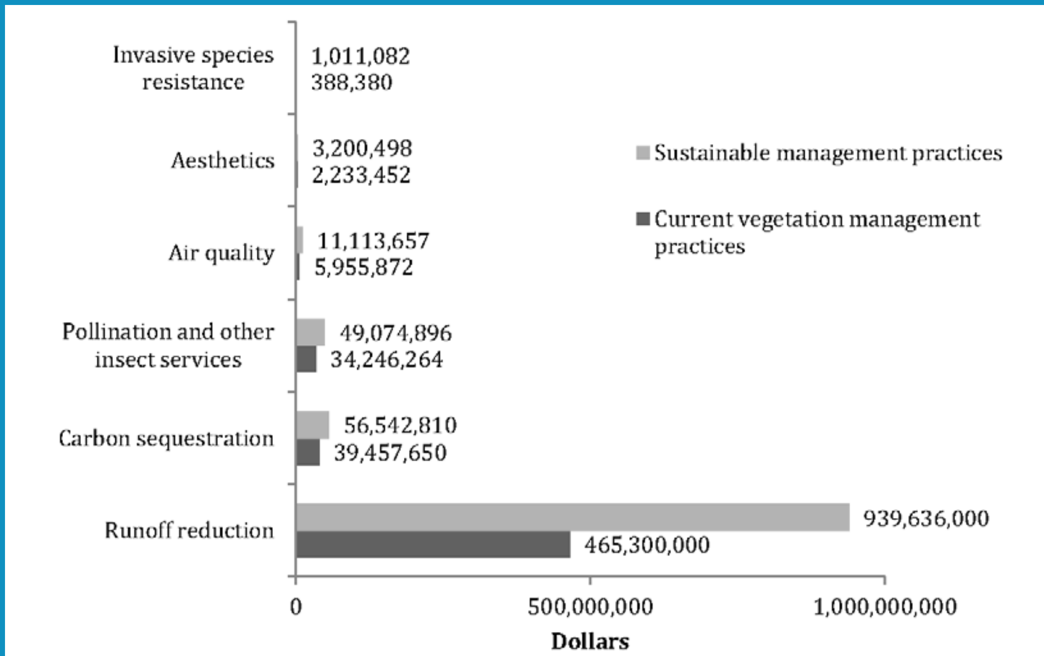
Roadside vegetation management during the growing season can adversely affect pollinators. Mowing, herbicide use, prescribed burning, and grazing all remove flowering plants that pollinators rely on for food. For example, mowing or conducting a prescribed burn during the growing season will also destroy larval pollinators present on plants (e.g., caterpillars on host plants) as well as the nests of tunnel-nesting bees and bumble bee colonies.

Roadsides Provide Important Ecosystem Services

A recent report from the University of Florida, Institute of Food and Agricultural Sciences estimated the value of ecosystem services and functions provided by Florida's roadsides. Pollination was among the ecosystem services identified. Other services roadsides support include carbon sequestration, improved air quality, reduction of invasive species, pest control by wild insects, runoff reduction, and aesthetics. The estimated total value of these services in Florida was over $500 million annually, a value that could be doubled if wildflower areas were designated and sustainable maintenance practices such as reduced mowing were widely adopted. (See graph on page 4-2.)

There are adjustments that can be made to keep roadside vegetation management cost effective and safe for motorists while also reducing harm to pollinators. Roadside inventories can identify existing habitat that is valuable to pollinators, sites in need of invasive species management, and potential sites for future wildflower plantings. The timing and frequency of mowing can be adjusted to accommodate pollinators. The use of spot-spraying herbicides and adoption of spray technologies can reduce off-target herbicide use and protect flowering plants and host plants valuable to pollinators. Grazing and prescribed burns can be timed to reduce impacts to any rare or declining pollinator species in the region as well as the general pollinator community. Integrated roadside vegetation management strategies used to support plant diversity will benefit pollinators.

Economic Benefits of the Ecosystem Services Provided by Florida's State Highway System



Data from Harrison 2014.

For the full report, "Economic Impact of Ecosystem Services Provided by Ecologically Sustainable Roadside Right of Way Vegetation Management Practices," visit http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_EMO/FDOT-BDK75-977-74-rpt.pdf.

Roadside Vegetation Inventories

Photo 4-1: Remnant prairie on an Oklahoma roadside.

A roadside vegetation inventory to map plant species of interest provides information to roadside managers that can improve roadside management. All plants of interest ideally would be included in inventories, including native species, invasive species, and noxious plants. Global positioning systems (GPS) and geographic information systems (GIS) are powerful tools that can improve the efficiency of inventories. Vehicle-mounted photographic equipment allows vegetation and GPS locations to be recorded easily and reviewed at a later date. Or personnel might inventory roadside vegetation by traveling roadways and entering the GPS data to record various attributes of the roadside vegetation while another person is driving. There are some limitations with using photos or driving surveys to characterize vegetation, and true inventories and assessments involve walking among the plants in the roadside. Photo or driving surveys can be followed with targeted field surveys if needed.

However the information is obtained, the establishment of baseline vegetation conditions and locations allows managers to make informed management decisions, target management operations to reduce costs, effectively evaluate conditions for future projects, share vegetation information between agencies, and assess the effectiveness of management activities over time.

Remnant Habitat

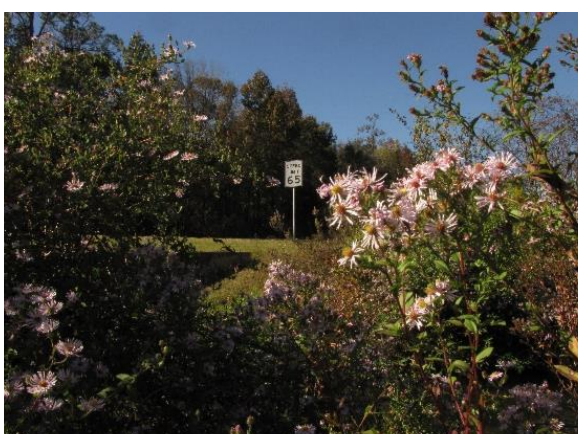
> "The wildflowers are already there. We just need to stop mowing them down." – Jeff Caster, Florida Department of Transportation

Roadside vegetation inventories can identify remnant habitat, which is portions of the natural habitat that was once present on a much larger scale before development took place. Because remnants are the last remaining patches of intact habitat, they often have high conservation value. Rare plants, and rare animals that depend upon those plants, may reside in roadside remnants.

Identification of remnant habitat can allow roadside managers to make informed decisions about how to manage remnant habitat to allow it to persist, to help sensitive species to survive, and to comply with applicable State or federal protection laws. Pollinators that are habitat specialists, with very specific habitat needs, particularly benefit from the preservation of roadside remnants.

Informed management of remnant roadside habitat can transform a degraded roadside remnant into a diverse, high quality roadside. Often a remnant just needs a carefully timed mowing or prescribed burn to return it to a diverse stand of native plants. Florida DOT has recently adopted a new procedure to focus on identifying naturally occurring wildflower areas and managing those areas with care. In Nebraska, where portions of remnant prairie have been identified along Nebraska Department of Roads rights-of-way, spraying and mowing are restricted until after October 1 (NDOR 2014). Delaying disturbance until the fall allows the wildflowers and grasses to produce seeds and complete their life cycles.

Photo 4-2: A stand of native asters on a Florida roadside provides late-season nectar and pollen for pollinators.



Once identified, signage can help indicate roadside remnant habitat. Texas DOT uses signage to indicate roadsides with rare plant species. Oregon DOT (ODOT) designates Special Management Areas to protect threatened and endangered plants on rights-of-way, using signage to indicate the approved site-specific management strategies.

Case Study: Florida Resolves to Protect Wildflowers on Roadsides

Florida, home to a great diversity of plants and animals, was once dubbed the "land of flowers" by a Spanish explorer in 1513. Many of these wildflowers can be found on Florida's 200,000 acres of roadsides. However, wildflower proliferation along roadsides can be limited by the frequency of mowing. Roadside mowing can be very intensive in some parts of Florida, particularly in urban areas. When showy stands of wildflowers were mowed during bloom when pollinators were present, concerned citizens contacted Florida DOT. Jeff Caster, State Transportation Landscape Architect with Florida DOT, describes the situation: "There would be butterflies on the side of the road feasting on the native vegetation and we would come in and mow it all down and we would get people naturally upset with us. Environmentally conscious citizens called us to complain that we were mowing down wildflowers and butterfly habitat."

Florida DOT isn't able to alter their management plans based on direct requests from a garden club or an individual that wants less roadside mowing. But citizens in Wakulla County found another way. They worked with their county commissioners to draft a resolution that made it county policy to preserve existing stands of roadside wildflowers. Then, county staff worked with Florida DOT to develop a roadside management plan to accommodate the resolution.

Recognizing the cultural, historical, and environmental significance of native wildflowers, 27 out of Florida's 67 counties have moved to adopt similar wildflower resolutions. These counties "make a commitment to saying they want to enjoy the visibility of wildflowers for whatever reason, some do it to attract nature-based tourism, some doing it to help their farms," Caster says. A model resolution can be found on the Florida Wildflower Foundation's website (http://flawildflowers.org/resolution.php).

Florida's unique grassroots approach to protecting wildflowers at the county level has great potential for pollinator conservation.

Invasive and Noxious Weeds

Many nonnative and invasive plants are disproportionately present in roadsides, where they have optimal conditions for invasion and dispersal (Tyser and Worley 1992; Hansen and Clevenger 2005). Invasive plants that displace native species can decrease the quality of roadside habitat for pollinators (Valtonen et al. 2006; Hopwood 2008). Inventories can aid in control of invasive and noxious weeds by identifying locations where eradicative measures are needed, and through the monitoring of sites over time to evaluate effectiveness of management efforts.

Tools to Identify Invasive Weeds

State DOTs can partner with other agencies, organizations, and the general public to help keep an eye out for infestations of invasive species. Indiana DOT, for example, is a member of the Great Lakes Early Detection Network. This network has a smartphone application (app) that anyone can use to enter invasive species pictures and location data into a monitoring system. The app can be found here: http://apps.bugwood.org/mobile/gledn.html. More information can be found here: https://www.eddmaps.org/indiana/.

Another phone app that may be useful is the United States Forest Service's map for identifying invasive species, available at http://www.srs.fs.usda.gov/news/499.

An electronic version of the book "Field Guide to Common Roadside Invasive Plants," is available here: http://www.fhwa.dot.gov/modiv/programs/invasive/.

Priorities for Future Restorations

Roadside inventories can help inform and direct future plantings, and can be used to identify rights-of-way that might be candidates for future revegetation efforts. For example, inventories can help pinpoint possible locations for pollinator plantings. If the objective is to provide a biological corridor for pollinators, DOTs can work with State agencies or conservation organizations to determine stretches of road between existing habitat patches to target for plant restoration. If the goal is to establish wildflower plantings to support pollinators, inventories can help with the selection of sites that meet criteria that will maximize the effectiveness of the planting, such as visibility to the public, moderate to low weed pressure, and adjacent to land that does not pose a threat to the persistence of the planting.

Pollinators and Integrated Roadside Vegetation Management

"Roadsides have historically been managed as a utility rather than as a natural resource. We maintained roadsides to keep nature from encroaching, thinking that roadsides are incompatible with functioning habitat and corridors for wildlife. But we know now that it can be done." -- Jeff Caster, Florida Department of Transportation

Once current roadside conditions and composition of vegetation is assessed, vegetation management plans can be developed. State DOTs may want to develop Integrated Roadside Vegetation Management (IRVM) plans. Because IRVM involves tailoring management to specific site conditions, an IRVM program can be very compatible with pollinator protection. By encouraging plant diversity and reducing mowing and herbicide use, IRVM improves the quality of the roadside habitat. IRVM practices that limit disturbance but maintain plant diversity, such as spot mowing to reduce weed seed production, limited grazing, and occasional prescribed fire, will likely also benefit pollinators. Species mixes that have been designed for IRVM plantings can fulfill functional roles that are valuable to roadside vegetation management but can also support pollinators.

Of the nine State DOTs we interviewed as part of this project, five—California, Iowa, Idaho, Oregon, and New York—have formal IRVM programs that are supported by policy, training, and guidance documents. The four agencies without a formal IRVM program—Arizona, Florida, Ohio, and Minnesota—report using some aspects of IRVM.

Case Study: Monarch-Friendly Roadside Management: Roadsides for Wildlife Program, Minnesota
Transportation corridors are a significant, yet often overlooked, opportunity for monarch butterfly conservation. Monarchs are typically present in Minnesota from May through early September, and roadside milkweeds are a prime resource in supporting their population. Recognizing roadsides as important resources, the Minnesota Department of Natural Resources (DNR) Roadsides for Wildlife Program has engaged rural landowners and State and local transportation agencies and presented them with a comprehensive set of management recommendations, which are intended to protect plants and wildlife while also balancing the need for road safety. Among these recommendations are: • Using native prairie plants for roadside revegetation. In Minnesota, more than 500,000 acres of roadsides are available for wildlife habitat in just the southern two-thirds of the State, a region that includes prime areas of pheasant habitat. The DNR encourages transportation agencies to replant these areas with native grasses and wildflowers whenever they are disturbed for routine maintenance or new road construction. In addition to supporting monarchs and other wildlife, deep-rooted native plants such as big bluestem (*Andropogon gerardi*) and lead plant (*Amorpha canescens*) (see also Figure 5-1) increase infiltration, capture runoff from nearby farmlands, and improve aesthetics. Working with the Minnesota State Department of Transportation and county and township highway departments, the DNR has completed hundreds of roadside prairie habitat restoration projects across the State, totaling thousands of acres of restored habitat. Many of these efforts include milkweeds. • Delaying mowing of roadside ditch bottoms and back slopes until after August 1. Although intended to protect ground-nesting birds, late-season mowing also provides a longer period of time for monarch caterpillars to develop and extends the availability of nectar plants later into the summer. From a monarch conservation perspective, mowing would ideally be delayed further into the fall, until migrating monarchs have left the State, but the recommendations recognize the need some transportation managers have to maximize mowing opportunities with limited staff resources. Widespread herbicide spraying and burning are not recommended in ditch areas. • Using shoulder and spot mowing to manage invasive species and safety concerns. The DNR points out to program participants that widespread mowing and herbicide spraying are not only detrimental to wildlife but are also expensive and often unnecessary. By focusing on problem spots, transportation agencies can save money and time. For more information about Minnesota's Roadsides for Wildlife Program, visit http://www.dnr.state.mn.us/roadsidesforwildlife/index.html.

Mowing Recommendations

Adoption of a reduced mowing regime for the vegetation beyond the clear zone is one of the most significant changes that State DOTs can make to benefit pollinators. When roadside mowing occurs during the growing season, it can directly kill pollinators in the egg or larval stages, such as butterfly caterpillars or bumble bee larvae within their colony's nest, because they cannot escape the mower (Humbert et al. 2010; Hatfield et al. 2012). The indirect impacts on pollinators through the temporary removal of flowering plants that provide nectar and pollen and butterfly host plants are even greater (Johst et al. 2006).

Although mowing during the growing season can be harmful to pollinators, limited mowing can also be beneficial to pollinators by rejuvenating wildflower populations and keeping woody plants from invading (Parr and Way 1988; Noordijk et al. 2009). Without some management intervention, roadside vegetation may become degraded by the encroachment of woody plants or by the invasion of noxious weeds. Mowing is an effective management tool to prevent vegetative succession and to help control weed populations. Strategic reduced mowing and consideration of the timing of mowing can improve roadside habitat quality for pollinators.

Photo 4-3: Reducing the frequency of mowing of vegetation beyond the clear zone benefits pollinators.

Beyond value to pollinators, reducing mowing can provide DOTs with significant cost savings. In 2011-2012, Florida DOT spent $13 million on roadside mowing. The University of Florida, Institute of Food and Agricultural Sciences report, "Economic Impact of Ecosystem Services Provided by Ecologically Sustainable Roadside Right of Way Vegetation Management Practices," found that Florida DOT could reduce its costs by 30% by implementing sustainable management practices such as reduced mowing (Harrison 2014).

Despite the economic and ecological benefits that reducing roadside mowing provides, it may not be adopted readily due to concerns that reduced mowing may increase dangerous animal-vehicle collisions. Common perceptions about reduced mowing include 1) that the unmown roadside vegetation will harbor more deer or other large herbivorous mammals that can be involved in vehicle crashes and 2) motorists will have greater difficulty viewing and avoiding animals entering the road.

In contrast to these perceptions, data indicates that reduced mowing of the entire roadside right-of-way may not influence deer-vehicle crash frequency. For example, researchers comparing deer-vehicle crash frequency data before and after reduced mowing was implemented in two Northeastern States found no relationship between mowing regime and crashes (Barnum and Alt 2013). In a Mississippi study comparing mowing and deer presence in roadside plant communities, researchers found that deer preferred the plots mowed four times a year over the plots mowed only once, though there were no significant differences in the height of the vegetation in the treatment plots three weeks after each mowing (Guyton et al 2014). Mowing can increase the palatability of some plants, thus increasing foraging by deer in roadsides (Mastro et al. 2008).

Frequency and Timing of Mowing

Mow roadside vegetation (beyond the clear zone) as little as possible.

- Do not mow more than twice a growing season.
- Optimal mowing time for pollinators varies with region but in general, delaying mowing until after the first frost will benefit pollinators.

Pollinator abundance and diversity found on roadsides is tightly linked to roadside floral abundance and the number of flowering plant species (Ries et al. 2001; Hopwood 2008). Mowing regimes that encourage plant diversity also benefit pollinators. In contrast, frequent mowing reduces wildflower bloom, stunts plant growth, and over time, leads to reduced wildflower diversity and density, which can negatively impact pollinators (Gerell 1997; Saarinen et al. 2005). Additionally, frequent mowing can be very costly (Harrison 2014).

To reduce harm to pollinators, roadsides mown no more than twice a growing season are ideal. Mowing a site only once a year, or even every other year, would have the least impact on pollinators. If weed management is the goal, mowing could be limited to patches of weeds and timed to reduce seed production (Brandt et al. 2011). Mowing techniques that reduce mortality of birds and small mammals, such as reduced mower speed, a high swath height (6 inches or higher), or the use of a flushing bar may also reduce risk to pollinators to some degree.

Some States have a reduced mowing policy that restricts the frequency of mowing or stipulates a time frame when mowing may be conducted. For example, in Minnesota, where concerns over declining pheasant habitat sparked adoption of a reduced mowing law, road authorities can only conduct mowing of the entire right-of-way between July 31 and August 31, a timing which reduces damage to grassland bird nests.

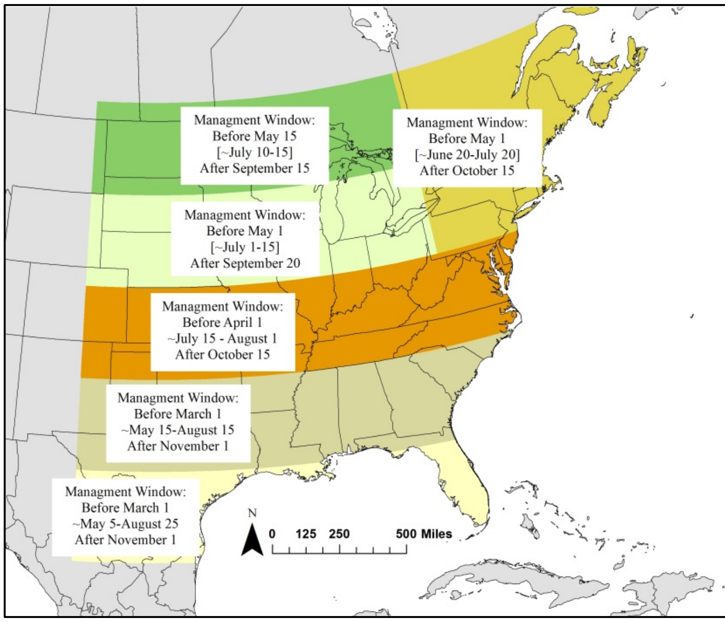
Timing roadside mowing to benefit pollinators can be a balancing act between other management priorities and the habitat needs of other wildlife. Delaying mowing until autumn after the first frost will benefit a variety of pollinators by allowing flowering plants to bloom uninterrupted throughout the growing season (Valtonen et al. 2006; Johst et al. 2006). It also reduces the risk of mortality by mower to larval stages that reside on vegetation (e.g., butterfly caterpillars, larval flower flies). However, it is difficult for many State DOTs in central and northern regions to conduct mowing in the fall when they are transitioning to winter operations. Some States contract out mowing operations, and this may be one way to free up staff to ready for winter and also avoid impacts to pollinators. Ultimately, State DOTs need some flexibility on when to mow during the growing season, in order to balance all the competing priorities for their time.

Timing mowing to reduce impacts on pollinators will vary from region to region. A single mow in Kansas in July can knock back dominant grasses and promote wildflower growth (Collins et al. 1998). In Texas, a mow in spring after the first bloom and then a second mow in the fall can stimulate wildflower propagation. In California or other arid regions, it might be most appropriate to mow after the first rain or when the relative humidity is high to avoid fires started by mowers.

Milkweeds, host plants of monarch butterflies, can commonly be found growing in roadsides (Hartzler 2010). Mowing of roadsides can influence the value of the roadside habitat for monarch butterflies by reducing host plant abundance as well as nectar sources. Mowing may be particularly detrimental for monarchs if it takes place during peak reproduction times, for example, between mid-March and early May in Texas (See Figure 4-1 for windows when mowing has the least impacts on the reproduction of monarchs). In upstate New York, mowing common milkweed in July spurred regrowth of the milkweed and increased monarch butterfly caterpillar development over unmown milkweeds (Fischer et al. 2015). In Oklahoma, a mid-summer mow or burn will promote milkweed growth that can support late summer monarch breeding (Baum and Mueller 2015).

If roadside habitat or vegetation is known to support endangered or rare and sensitive pollinator species, such as the Karner blue butterfly (*Lycaeides melissa samuelis*) or regal fritillary (*Speyeria idalia*), mowing should be timed to minimize disruption to the life cycle of the species as much as possible. For a full list of pollinator species listed under the authority of the Endangered Species Act, please see the U.S. Fish and Wildlife Service web page at http://www.fws.gov/pollinators/programs/endangered.html.

Figure 4-1. Regional Recommendations for Times to Mow Based on the Timing of the Monarch Butterfly Lifecycle



Management Windows

Windows when mowing may be safer for monarchs in spring, summer, and fall by regions (separated primarily by latitude). These windows are based on timing of breeding activity and peak migration.

Options in [ ] are recommended only if necessary. Mowing at these times may still kill monarchs but that mortality would be minimized.

Variation from year to year may occur. This data is based on long-term trends from the Monarch Larva Monitoring Project.

Reprinted with permission by the Monarch Joint Venture (www.monarchjointventure.org).

Case Study: Mowing to Benefit Rare Butterflies Requires a Holistic Approach
Though the frosted elfin butterfly (*Callophrys irus*) has a wide distribution across the eastern half of United States, it is an uncommon and rare species. It is not federally-listed but is State-listed as endangered, threatened, or as a species of concern in eleven States. The butterfly uses host plants in the bean family, and particularly prefers wild lupines (*Lupinus perennis*), a species that has State protected status in certain States (e.g., endangered status in Vermont, threatened status in Iowa) and can itself be rare in portions of its range. In Florida, neither species are on State or federal lists, but due to their rarity, there is interest in protecting both frosted elfin butterflies and wild lupines. In a right-of-way adjacent to Florida Forest Service land, Florida DOT was alerted to the presence of both lupines and frosted elfin butterflies. Florida DOT addressed concerns about protection of the butterfly by agreeing to suspend mowing until after June 1, by which point both the plant and the butterfly have completed their lifecycles. However, after June 1, mowing of the right-of-way resumed on a 30-day cycle. Such frequent mowing did not allow other wildflowers present to bloom and also caused severe soil compaction that led to the suppression of other native plants. Although the frosted elfin had access to its host plant during its flight period, the habitat quality for pollinators and other wildlife was highly diminished for the rest of the growing season. Now, with input from a natural resources contractor, the site is currently being restored by reduced mowing throughout the growing season. The roadside is mowed only as necessary to prevent encroachment of woody vegetation and regular monitoring and herbicide spot treatment is used to control invasive plant species. A holistic roadside vegetation management approach that benefits a diversity of plants is preferable over a plan that focuses on protecting a single species while overlooking other plants and wildlife.

Case Study: Pilot Project in Florida Reveals Energy and Cost Savings
Typically, the rights-of-way of highway I-10 in Madison County, Florida, are mowed up to seven times a growing season. In 2009, a pilot study on a 1-mile segment of the highway was initiated to look at potential effects of a reduced mowing regime on plant composition, soil erosion, expenses, and highway operations. From 2009 to the project's completion in 2013, mowing fence to fence (or tree line to tree line) was limited to once a growing season, in the fall. A 10-15 foot wide clear zone adjacent to the pavement continued to be mowed seven times each growing season. The vegetation was monitored over the years, and as time passed the disparity between the vegetation in the constantly mowed clear zone and the remainder of the right-of-way increased. With time, more and more desirable plant species were found in the section of the right-of-way with the reduced mowing regime. As blooming wildflowers increased, the section of the road became more aesthetically appealing, particularly in the spring. Additionally, mowing costs were reduced by $1,000 per mile. The modified mowing regime did not increase soil erosion or have negative impacts on normal highway operations. The pilot study demonstrated that Florida DOT could experience cost savings as well as safety, aesthetic, and ecological benefits, by implementing reduced mowing procedures (Norcini 2014).

Herbicide Recommendations

Reduce herbicide use to reduce impacts on non-target vegetation that provides food and shelter for pollinators.

- Use selective herbicides, applying during the life stages when weeds are most vulnerable.
- Keep applications on target and minimize drift. Plant identification skills and the ability to recognize native plants as well as invasive weeds will reduce unintended damage to non-target plants.

Used indiscriminately, herbicides can reduce the quality of habitat by removing floral resources and host plants, and may be directly toxic to some pollinators (Smallidge and Leopold 1997; Kearns et al. 1998; Stark et al. 2012). Overuse of herbicides can also weaken stands of vegetation, making them more vulnerable to weed invasions (Brandt et al. 2011), which also indirectly affects pollinators. However, herbicides are a cost-effective vegetation management tool and are the only tools available to control some noxious weeds. Judicious herbicide use can suppress undesired vegetation while maintaining diverse habitat. Roadside managers can protect pollinators by targeting herbicide applications, timing applications effectively, managing herbicide drift, and working with adjacent landowners to reduce disturbances that cause weed invasions in the rights-of-way.

> "Hundreds of dollars' worth of goodwill and wildflowers can be destroyed by not sticking to the spot spraying policy." – Nebraska Department of Roads

To limit the destruction of pollinator host plants or forage plants, avoid broadcast spraying or pellet dispersal. Spot treatment of individual invasive or noxious weeds or woody plants with a backpack sprayer, weed wiper, or similar appropriate technology can target weeds without weakening non-target species. Manage herbicide drift by calibrating equipment regularly, using precision equipment for applications, maintaining a buffer zone of 30 feet or more near sensitive vegetation and avoiding applications if winds are at or above 15 mph (Marrs et al. 1993; Harper-Lore et al. 2014).

Use selective herbicides whenever possible to reduce damage to non-target plants. Apply herbicides at the stage of growth when the weed is most vulnerable, when application will be most successful. For many weeds, this will be the seedling stage.

Training is a key component to reducing herbicide use. Applicators need training to help them determine the preferred herbicides, the best timing for weed control in each situation, and to improve the efficacy of herbicide use. New technologies can target the delivery of herbicides, and GPS/GIS systems can help roadside managers track sensitive sites as well as weed issues. Annual training can keep crews up to date on new technology.

Plant identification of invasive weeds and native vegetation are also important to be included in training. Some noninvasive, native plants that are valuable for pollinators are often mistakenly identified as weeds. Native thistles (*Cirsium* spp.), which attract and support many pollinators, including several imperiled species of bumble bees and butterflies, are often mistaken for nonnative invasive thistle species (e.g., musk thistle [*Carduus nutans*], Canada thistle [*Cirsium arvense*]) and are sprayed with herbicides. Milkweeds (*Asclepias* spp.), which are host plants for monarch butterflies, are another group of plants that are targeted as weeds but do not cause problems on roadsides and rarely encroach upon adjacent lands.

Photo 4-4: Milkweed is an attractive component of roadside plantings and supports many pollinators.

Plant identification skills will help applicators know types of habitat (such as roadside prairie or wetland remnants) or stands of native plants to avoid spraying and will help to keep their applications on target. Educational materials such as booklets or posters may help. Iowa DOT and the Iowa Living Roadway Trust Fund maintain a database of native and invasive plants. Minnesota Department of Natural Resources Roadsides for Wildlife program developed a poster about invasive species in Minnesota, and many roadside managers hung the poster in maintenance sheds where it could be easily viewed. The Nebraska Weed Control Association, in cooperation with the Nebraska Department of Agriculture, put together an identification guide to help weed managers avoid treating native thistles (available at: http://www.neweed.org/Documents/Thistles%20of%20Nebraska.pdf).

Are Milkweeds Really Weeds?

Each year monarch butterflies east of the Rocky Mountains make a spectacular journey, traveling thousands of miles to overwinter in Mexico. Monarchs west of the Rockies make a shorter migration from the Great Basin, Pacific Northwest, and Intermountain West to coastal California. The migration of the monarch butterfly is a natural wonder, but that wonder is threatened by the loss of milkweeds (*Asclepius* spp.), the exclusive larval host plants of the butterfly. Monarch caterpillars only eat milkweed leaves, and in doing so they acquire chemical protection from predation by incorporating the milkweed's cardenolide chemical compounds into their own bodies.

The winter of 2013/2014 saw the lowest monarch populations overwintering in Mexico ever documented, representing a 90% decline (Jepsen et al. 2015). Western monarchs have declined by over 50% since 1997 (Jepsen et al. 2015). Increasing milkweed populations in North America is critical to the recovery of the monarch butterfly, but one obstacle to widespread inclusion of milkweeds in new plantings is the perception that milkweeds are in fact weeds. Concerns include the potential for milkweed populations to expand their populations from the original planting site and encroach on adjacent land, and the chemical compounds present in milkweeds and their toxicity to livestock.

Although milkweed, the common name for plants in the genus *Asclepias*, implies that the plants are indeed weeds, milkweeds are a diverse group of native wildflowers that are not listed as noxious weeds at either the State or the federal level in the U.S. Milkweeds may be perceived as weeds because a few of the nearly 100 species in the U.S. will colonize disturbed areas. These species tend to reproduce vegetatively (in addition to reproduction by seed), sending up new shoots from roots that spread outward from the parent plant. This clonal reproduction allows their populations to expand over time, and plants may spread out of their original area. Common milkweed (*Asclepias syriaca*) exhibits the highest degree of clonal reproduction, and vegetative growth also occurs to a lesser degree in horsetail milkweed (*A. subverticillata*), narrowleaf milkweed (*A. fascicularis*), plains milkweed (*A. pumila*), prairie milkweed (*A. sullivantii*), showy milkweed (*A. speciosa*), and whorled milkweed (*A. verticillata*) (Borders and Lee-Mader 2014). Despite the vegetative growth, many of these species are unlikely to create an ongoing and unmanageable weed problem for roadside managers (or other land managers, homeowners, etc.).

Another contributing factor to the perception of milkweeds as actual weeds is the presence of cardenolides, steroid plant compounds milkweeds use as a defense against herbivores. The amount of cardenolides present in plant tissue varies with the species of milkweed (it can also fluctuate seasonally) and can make the plants potentially toxic to livestock (Burrows and Tyrl 2013). Farmers and ranchers with livestock are often concerned about the presence and proximity of milkweeds to their stock.

However, in properly managed rangeland and pasture, milkweed should pose no risk to livestock. Milkweeds are toxic only if consumed in large quantities, and milkweeds are highly unpalatable (Fulton 1972). Livestock, cattle in particular, will only consume milkweeds in the absence of other forage; a pasture must be barren in order for milkweed to poison a cow.

Many animals eventually recover from milkweed poisoning, but because there is no established treatment, prevention of poisoning is the best option. There are a number of steps that reduce risk of poisoning to cattle. Because milkweed is not preferred forage, maintaining a sustainable stocking rate is the key to preventing milkweed poisoning. Ensuring that hungry cattle or other animals are not confined in places with abundant milkweed should prevent most poisonings (Pfister et al. 2002). Additionally, because milkweed retains its toxicity when dry (and may even increase in palatability), it is important to verify that sources of hay are milkweed-free (Pfister et al. 2002).

Most eastern monarchs produce their first generation in Texas, Oklahoma, and eastern Kansas after flying north from Mexico, making the presence of milkweeds in the region absolutely critical. Western monarchs use milkweeds throughout the western US. Rangeland is abundant in these States, and outreach to ranchers can help them to prevent milkweed poisoning and understand the critical role they can play in helping to conserve the Monarch butterfly migration.

Case Study: Oregon Department of Transportation's Herbicide Reduction Program
In 2010, ODOT received an internal directive to reduce herbicide use, with the goal of reducing the amount of active ingredient used by 25%. Maintenance staff replaced older application equipment with updated, more efficient equipment, applied more dilute rates of application, moved to using spot sprays for noxious weeds, and avoided routine sprays. By 2015, ODOT has met its objectives of reducing use of pounds of herbicide active ingredients; in most places they have reduced it by nearly 50%.

Alternative Vegetation Control Methods

Prescribed burning, prescribed grazing, and biological control agents are additional tools in the IRVM toolbox. Though each of these tools has limitations, they may be highly effective under certain circumstances. Prescribed burns, for example, may be useful for sites with woody plant encroachment or sites where grasses have crowded out wildflowers. Prescribed grazing using goats and sheep, which can be herded and prefer to eat broadleaf plants, can control large infestations of invasive weeds and can be effective in areas near water or in inaccessible spots such as steep slopes. The use of biological control agents on roadsides can inhibit the growth of targeted weeds and reduce herbicide use, and control can be widespread and tong-term. Roadside managers can reduce impacts of these management practices to pollinators by considering the timing and intensity of the practices.

Prescribed Burns

Use rotational prescribed burns no more than every 3 to 5 years to allow time for pollinator populations to recover.

- Consider the timing of the burn to avoid impacts on rare, endemic, or sensitive and declining species of pollinators.

Prescribed burns can be harmful to many pollinators and have long-term impacts on the populations of some species (Ne'eman et al. 2000; Panzer 2002; Potts et al. 2005). Modifying the use of prescribed fire as a roadside management tool by timing burn events seasonally or limiting the scale and frequency of the burns will help to make this management practice more pollinator-friendly.

The timing of a burn is important with respect to its impact on the roadside plant community. Intense summer fires are most efficient at controlling woody species such as red cedar; dormant-season burns in fall or winter encourage the growth of cool season grasses. Burns at either of these times affects pollinators. Summer burns remove vegetation at a time when pollinators need floral resources, host plants, and nesting materials. Winter burns destroy species that overwinter in leaf litter or stems. Burning an entire roadside corridor runs the risk of extirpating the local pollinator community. By leaving adequate refuge habitat, enough pollinators remain to recolonize the burned areas, thereby sustaining the temporary decrease in habitat quality. Rotational burning of small sections of roadsides no more than every 3 to 5 years that leaves refuge habitat will provide the benefits of prescribed fire without causing irreparable damage to the local pollinator community (Black et al. 2011).

Grazing

Time grazing carefully to avoid impacts on rare, endemic, or sensitive and declining species of pollinators.

Livestock grazing can directly adversely affect pollinator populations by trampling of individuals or destruction of nests, and indirectly by the removal of pollen and nectar resources, as well as host plants (Sugden 1985; Carvell 2002; Hatfield and LeBuhn 2007). Light or moderate grazing that maintains favorable vegetation heights as well as habitat heterogeneity can be favorable to some butterflies (Davies et al. 2005). For grazing to have minimal impacts on pollinators, it is important to carefully consider specialist or rare pollinators as well as the timing, intensity, and duration of grazing.

Grazing plans work best when they are site-specific and carefully timed to encourage the grazers to feed selectively on the undesirable species. For example, grazing may only beeffective when the weed is palatable. However, managers may want to carefully time the introduction of grazers, balancing the need to control weeds with the needs of pollinators. If habitat specialist pollinator species are present, it is recommended to avoid grazing during the adult flight period or when butterfly larvae are feeding on the host plant. Additionally, grazing during periods when floral resources are already scarce (e.g., mid-summer) may result in insufficient forage for pollinators such as bumble bees, which need forage in late summer and fall (Carvell 2002).

The duration of grazing will depend on the density of grazers. If stocking density is high, the grazers will need to be on the roadside for short periods of time. Hatfield and LeBuhn (2007) found that uncontrolled sheep grazing removed enough flowering plants to eliminate bumble bees from some study sites. Generally speaking, grazing periods ideally are be short, with relatively long recovery periods for the habitat. Grazing is not right for every roadside locale, but when the grazing plan suits local conditions, it can be compatible with pollinator conservation.

Biological Control

Use biological control agents that have not demonstrated host plant expansion.

The use of biological control on roadsides can inhibit the growth of targeted invasive weeds (e.g., leafy spurge [*Euphorbia esula*] and purple loosestrife [*Lythrum salicaria*]) and reduce herbicide use (Harper-Lore et al. 2014). Biological control of roadside weeds has the potential to benefit pollinators indirectly by reducing the use of herbicides and thus the effects on non-target vegetation. However, when biological control agents are introduced outside of their natural range to control invasive plants, there is the potential for unpredictable and irreversible ecological consequences. For example, the Eurasian weevil (*Rhinocyllus conicus*) was introduced to control musk thistle (*Carduus nutans*); however, it also feeds on native thistles, including rare thistle species (Louda et al. 1997). The loss of native thistles or other native species harms pollinators that visit the plants for pollen and nectar, such as butterflies, moths, bees, wasps, beetles, and flies, as well as butterflies that use the plants as host plants for their caterpillars.

Do not use biological control agents that have expanded their hosts to native plants, such as the Eurasian weevil. Work closely with the State Department of Natural Resources and Department of

Agriculture to find the biocontrol agent that is the least disruptive. Keep careful records about release of the agents, and monitor release sites annually, monitoring not only the target weed species for population declines but also potential non-target native species (particularly those related to the target weed species). If, through inventories or monitoring, you observe that native species are being negatively impacted by biological control agents, alert partner agencies and discontinue use. If using biocontrol in large areas of monotypic stands of the target weed, ensure that there is a revegetation plan that addresses the rights-of-way and adjacent lands to prevent soil destabilization and other impacts to potential habitat.

Photo 4-5: Native thistle species are highly attractive to many pollinators and are an important nectar source for monarch butterflies.

Haying

Some States permit adjacent landowners to cut and remove the roadside vegetation for animal fodder. States might grant emergency hay permits under drought conditions, for example, or allow annual haying by adjacent landowners on certain roads throughout the growing season (e.g., Minnesota). While not a tool utilized by roadside managers, haying does impact roadside vegetation and thus pollinators. In general, haying once in the middle of the growing season can result in high plant diversity, by favoring wildflowers and cool season grasses that are often suppressed by dominant warm-season grasses. However, too-frequent haying can reduce roadside revegetation over time (Jacobsen et al. 1990), reducing floral resources for pollinators. A poorly timed haying may have severe consequences for rare or endemic pollinator species. Although road authorities may have some restrictions in place on when and how often roadsides can be mowed (e.g., mowing only takes place once a year in August), these restrictions do not often extend to haying. States report that citizen haying might take place multiple times during a growing season. State regulations that manage the frequency and timing of haying would help to reduce the negative impacts of repeated haying on roadside vegetation and pollinators.

Management for State-Listed, Federally-Listed, Rare, Endemic, and/or Sensitive and Declining Species of Pollinators

Species that are federally-listed as threatened or endangered are regulated by the U.S. Fish and Wildlife Service (USFWS). States also have State-listed special status species that are usually regulated by State agencies such as Departments of Wildlife. Management of vegetation that may impact habitat of a federally-listed species may require conservation measures to avoid impacts or a permit for impacts to that species (known as incidental take) if avoidance is not possible. USFWS consults on species conservation measures and issues incidental take permits through Section 7 of the Endangered Species Act (ESA) for federal actions (projects or activities with a federal nexus), or through Section 10 of the ESA for non-federal projects or actions. If there is the potential for a State-listed or federally-listed species to be impacted, the potential effects of the project or activity should be determined by the federal action agency (for federal actions) or the project proponent (for non-federal actions) based on information provided by a qualified biologist. The USFWS and/or State Department of Wildlife should be consulted if actions are likely to adversely affect one or more listed species.

Management for rare, endemic, or declining pollinator species can also generally benefit other pollinators, as well as other plants and animals. Additionally, seasonal avoidance for listed species other than pollinators, such as ground nesting birds, can benefit pollinators when the seasonal avoidance for a listed species coincides with habitat requirements of pollinators. In some cases, pollinator habitat requirements may extend slightly beyond the seasonal avoidance window for other species. In States where DOTs are already carefully timing and reducing mowing or other roadside management practices to avoid listed species, understanding pollinator needs may show that a slight extension of a seasonal avoidance may benefit pollinators as well as the listed species.

Case Study: Oregon Department of Transportation's Special Management Areas

Oregon DOT's Special Management Area (SMA) program has been in place for over 20 years, developed out of a need to formalize and organize protection of rare and protected plants on Oregon roadsides. Following roadside inventories for State or federal protected plants, over 100 SMA areas have been established. SMAs also include compensatory wetland mitigation sites, cultural resources, and other areas that need specialized maintenance. Sites are monitored every year, and plant population counts are made every three years.

Signage designates each SMA site. Signs include codes for the particular maintenance activities (e.g., mowing, herbicide spraying, blading) allowed on the site. Each site has a unique management plan, approved by ODOT Geo-Environmental Section, ODOT district maintenance personnel, and relevant State and federal agency personnel. ODOT has programmatic agreements in place with Oregon Department of Agriculture (the agency that is responsible for State-listed species) and is finalizing a Habitat Conservation Plan with the USFWS for incidental take of listed plants and animals that may occur during maintenance and resulting wetland mitigation actions. ODOT credits the success of the SMA program to effective communication and cooperation within the department and with partners.

Case Study: Karner Blue Butterflies and Wisconsin's Roadsides

Wisconsin's roadsides are home to the endangered Karner blue butterfly (*Lycaeides melissa samuelis*), a federally-listed endangered species that relies entirely on wild lupine (*Lupinus perennis*) as its host plant. In addition to roadsides with dry, sandy soils, lupine is found in oak savanna and pine barrens, as well as other areas that are maintained as early successional landscapes through disturbance such as mowing or prescribed burns. The future of the Karner blue butterfly is tied to maintaining the landscapes that can support lupine. Wisconsin Department of Transportation (WisDOT) partnered with a number of organizations, agencies, and counties in Wisconsin to develop a habitat conservation plan for the butterfly.

WisDOT inventoried roadsides with sandy soils for the presence of lupines. Once identified, these sites were managed with mowing and brush removal timed to avoid the growing season and spot applications of herbicides for invasive weeds. Working with the U.S. Fish and Wildlife Service and the Wisconsin Department of Natural Resources, WisDOT also identified potential roadsides that could serve as corridors for dispersal of the butterfly between larger areas of habitat. If construction takes place in these regions, lupines are included in the seed mix used for revegetation. Training and education around Karner blue butterflies and lupine identification was provided for WisDOT maintenance crews and field personnel.

Wisconsin's landscapes currently support the largest numbers of Karner blue butterflies. Every effort to protect the butterfly and supplement its habitat is important if the species is to survive.

Summary of Recommendations for Adjusting Roadside Vegetation Management to Benefit Pollinators

Roadside Vegetation Inventories

- Use GPS and GIS to track vegetation conditions.
- Use roadside photo imagery (can be from car-mounted cameras if available) and location data to document baseline vegetation information.
- Follow driving surveys and photographic identification with ground truthing field surveys when possible.
- Identify remnant habitat and prioritize vegetation management in those areas to maintain and expand native vegetation.
- Inventory nonnative, invasive, and exotic vegetation to target them for control.
- Use online resources and technology such as smartphone apps to help identify and record vegetation information.
- Prioritize areas of high likelihood for successful pollinator-friendly plantings.

Pollinators and IRVM

- Develop IRVM plans, tailoring management to specific site conditions.
- Mow roadside vegetation as little as possible – no more than twice per year.
- Time mowing to minimize disruption to the life cycles of pollinators, especially State-listed, federally-listed, rare, endemic, sensitive, and declining species of pollinators.
- Delay mowing until the fall, preferably after first frost, to benefit a variety of pollinators by allowing flowering plants to bloom uninterrupted throughout the growing season and by reducing the risk of mortality by mower to larval stages of butterflies, moths, flower flies, and other pollinators that reside on vegetation.
- Reduce herbicide use and subsequent impacts of herbicides on pollinators by using selective herbicides, spot-spray applications, and timing applications to the most vulnerable life stage of the weed.
- Provide vegetation maintenance crews with plant identification tools and training to recognize native plants as well as invasive weeds, to reduce unintended damage to non-target plants during herbicide use.
- If sheep or goats are used to graze invasive weeds on roadsides, take into account the timing of the life cycles of rare, endemic, sensitive, and declining species of pollinators.

- If prescribed burns are used, use rotational burning of no more than every 3 to 5 years to allow time for pollinator populations and their habitats to recover.
- If biological control agents are used to control weeds, use only those agents that have not demonstrated plant host expansion beyond the target weed.
- If haying occurs in your State, limit it to once a growing season and restrict it in areas that support rare and declining pollinator species.
- Specific conservation measures are needed to protect State or federally-listed pollinator species, but these measures may also generally benefit pollinators.

Photo 4-6: Roadside remnant habitat is often home to unique plants that support unique pollinators, and mindful management can help maintain the diversity of the remnant habitat and protect pollinators.

Chapter 5
Using Native Plants to Restore Roadsides for Pollinators

Overview

Vegetation used in roadside plantings may achieve multiple goals, including safety, function, and aesthetics. Additionally, the plants are ideal when they are able to thrive in the highly disturbed, compacted, and nutrient-poor soil that remains following road construction. There are many native plants that can meet these objectives while also providing valuable resources for pollinators. In contrast, maintenance of roadsides as turf grass provides few resources for pollinators (and other animals) and is costly.

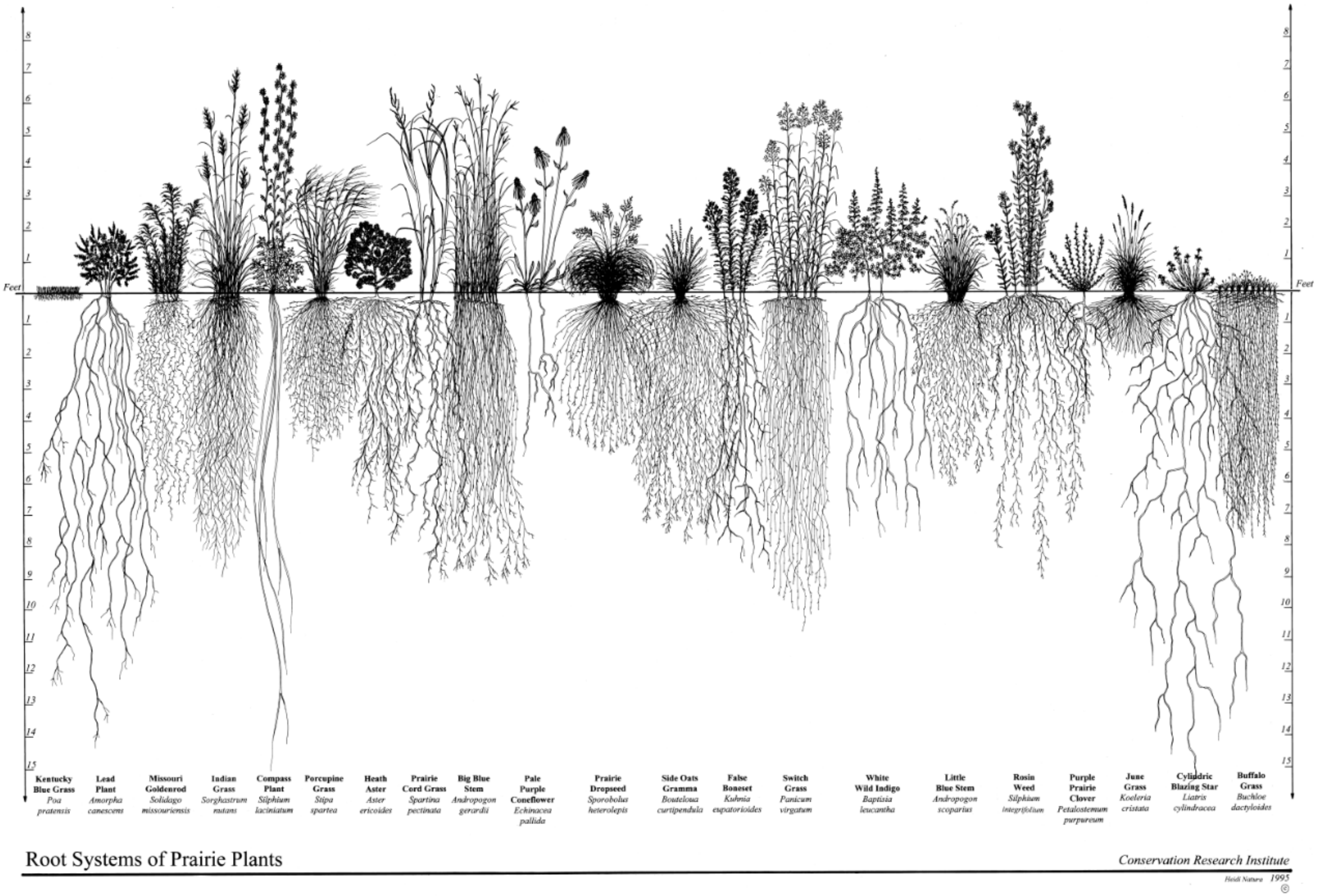
When designing roadside plantings, there are several considerations that can improve the value of the planting for pollinators. These include designing mixes with a moderate to high density of wildflowers, including species that bloom sequentially so there are flowers blooming throughout the growing season, including host plants for butterflies and shrubs that can provide bee nesting material when possible, and using native plant material that is locally or regionally sourced.

Value of Native Plants in Roadside Plantings

> "Growing native plants on roadsides needs to be routine." -- Carmelita Nelson, Minnesota Department of Natural Resources

Establishing regionally native plants on roadsides can help roadside managers achieve management goals such as soil stabilization and preventing storm water runoff (Cramer 1991; Quales 2003). Adapted to local conditions, native plants are better equipped than nonnative species to survive droughts and require fewer inputs like fertilizer and water during establishment. Due to strong root development (Figure 5-1), stands of native vegetation can provide effective erosion control (Quales 2003). Additionally, some species are particularly able to tolerate the poor growing conditions found on roadsides (Harper-Lore and Wilson 2000; O'Dell et al. 2007). Under some conditions, native plants may have a competitive advantage over nonnatives. Native seed mixes in a Texas study resulted in faster and denser ground cover established in roadsides than a mix with a nonnative species selected for its rapid establishment and soil stabilization (Tinsley et al. 2006).

Figure 5-1. Root Systems of Native Plants



Heidi Natura, reprinted with permission from the Conservation Research Institute

An established stand of native grasses and wildflowers will also resist weed colonization (Blumenthal et al. 2005; Falk et al. 2013). The root systems of native plants also help to reduce runoff in the spring and improve infiltration; this helps reduce storm water contamination and replenishes groundwater (Bugg et al. 1997; Harrison 2014). In northern States, native grasses and shrubs can act as snow fences in the winter, trapping and preventing snow from blowing across roads (Johnson 2000).

Although the establishment of native vegetation can take time and the initial costs may be higher, native plants are more cost effective in the long term. Once established, the plantings persist over time and require less mowing, herbicides, and other weed control measures, decreasing long-term maintenance efforts and cost (O'Dell et al. 2007; Harper-Lore et al. 2014). In contrast, controlling the growth and spread of invasive plants along roadsides through repeated mowing and rigorous herbicide use is very expensive (Westbrooks 1998).

In 1987, the Department of Public Works in Massachusetts managed roadsides at a cost of about $1.1 million, or $330 per acre; if every acre was instead managed as wildflowers, nearly $280 per acre per year could be saved (Ahern et al. 1992). Costs of installing and maintaining native vegetation will vary from site to site, depending on factors such as weed pressure. In California's Yolo County, Robins et al. (2001) estimated roadside native vegetation installation costs, which included earthwork, tillage, herbicide, and seeding, at $522 to $1,433 per acre of roadside. They estimated maintenance costs for each of the first 3 years of establishment at $52 to $153 per acre, with similar costs occurring subsequently every 2 to 3 years.

Wildflowers and native plants have a natural beauty that can be a useful promotional tool, for DOTs as well as for tourism. Drivers form perceptions about regions based on their views of the highway landscape. Minnesota DOT conducted a study to learn more about landscape maintenance and characteristics attractive to travelers, and found that they preferred roadsides with perennial wildflower plantings or shrubs (Carmelita Nelson, pers. comm.). Over 90% of survey respondents in Mississippi preferred "natural-looking roadsides with native grasses, wildflowers, and butterflies," (Guyton et al. 2014). Stands of native grasses and flowers are aesthetically attractive and can be designed for season-long blooms. Native plantings can showcase a region's natural beauty and provide a sense of place, natural heritage, and opportunities for education.

Native plants can fulfill all these functional roles while also supporting pollinators (See Table 5-1 for examples). In fact, native plants support more wildlife, including pollinators, than do nonnative plants (Tallamy and Shropshire 2009; Williams et al. 2011). Roadsides with native wildflowers support a greater number of individuals and species of butterflies and bees compared with those dominated by nonnative grass and flowers (Ries et al. 2001; Hopwood 2008). For honey bees, many native wildflowers serve as important nectar plants for honey production and can also support immune system health by providing diverse sources of pollen. For more information about plants that are beneficial to pollinators, see additional resources listed in Chapter 7.

Although introduced species with wide ranges of tolerances are competitive and can establish quickly at low cost, they are also more likely to move beyond roadside plantings. Crown vetch (*Securigera varia*), sweet clover (*Melilotus* spp.), sericea lespedeza (*Lespedeza cuneata*), reed canary grass, and smooth brome (*Bromus inermis*) are just a few examples of introduced plants that have been used for roadside revegetation and became weed problems elsewhere (Harper-Lore and Wilson 2000). In contrast, native grasses and flowers on roadsides rarely become weed issues (Harper-Lore and Wilson 2000).

Many native plants can take time to establish. During the early stages of growth, some perennial species have difficulty competing with invasive weeds. If immediate growth is needed, consider including a sterile wheat grass or a cool season nurse crop such as oats that can establish quickly and provide erosion control and weed suppression while native perennials are establishing. Annual and biennial wildflowers can also be included, so that there are blooms in the first and second years of the planting in the interim before the longer-lived perennials begin to bloom.

Different plant groups provide different functional roles and benefits. A comprehensive seed mix includes species that can occupy different niches, such as annual forbs, perennial forbs with taproots, bunch grass, and rhizomatous grass. The resulting plant communities will be better able to prevent erosion, resist weeds, be aesthetically pleasing, and contribute to a healthy environment. Cool season grasses green up early in the spring and can provide erosion control from late winter into early summer, while warm season grasses provide erosion control as they grow through the warm summer months and into the fall. Legumes can fix nitrogen and improve soil health. Native species that can establish quickly, such as black-eyed Susans (*Rudbeckia hirta*), can provide attractive vegetative cover, erosion control, and food for pollinators and birds while other more slow growing species establish.

Some additional criteria to consider when developing plant lists for roadsides and pollinator health include:

- Include wildflowers or shrubs with known value to pollinators and other wildlife such as songbirds or game birds. Include species that bloom in spring, species that bloom in summer, and species that bloom in fall.
- Taller herbaceous plants should be avoided in areas where lines of sight could be blocked, such as intersections.
- Reduce large herbivores like deer by avoiding known palatable species, especially if deer food sources are low at certain times of the year when the plants are most palatable. For example, consider avoiding using cool season legumes (e.g., white clover [*Trifolium repens*]) in erosion control seed mixtures, because these plants are forage for deer through the fall and early spring, a time when other plants for deer are scarce.
- In northern States, species to be planted close to the road it is ideal that they have some level of salt tolerance to reduce damage from road salt applications.
- Include species adapted for the soil conditions present at the roadside site (e.g., use moisture-tolerating species for wet ditches), or, if seed mixes cannot be context-specific, include species adapted to a wide range of growing conditions.
- Focus on wildflowers that establish easily and are relatively inexpensive, but include some species that are harder to establish and may be a bit more expensive to increase the aesthetics of the planting and the value of the habitat.

When installing native plant materials, consider the season in which the materials are installed. If installing plants, the best planting windows are in early spring when there is adequate soil moisture or in the fall when dormant plants can be installed. Planting during the summer can stress transplants and will reduce establishment, unless irrigation is available and the plants are handled with care. The window to install seeds varies by site and temperature and moisture levels, but is generally best in the fall or in the dormant season to aid the establishment of species that require an extended period of stratification in order to germinate. If seed mixes do not include species that need stratification, sowing seeds in spring or summer allows seeds to germinate and establish before winter. See Steinfeld et al. (2007) for more information.

Additional obstacles to widespread use of native plants on roadsides include the cost of native plant material and limited availability of locally native plant material in some regions, as well as a lack of expertise with native plant establishment (see Chapter 6 for more information). Despite these obstacles, native plants are effective tools that roadside managers can use to stabilize roadsides, while also supporting pollinators and overall ecosystem health.

Table 5-1. Examples of Native Plant Species Suitable for Use in Roadside Revegetation and Examples of the Ecosystem Services they Provide

Name	Regional Distribution	Type of Plant	Examples of Functional Roles/ Ecosystem Services
Canada wild rye (*Elymus Canadensis*)	Northeast, Midwest, Great Plains, Intermountain west, Southwest	Cool season grass	• Establishes quickly • Erosion control • Cover in early spring-summer • Cover and nest material for birds • Host plant for a skipper species
Western wheatgrass (*Pascopyrum smithii)*	Across West, Southwest, Great Plains, Midwest, extending to Texas, Kentucky, and Michigan	Cool season grass	• Erosion control • Cover in early spring-summer • Nesting material for birds
Sedges (*Carex spp.)*	Across the U.S.	Cool season plants	• Erosion control • Cover in early spring-summer • Many tolerate moist soils • Nesting material for birds • Host plants for skippers and moths
Bluejoint grass (*Calamagrostis canadensis)*	Northeast south to North Carolina, extending west to Washington and California	Cool season grass	• Establishes quickly • Erosion control in wet areas • Nesting material for birds • Cover for small animals
Little bluestem (*Schizachyrium scoparium)*	Maine south to Florida, extending west to Idaho and Arizona	Warm season grass	• Provides long-term erosion control • Host plant for many skippers • Food for birds • Structure for bumble bee nests
Side oats grama (*Bouteloua curtipendula)*	Present throughout U.S. except the Pacific northwest	Warm season grass	• Long-term erosion control • Bird nesting habitat and cover • Food for birds • Host plant for skippers
Tall dropseed (*Sporobolus compositus)*	Present in much of the U.S. except Florida, California, Nevada, and Oregon	Warm season grass	• Establishes quickly • Erosion control • Food for birds • Bird nest habitat • Structure for bumble bee nests

Name	Regional Distribution	Type of Plant	Examples of Functional Roles/ Ecosystem Services
Golden alexanders (*Zizia aurea)*	Eastern U.S., extends west to Great Plains	Wildflower	• Spring bloom • Food for pollinators • Host plant for swallowtail butterflies
Silverleaf phacelia (*Phacelia hastata*)	West coast to western Great Plains	Wildflower	• Spring bloom • Food for pollinators
Firecracker penstemon (*Penstemon eatonii*)	Western U.S.	Wildflower	• Spring bloom • Very showy • Food for pollinators
Lead plant (*Amorpha canescens)*	Michigan south to Louisiana, west to New Mexico and Montana	Wildflower, legume	• Fixes nitrogen-improves soil quality • Early summer bloom • Food for pollinators • Food for birds
Wild bergamot (*Monarda fistulosa)*	Extends across the continental U.S. except California and Florida	Wildflower	• Establishes quickly • Early summer bloom • Food for pollinators
Showy milkweed (*Asclepias speciosa)*	Extends from Great Lakes region south to Texas and west to Pacific coast	Wildflower	• Early summer bloom • Very showy • Food for pollinators • Monarch butterfly host plant
Black-eyed Susan (*Rudbeckia hirta*)	Throughout the U.S.	Wildflower	• Establishes quickly • Summer bloom • Food for pollinators • Food for birds • Host plant for butterflies
Partridge pea (*Chamaecrista fasiculata)*	Eastern U.S. and Great Plains	Wildflower, legume	• Fixes nitrogen-improves soil quality • Establishes quickly • Summer bloom • Pollinator food • Food for birds, small mammals • Host plant for butterflies
Blanketflower (*Gaillardia aristata*)	Western U.S. into the Great Lakes region	Wildflower	• Summer bloom • Very showy • Food for pollinators • Food for birds
Purple coneflower (*Echinecea purpurea)*	Eastern U.S. into the Great plains	Wildflower	• Summer bloom • Very showy • Food for pollinators • Food for birds
Swamp milkweed (*Asclepias incarnata)*	Extends across Eastern U.S. to Idaho and Arizona	Wildflower	• Adapted to moist/wet soils • Summer bloom • Food for pollinators • Monarch butterfly host plant

Name	Regional Distribution	Type of Plant	Examples of Functional Roles/ Ecosystem Services
Sulfur buckwheat (*Eriogonum umbellatum*)	Western U.S.	Wildflower	• Summer bloom • Food for pollinators • Food for birds • Butterfly host plant
Blazing star (*Liatris punctata*)	Michigan south to Louisiana, west to New Mexico and Montana	Wildflower	• Adapted to moist soils • Summer bloom • Very showy • Food for pollinators • Food for birds
Lavender hyssop (*Agastache foeniculum)*	North central U.S., from Montana to Great Lakes and south to Colorado and Kentucky	Wildflower	• Establishes quickly • Late summer bloom • Food for pollinators • Food for birds
Mist flower (*Conoclinium coelestinum*)	Eastern U.S. into southern Great Plains	Wildflower	• Adapted to moist/wet soils • Late summer bloom • Food for pollinators • Food for birds
Maximilian sunflower (*Helianthus maximiliani)*	Present across most of the U.S. except the Southeast	Wildflower	• Establishes quickly • Fall bloom • Food for pollinators • Food for birds • Butterfly host plant
Showy goldenrod (*Solidago speciosa)*	Eastern U.S. and Great Plains	Wildflower	• Fall bloom • Food for pollinators • Food for birds
Western goldentop (*Euthamia occidentalis*)	Western U.S.	Wildflower	• Adapted to wet/moist soils • Fall bloom • Food for pollinators
New England aster (*Symphyotrichum novae-angliae)*	Northeastern U.S. south to Georgia, extending across much of the West	Wildflower	• Establishes quickly • Fall bloom • Food for pollinators • Food for birds • Butterfly host plant
False goldenaster (*Heterotheca villosa*)	Western U.S. into northern Great Plains and western Great Lakes region	Wildflower	• Mid-summer to fall bloom • Adapted to dry conditions • Food for pollinators • Food for birds

Why Use Native Plants?

- Native grasses and flowers are best adapted to local growing conditions, require minimal inputs for establishment, and are able to tolerate drought or cold.
- The root systems of native plants can increase water infiltration, which reduces runoff and water pollution.
- An established diverse plant community provides the most stable cover for reducing erosion and keeping out weeds.
- Improved weed and erosion control can reduce the need to spray herbicides and to mow, thereby reducing long-term maintenance costs.
- Native plants are less likely to encroach on land bordering roadsides.
- Native plant communities can act as snow fences in the winter, trapping and preventing snow from blowing across roads.
- Native plantings are aesthetically pleasing, can support tourism, and can reduce driver stress and sleepiness.
- Native plant communities support more birds, pollinators, and other wildlife.

Case Study: Bringing Prairie Back to Iowa: Iowa's Integrated Roadside Vegetation Management Program and Living Roadway Trust Fund

Prairie once dominated Iowa's landscape, covering more than 85% of the State. With less than 0.1% of virgin prairie remaining, and more than 95% of Iowa's original wetlands destroyed, Iowa has the nation's most altered landscape. Prior to the mid-1980s, roadside weed control in Iowa relied heavily on blanket spraying, putting large amounts of herbicide into the environment with undesirable consequences. Recognizing Iowa's lost heritage and the need to protect groundwater and surface waters, Iowa roadside managers began making some changes. For example, they began using native prairie grasses and wildflowers for erosion control and reintroduced "a little wildness," according to Kirk Henderson, retired from the Native Roadside Vegetation Center at the University of Northern Iowa.

In 1989, the Iowa legislature passed IRVM legislation to promote an ecologically integrated approach to roadside management while maintaining a safe travel environment (Code of Iowa, Section 314). The legislation emphasized the establishment and protection of native vegetation as well as judicious use of herbicides, mowing, prescribed burning, and other management tools. Iowa is widely seen as a leader in IRVM, in large part because of this legislation. The bill also established the Living Roadway Trust Fund, an annual competitive grant program administered by the Iowa DOT that provides funding for school, city, county and State projects, as well as research projects involving IRVM. Iowa's road use tax, along with several other sources, funds the Living Roadway Trust Fund. Roadside managers can submit applications to obtain resources to help them implement IRVM, including vegetation inventories, purchasing native seed, equipment for burns or plant establishment, GPS units, signage, workshops, and more. Roadsides are seeded with mixes of species that are appropriate for a particular site, including many wildflowers that are attractive to pollinators. Seed mixes also contain species that bloom at different times throughout the growing season, which helps support pollinators all season long. The targeted vegetation management practiced by Iowa's roadside managers also benefits pollinators (Ries et al. 2001).

Research projects have also been supported by the Living Roadway Trust Fund, including studies of restoration techniques, as well as studies of the impact of roadside habitat on butterflies (Ries et al. 2001) and bees (Hopwood et al. 2010). Since the bill, more than 100,000 acres of Iowa's nearly 600,000 acres of State and county roadsides have been planted to native vegetation (Brandt et al. 2011). In the process, Iowa has fostered the development of experienced roadside managers who are equipped to collaborate with other land managers around the State and bring habitat, and wildlife such as pollinators, back to Iowa's landscape.

Case Study: Cost Analysis of Wildflowers for Indiana Highways

A joint highway research project undertaken by researchers in Purdue University's School of Civil Engineering, the Indiana Department of Transportation, and the Federal Highway Administration evaluated plants for use on Indiana's roadsides (Dana et al. 1996). The project investigated establishment of turf species, garden wildflower mixes, and native wildflower mixes, and also calculated costs of establishment and maintenance of each approach.

The turf plantings were installed with a mix of tall fescue (*Festuca arundinacea*), perennial rye (*Lolium perenne*), and creeping red fescue (*Festuca rubra*). The garden wildflowers mix included eleven species of annual and biennial native and introduced species such as cosmos, California poppy, rocket larkspur, Indian blanket. The native prairie mix consisted of eight species, three native grass species (20% of the mix) and five wildflower species (80% of the mix).

The researchers found that garden wildflowers were the least costly to establish but required more costly maintenance over time, including requiring reseeding over time because of the short lifespan of the plants. They also noted that the garden wildflowers mix would not be appropriate for sites requiring erosion control. The prairie plant mixes were more costly initially but researchers found that the more permanent turf grass and prairie plantings were cost competitive when long-term management costs were incorporated. Published in 1996, this study's cost findings reflect the higher prices of native seed of the time. The seed mix used in the study included only five species of native wildflowers and three species of native grasses. Today, seed of native species is more available, and a seed mix with the species tested in this study would cost significantly less. For example, in 2015 an Indiana commercial native plant nursery offered a seed mix appropriate for roadsides that contained 22 species of native plants, including 15 species of native wildflowers, seven species of native grasses, and two species to provide temporary cover. The cost of this mix is $395 per acre, considerably less than the $2179.44 cost per acre for the mix included in the 1996 analysis. An updated analysis of the costs associated with revegetation of roadsides and roadside vegetation management would be highly beneficial.

Cost Estimates, per Acre, of Roadside Vegetation Installation by Seeding and Maintenance, Made in 1996

	Turf	Garden Wildflowers	Prairie Wildflowers
Installation			
Site preparation (herbicide applications, tillage)	$443.50	$443.50	$443.50
Seed mix	$467.50	$569.30	$2179.04
Fertilizer, mulch	$828.00	N/A	N/A
Total cost per acre	*$1739.00*	*$1002.80*	*$2575.04*
Annual Maintenance			
Mowing	**$66.00**	**$22.00**	**$22.00**
Heribicides	**$11.13**	**$118.50**	**N/A**
Reseeding	**N/A**	**$334.27**	**N/A**
Prescribed burn (every three years)	**N/A**	**N/A**	**$39/year**
Total cost per acre per year	*$73.13*	*$474.77*	*$59.00*

Using Native Plants in Roadside Plantings to Benefit Pollinators

Photo 5-1: A diverse native roadside planting in Central Iowa.

Improving the quality of roadside habitat can increase the number and diversity of pollinators, and may increase pollination services as a consequence. There are two main goals when restoring habitat for pollinators: 1) increase the abundance of pollen, nectar, and host-plant resources with use of a diverse range of plants that flower throughout the growing season, and 2) foster vegetation that provides nesting, egg-laying, and overwintering locations for pollinators. Roadside habitat restoration can take the form of wildflower plantings, inter-seeding low-statured pollinator-attractive plants in existing grassy areas, and establishing flowering shrubs and trees in living snow fences, windbreaks, or slope stabilization efforts.

Bees and butterflies are more abundant and diverse on roadsides with native plants compared with those dominated by nonnative grass and flowers (Ries et al. 2001; Hopwood 2008). In addition to the use of native plants, key components of roadside plantings that will benefit pollinators include a focus on high diversity and density of flowering species, selecting plants that provide pollen and nectar, plants that are host plants for butterflies and moths, plants that provide nesting and shelter for pollinators, and prioritizing the use of species found in the project's ecoregion.

Plant Diversity and Density

To benefit pollinators, increase the diversity and density of native flowers in roadside plantings.

- At least 50% of seed mixes for erosion control projects ideally would be wildflowers. Showy plantings, such as those for landscape projects, would ideally have higher densities of wildflowers.
- Include a diversity of blooming plants (e.g., a minimum of 15 species of wildflowers).

Diverse plant communities provide higher habitat value for pollinators. For example, bee diversity increases with increasing flowering plant diversity (Potts et al. 2003). Diverse plantings that resemble natural native plant communities are also the most likely to resist pests, disease, and weed invasions (Tilman et al. 2006; Oakley and Knox 2013) and thus confer the most benefits to DOTs and pollinators over time.

Ideally, seed mixes have an even grass to forb ratio. Although it is more affordable to increase the amount of grass in mixes than to increase wildflowers, if grass density is too high, or if mixes include a large percentage of a dominate grass species (e.g., big bluestem [*Andropogon gerardii*]), grasses can outcompete and suppress wildflower abundance over time. To achieve high plant diversity and long-term stability of a stand of vegetation intended for erosion control, a minimum of 25% of the seed mix are wildflowers, but 50% results in a considerably more diverse planting. In highly visible areas, seed mixes for showy plantings are best when they include greater than 50% wildflower component. Whenever the site characteristics and project budget can accommodate it, increasing wildflowers is ideal.

Plant Selection

Pollinator Attractiveness and Bloom Time

Include a diversity of flowering plants with sequential bloom times so that floral resources are available to pollinators throughout the growing season.

It is important that flowers are available to pollinators throughout the entire growing season. Early-season pollen and nectar sources may lead to greater reproduction of bees by encouraging bees that are emerging from hibernation to start their nests nearby or increasing the success rate of nearby nests. Late season flowers provide resources that ensure that queen bumble bees have ample food going into winter hibernation, and that honey bee colonies have enough food stores to last through the winter.

Focus on selecting plants known to provide quality forage to pollinators. See Pollinator Plant Recommendations in Chapter 7. To encourage the greatest number and diversity of pollinators, include a diversity of plants with different flower colors, sizes, and shapes as well as varying plant heights and growth habits. Bees typically visit flowers that are purple, violet, yellow, white, and blue (Procter et al. 1996). Butterflies visit a similarly wide range of colors, including red, whereas flies are primarily attracted to white and yellow flowers (Procter et al. 1996). Thus, by having several plant species flowering at once, as well as a sequence of plants flowering through spring, summer, and fall, restored habitat can support a wide range of pollinator species that fly at different times of the season. Additionally, diverse plantings provide greater diversity of pollen and nectar sources for honey bees. Diversity in diet can help support honey bee immune system health (Alaux et al. 2010; Di Pasquale et al. 2013).

Host Plants for Butterflies and Moths

Include butterfly and moth host plants in revegetation seed mixes and planting plans.

Egg-laying sites for butterflies and moths consist of plants upon which the adult will lay eggs and the larvae will feed after hatching. Roadsides with host plants can support habitat generalist butterflies as well as habitat specialists and migrant species such as the monarch butterfly (Ries et al. 2001). Some butterflies may rely on plants of a single species or genus for host plants (the monarch butterfly is an example, with caterpillars feeding only on species of milkweed [*Asclepias* spp.]). Others may exploit a wide range of plants, such as some swallowtails (*Papilio* spp.), the larvae of which can feed on a range of trees, shrubs, and wildflowers. Given this lifecycle pattern, establishing caterpillar host plants is recognized as a way to sustain butterfly populations (Croxton et al. 2005; Feber et al. 1996). Many plants already used in erosion control native plant species mixes are butterfly and moth host plants, but it may be necessary to include additional species to support certain butterflies or moths. For example, planting milkweeds will contribute to the recovery of the monarch butterfly.

Nesting, Shelter, Overwintering Habitat

Include plant species known to provide nesting or shelter habitat for pollinators.

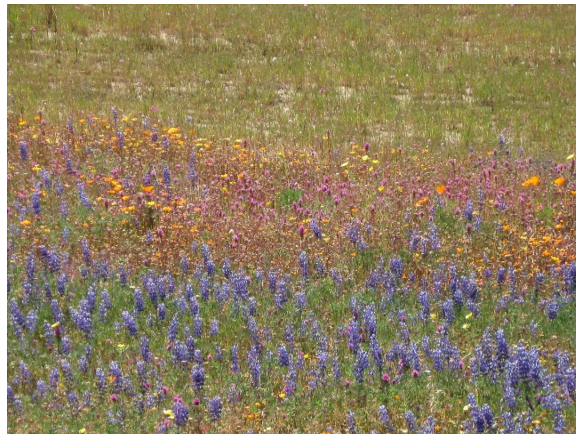
Grasses and sedges often provide food or shelter resources for pollinators (see Table 3-1 for pollinator habitat needs), serving as larval host plants for some butterflies, potential nesting sites for colonies of bumble bees, and possible overwintering sites for various beetles (Kearns and Thompson 2001; Collins et al. 2003). Tall vegetation can provide shelter for adult butterflies and moths, as well as other pollinators such as flower flies. Most of North America's native bee species (about 70%) nest in the soil and need access to soil surfaces between vegetation to excavate and access their nests (Michener 2007). Bunch grasses tend to provide better nesting habitat than sod-forming grass species, and roadsides with native bunch grasses have more nesting opportunities for ground-nesting bees and, consequently, a greater abundance of ground-nesting bees (Hopwood 2008).

Other native bees nest in tunnels in wood, such as abandoned beetle tunnels in logs, stumps, and snags, or excavations in the centers of woody plant stems and twigs (Michener 2007). Where site appropriate, planting native wildflowers with pithy stems, such as cupplant (*Silphium perfoliatum*), ironweeds (*Vernonia* spp.) and sunflowers (*Helianthus* spp.), along with shrubs such as wild rose (*Rosa* spp.), elderberry (*Sambucus* spp.), sumac (*Rhus* spp.), or agave (*Agave* spp.), will provide resources for stem-nesting bees.

Sourcing Native Plant Material

Prioritize the use of locally or regionally sourced native plant material.

Photo 5-2: A diverse roadside in California with native wildflowers.



The source of the plant material can have implications for the quality of the restoration and quality of pollinator habitat. Where available and economical, native plants and seed are best when procured from local ecotype providers. Local ecotype plant materials that originated in geographic proximity to the project site will generally establish and grow well because they are adapted to the local climatic conditions (Lippit et al. 1994). Plant material of native species that originated from an area where the climate, moisture, soil, and pest pressures differ may be less adapted for local conditions and may not establish. Alternatively, they could establish to such an extent that they become problematic. The phenology of non-locally sourced seed can also differ (Norcini et al. 2001; Houseal and Smith 2000; Gustafson et al. 2005). Bloom times of non-locally sourced plants have the potential to be out of sync with pollinators, especially specialist pollinators that are reliant on the pollen from a small subset of plants and time their emergence annually with the bloom time of their host plants.

The use of cultivars in roadside plantings can diminish nearby remnant habitat by introducing new diseases or contaminating gene pools (Houseal and Smith 2000). Additionally, some cultivars have been bred for a particular trait such as showiness and may have little to no pollen and nectar and therefore little value to pollinators.

Although the use of locally native seed and plant material sources is an ideal, where such sources are not available, regional designations may be an acceptable way of sourcing plant material.

Case Study: California Department of Transportation Eco-Regional Seed Mixes

Vegetation to control erosion is effective when it maintains water quality and increases infiltration by keeping soil in place and reducing runoff. Recognizing the value of native plants in controlling erosion, Caltrans, California's Department of Transportation, uses California natives for nearly 99% of plants used in their erosion control projects.

With 19 ecoregions ranging from coast to desert to mountains, California has extraordinary botanical diversity. To aid Landscape Architects in their selection of regionally appropriate native plant species for erosion control and revegetation, Caltrans has developed TransPLANT (found at: http://transplant.dot.ca.gov/TransPlant.php), a plant selection tool. Elevation, soil type, regional plant communities, and rainfall are all incorporated into the tool. Landscape Architects enter in information about a project's location and are provided a list of potential species to include in seed mixes based on ecoregional classifications, project sight parameters, and seed availability.

By focusing on ecoregional mixes, Caltrans controls roadside erosion using plant species adapted to the specific region and benefits from the many environmental advantages of these native plants.

Tips from Experts – Sourcing Seed Mixes

To increase the success of roadside revegetation, restoration ecologists recommend using locally sourced plant material whenever possible. Adapted to local conditions, locally native plant material is more likely to establish and flourish over time. Additionally, local plant population genetics are protected.

Some DOTs coordinate with local native plant vendors to let them know about their future roadside projects, so that the vendors can plan ahead to have plant material available. However, in some parts of the country where native plant materials are less available, there might not be sufficient quantities of plant material available for revegetation projects. In such cases, experts recommend these options:

1. Delay seeding until the appropriate seeds becomes available, using temporary soil cover for erosion control in the interim.
2. Use native plant material that does not originate from local genetic sources or native species that do not occur naturally in the local ecosystem. These might include commercial cultivars, which are generally less preferable due to concerns over adaptability and the potential for genetic spillover into local gene pools. Consult restoration experts and seed producers to determine the most appropriate cultivar for your area.
3. Use introduced nonnative species that are noninvasive, sterile, or nonpersistent. These could include sterile hybrids or annuals like common oat (*Avena sativa*) and common wheat (*Triticum aestivum*). Do not include species that will aggressively compete with and displace native plant communities, such as smooth brome (*Bromus inermis*), crested wheatgrass (*Agropyron cristatum*), orchard grass (*Dactylis glomerata*), yellow and white sweetclover (*Melilotus officinalis* and *M. albus*), red clover (*Trifolium pretense*) and oxeye daisy (*Leucanthemum vulgare*).

For more information about these and other roadside revegetation recommendations, see Steinfeld et al. (2007).

Vetting mixes that originate outside of the DOT is important. Sometimes packaged mixes can contain species that originate well outside of the area targeted for planting. Mixes advertised as "meadows in a can," for example, are best to view with extreme caution. State DOTs that have purchased such mixes reported not recognizing that they had purchased species mixes primarily composed of flowers with distributions outside of their area, including species from Europe. In some cases, the plantings did not persist beyond a year, while in others, exotic species spread to become weed issues. The failed mixes used time and resources that could have been spent more effectively and significantly set back efforts to use wildflowers in roadside plantings.

Compatibility with Highway Safety

Native plants beneficial to pollinators can be included in roadside plantings without compromising higway safety.

Vegetation management is a key component of highway safety (Federal Highway Administration 2008). The American Association of State Highway and Transportation Official's Highway Safety Manual has data showing that widening the paved shoulder area may reduce the potential for crashes. Landscape plantings as well as revegetation efforts are designed to adhere to standards governing setbacks, visibility, and other safety concerns. For many roadside managers, the biggest concerns about the presence of taller native vegetation along roads are sight distance and reducing the potential for collisions with large herbivorous mammals like white-tailed deer.

Native plants beneficial to pollinators can be included in roadside plantings without compromising highway safety. Potential adjustments include:

- Maintaining a regularly mown clear zone, the vegetation adjacent to the pavement. A regularly mown clear zone can increase sight distance and reduce deer-vehicle collisions (Mastro et al. 2008). Though nonnative grasses are typically planted in that zone, there are several native grass species that can be maintained as turfgrass, including buffalo grass (*Bouteloua dactyloides*), blue grama (*Bouteloua gracilis*), and curly mesquite (*Hilaria berlangeri*) (Simmons et al. 2011).
- Where regionally appropriate, install living snow fences to reduce ice and drifting snow. Living snow fences composed of shrub species that provide pollinator forage, host plants, or nesting material can provide multiple ecosystem services while maintaining sight distance.
- Use native grasses, herbaceous perennials, and small shrubs for the clear zone, the zone of vegetation that remains clear of fixed objects (such as trees).
- Avoid tall grasses (e.g., Indiangrass [*Sorghastrum nutans*]) and tall wildflowers (e.g., cupplant [*Silphium perfoliatum*]) in high crash zones, and within the lines of sight at intersections and around curves.
- Modify the behavior of large herbivores like deer by making the roadside less attractive for foraging. Avoid planting known palatable species, especially if deer food sources are low at certain times of the year when the roadside plants would be most palatable. Arizona DOT's approach has been to plant unpalatable species near the shoulder of roads and in high crash areas, and plant palatable species in areas leading to designated bridged wildlife crossing or in the habitat adjacent to the roadside rights-of-way (Brown et al. 1999).
- Reduced mowing beyond the clear zone may also decrease deer foraging because mowing can increase the palatability of some plants (Mastro et al. 2008).

The presence of native wildflowers and grasses on roadsides may actually increase highway safety. Research indicates that non-turf roadside vegetation provide aesthetic variety and break up monotony (Billings 1990) and can have a positive effect on human performance and improve highway safety (Topp 1990; Cackowsky and Nasar 2003; Mok et al. 2006). Anecdotal evidence backs it up as well: the Federal Highway Administration (FHWA) once received a handwritten letter from a truck driver thanking them for all of the wildflowers along the road, to which he credited with keeping him awake throughout his long drives. In urban settings, where State DOTs report that citizens have a lower tolerance for non-turf vegetation, studies show that highways with natural vegetation

Photo 5-3: Living snow fences composed of shrubs such as willows can reduce snow drift and support pollinators.

contributed to clearer thinking (Macdonald et al. 2008). In Mississippi, public perception surveys found strong support for wildflowers on roadsides and reduced mowing, and respondents indicated they would tolerate a less manicured roadside if it made the roads safer (Guyton et al. 2014).

Case Study: New York's Living Snow Fences
Blowing snow can cause hazardous driving conditions and transportation agencies spend a great deal of money in efforts to manage snow and ice. Living snow fences, rows of shrubs or trees, can trap snow as it blows across open areas and improve highway safety and reduce maintenance costs. The New York State Department of Transportation is partnering with university researchers at the State University of New York's College of Environmental Science and Forestry at Syracuse to learn more about living snow fences planted in roadsides over the last decade. The project, which obtained funding from Federal Highway Administration's Statewide Planning and Research program, has identified 28 plant species suitable for living snow fences in New York. Height and percentage of open space within the plant (porosity) are the two most important traits, but tolerance of a variety of soil conditions and stress are also important characteristics. Some of the species identified by the project also have value to pollinators. Examples include shrub willows (*Salix eriocephala*), American plum (*Prunus americana*), serviceberry (*Amelanchier arborea*) and silver buffaloberry (*Shepherdia argentea*). These shrubs, which bloom in the spring, are important sources of pollen and nectar for pollinators during a time when resources can be limited. Although pollinators are not a primary consideration when selecting plants to include in living snow fences, including pollinator-friendly species when possible can increase the value to pollinators and amplify multiple benefits of the planting. Depending on site conditions and funding, it may be possible to add other pollinator-friendly plants when planting a living snow fence.

Prioritizing New Plantings for Pollinators

When undertaking native plant establishment, consider the context of the surrounding landscape, visibility, existing weed pressure, and potential for engagement with the community when selecting sites.

Prioritizing roadside sites for restoration can help to maximize restoration success, use limited resources effectively, and garner public approval. There are several considerations to help prioritize projects that establish native plants on roadsides (including landscape plantings and revegetation for erosion control). Restoration experts suggested selecting sites for pollinator-friendly plantings with care, working with restoration experts to build internal DOT restoration experience, and conducting public outreach.

Successful establishment, persistence, and public perception of roadside plantings to benefit pollinators can depend on site selection. Roadside sites that are unlikely to undergo construction within 10-15 years might be prioritized for revegetation or pollinator-friendly landscape projects over other sites to ensure the long-term persistence of the plantings and to protect the investments of cost and time. Efforts focused on the widest roadsides will maximize potential habitat for pollinators. Butterflies in particular appear to prefer wider roadsides (Munguira and Thomas 1992; Saarinen et al. 2005).

Feasibility of restoration is also important to consider during site selection. Efforts may first be aimed at areas with low weed pressure before restoring other areas. In areas with high weed pressure, native plant establishment can mean more time, expense, and restoration expertise. DOTs that have limited experience with native plant revegetation may want to begin their efforts by starting with small-scale projects. Experience gained from smaller test areas can then be applied to larger projects. Working with local partners or experts to augment restoration expertise is also recommended.

Selection of sites may also take into account surrounding land use. Placing a site in the wrong location in the landscape can lead to a loss of the investment in the plant material and staff time for the restoration and may affect public approval. Even worse, poorly sited projects can become a sink for pollinators and other wildlife, where the animals are drawn into the habitat but are a subsequently killed by insecticide drift or too much mowing, haying, or herbicide use at the site.

Native plants established on roadsides can be subject to accidental disturbances from adjacent land management (e.g., pesticide drift) or intentional disturbances (e.g., excessive haying, mowing, or herbicide applications to the roadside by adjacent landowners). Off-target herbicide applications can damage roadside plantings, which can reduce the habitat quality for pollinators and other wildlife and also increase opportunities for weeds to invade the planting, further decreasing its quality. This type of damage can occur in roadsides adjacent to herbicide-resistant crops when boom sprayers are not turned off as sprayers turn around at the edges of fields in the process of applying herbicides. Insecticide drift onto roadsides can also occur if applications are made to crops under improper weather conditions, if equipment isn't calibrated properly, or when dust sloughs off of insecticide-treated seeds during crop planting and drifts onto roadside plants. Intentional herbicide applications, or excessive mowing or haying of the roadside by the adjacent landowner, can also decrease the quality of habitat. If using native plants, high quality seed mixes or plant materials are often involved in the establishment process. Sites could be located to protect these investments as much as possible. Plantings could be located next to places where the adjacent landowner will not impact habitat quality, such as rest areas, parks, public areas, churches, organic farms, or if adjacent landowners are aware of the value of protecting the habitat, next to farms or businesses.

> "For a native plant program to be successful, you need areas with showy plants to wow people driving by at 60-70 miles an hour. The best public relations approach is having showy wildflowers: color sells!" – Dr. Jeff Norcini, roadside wildflower expert and ecological horticulturalist

If a project goal is to highlight the value of DOT rights-of-way, sites planted with showy wildflowers to benefit pollinators are ideal when located in areas that are visible to the public, such as rest areas, or sites near farms that could benefit from the pollination services the roadside habitat would help to support (e.g., roadside sites near almond orchards in California). Public education and perception of the planting is important and can influence the persistence of the planting. Visible plantings may make surrounding landowners more aware of the importance of roadside habitat, which may decrease landowner spraying, mowing, or haying of the roadside.

Visible plantings are one component of community outreach. Signage, either on roadsides or at rest areas, can also inform the public. Community meetings might also be a useful tool for obtaining by-in from local citizens, as can making information about the plants themselves available online through a DOT's website.

Photo 5-4: Signage to designate roadside plantings valuable to pollinators can be a valuable component of public relations.

Case Study: Ohio Department of Transportation's Bee Pollinator Program
Very few remnant prairie roadsides remain in Ohio. Instead, most roadsides in Ohio are predominately planted with nonnative cool season grasses. In the fall of 2013, Ohio DOT's District 9 initiated a roadside restoration project to convert grassy rights-of-way to pollinator habitat. The Bee Pollinator Habitat Project is led by Ohio DOT's Dianne Kahal-Berman, who initiated the project with members of other State agencies as part of an Ohio Certified Public Managers Program class. Pollinator decline played a driving role in the formation of the project. "If we don't do anything about the loss of pollinators, the alternative scenario is unacceptable," said Kahal-Berman. Kahal-Berman spearheaded the project, believing that DOTs could play a key role in reversing declines by providing habitat and education to the public. "It is important to let people know pollinators are important to them, and that as a DOT we have the resources in terms of land to help pollinators. We just need to generate excitement about it," she said. "We feed the pollinators so that they can feed us." As a first step, Kahal-Berman located sites for the plantings, selecting two 1-acre sites along State Route 207 adjacent to the Ross County fairgrounds that were highly visible to the public. The sites were also not overrun with invasive species, making the restoration process more manageable. She also sought out internal and external support, holding stakeholder meetings in the area to provide some education and engagement with the public. Since Ohio DOT did not have a great deal of experience with prairie establishment, they sought expertise from experts such as Bonnie Harper-Lore (retired restoration ecologist with FHWA) and a local chapter of Pheasants Forever to learn from their experiences with plant establishment.

The project has developed a website, where several brochures and handouts about the project, including planting guidelines, a poster about the prairie plants used in the seed mixes, and information about obtaining Ohio-sourced plant material are available to download. Although the program is in its beginning stages, Kahal-Berman has seen a great response, internally at Ohio DOT as well as from the public. Scott Lucas, Head Maintenance Administrator at Ohio DOT, has enthusiastically lent his support to the Bee Pollinator Habitat Project and has also initiated a successful Statewide project to plant sunflowers along highways for beautification and as food for pollinators and birds. The hope is that these restoration projects will inspire additional roadside plantings to protect Ohio's pollinators, and there are indications that additional pollinator habitat will be established in Ohio DOT's other districts.

Information about the program is available at: http://www.dot.state.oh.us/districts/D09/Pages/Bee-Pollinator-Program.aspx

A Framework for Making Roadside Management Decisions to Benefit Pollinators

The first step is to conduct an inventory of roadside vegetation. Then, use the key below to help develop management plans.

1.
    a. Roadside site has existing stands of native wildflowers or is remnant habitat. Go to 2.
    b. Roadside site is predominately nonnative vegetation. Go to 3.
2.
    a. Invasive species are present in the remnant habitat. Control invasives using one or more of the following methods: spot-treatment applications of appropriate herbicides, avoiding nontarget vegetation; use of prescribed grazing using sheep or goats, timed to avoid impacts on rare pollinators, if present.
    b. The remnant habitat is not invaded or invasive species are under control. Develop a management plan (consult with State agencies or experts as needed) to maintain remnant habitat health and plant diversity, using carefully timed mowing and/or prescribed burns to revitalize the site.
3.
    a. Roadside site has invasive species, high weed pressure, is slated for future construction, or is located in a landscape which may reduce the habitat quality and is not an appropriate site for native plant revegetation at this time. Go to 4.
    b. Roadside site has moderate weed pressure. The site could be a candidate for native plant revegetation but would need a site-specific restoration plan to maximize success. Go to 5.
    c. Roadside site is a good candidate for revegetation using native plants (e.g., low to moderate weed pressure, visible location, the right-of-way is wide, adjacent to land that poses no threat to the future persistence of the planting). Go to 6.
4.
    a. If invasive species are present, control invasives using one or more of the following methods: spot-treatment applications of appropriate herbicides; use of prescribed grazing using sheep or goats, timed to avoid impacts on rare pollinators.
    b. If invasive species are not present or are under control, reduce mowing frequency to allow any wildflowers present to bloom and to reduce impacts on butterfly host plants (e.g., mow the area beyond the clear zone no more than twice a year).
5. If the site is potentially an appropriate candidate for native plant restoration (e.g., the right-of-way is wide and is adjacent to land that poses no threat to the future persistence of the planting), develop a restoration plan that incorporates site preparation to reduce weed pressure before undertaking native

plant revegetation. To benefit pollinators, include native flowering species with overlapping bloom times and host plants for butterflies in the revegetation plan.

6.
   a. Revegetation goals include one or more of the following: erosion control, restoration, weed control, or wildlife protection. Go to 7a.
   b. Revegetation goals include landscaping or visual enhancement. Go to 7b.

7.
   a. Design seed mix using eco-regional native plants to address revegetation goals, selecting wildflower species with sequential, overlapping bloom times throughout the growing season and including host plants for key butterflies (e.g., milkweeds for monarch butterflies).
   b. Design landscape planting to address revegetation goals, prioritizing the use of native plants, avoiding cultivars bred for showiness, and including shrubs (if site appropriate) that provide nesting habitat for wild bees.

Summary of Recommendations for Using Native Plants in Roadsides to Benefit Pollinators

Photo 5-5: Native vegetation can support managed pollinators such as honey bees, as well as wild pollinators such as the monarch butterfly and leafcutter bee foraging on this milkweed flower.

- Prioritize the use of native plants in erosion control and landscape projects.
- Increase the diversity and abundance of native flowers on roadsides, especially flowering plants that benefit pollinators. Seed mixes for erosion control projects are ideal when they have 50% wildflower component, and landscape projects are ideal when they have higher densities of flowering plants.
- Select flowering species that have sequential and overlapping bloom times to provide resources for pollinators throughout the growing season.
- Include plant species known to provide quality forage to pollinators or nesting materials.
- Include butterfly and moth host plants (e.g., milkweeds for monarch butterflies).
- Prioritize the use of locally sourced plant material, which can improve establishment and persistence of plantings, as well as the value to pollinators.
- Avoid compromising highway safety by maintaining a strip of vegetation adjacent to the pavement that is mown regularly, avoiding tall plants in high crash zones and within lines of

sight, avoiding planting species that are palatable to deer, and installing living snow fences to help reduce drifting snow.

- Prioritize sites for new high quality roadside restorations to maximize restoration success and use resources effectively. Select roadside sites that have low to moderate weed pressure, are wide, are not going to be subject to construction, and will not be impacted by adjacent land use such as pesticide drift.
- By starting with small projects and forming partnerships with restoration experts in State agencies or local conservation organizations, DOTs with limited restoration experience can develop internal expertise and expand by building off of successful projects.

Chapter 6
Overcoming Obstacles to Implementing Pollinator-Friendly Practices

In order to better understand existing roadside vegetation management practices and how they relate to pollinator conservation, we interviewed State DOT representatives and roadside restoration experts. The interviews revealed challenges to implementing roadside vegetation management strategies that can benefit pollinators, as well as ideas about tools and resources to mitigate challenges to implementation.

Reducing Mowing

Several transportation agency personnel and restoration experts interviewed were of the opinion that some State DOTs are not open to simple changes like reduced mowing. Reasons cited include a culture within the agency that prefers the status quo, a lack of knowledge about the benefits of reduced mowing, and misinformation about the effects of reduced mowing on vegetation and erosion control. As an example of barriers to reducing mowing, one State representative pointed out that roadside mowing guidelines have been guided by the turf management program at local universities.

Internal support for adoption of reduced mowing practices can be built by learning from the experiences of other nearby State DOTs. States that have successfully implemented reduced mowing can serve as examples and as technical resources for other States. Internal support can also be increased by making small changes and observing results. Florida DOT's Research Center undertook a research project that piloted a reduced mowing regime along a highway. The study followed the changes in vegetation that resulted from reduced roadside mowing beyond the clear zone, monitored soil erosion, and tracked costs (Norcini 2014). When results revealed that reduced mowing did not impact soil erosion, but did reduce maintenance costs and improved aesthetics by allowing wildflowers to bloom, the agency became more open to the possibility of reducing mowing across the State.

Photo 6-1: Reducing mowing can increase aesthetics and reduce maintenance costs.

State DOTs also expressed concern about how the general public might view reduced mowing. Particularly in urban areas, where unmown grassy roadsides are more likely to be viewed as "messy," there is pressure to maintain roadsides through frequent mowing. However, the findings of several DOT surveys suggest that mown turf roadsides are not the only favorable option. In Minnesota, a survey found that travelers prefer wildflowers or shrubs over a manicured turf

(Carmelita Nelson, pers. comm.). In Delaware, survey respondents rated an unmown roadside with a mowed edge as attractive as a fully mowed turf roadside (Barton et al. 2009). By only mowing the strip of roadside adjacent to the pavement and allowing the rest of the vegetation to grow as a meadow, States can reduce costs and the roadside will remain attractive.

Public opinion around reduced mowing can be improved by outreach efforts. Public education is an important component of maintenance programs. Education about the economic benefits as well as the ecological benefits will help to make reduced mowing palatable to the public. Web resources, posters, brochures, signage on roadsides and at rest areas, community meetings, or news articles are all possible avenues for education. States can also develop partnerships with other State agencies (e.g., Departments of Natural Resources or Fish and Game) or organizations such as native plant societies or land management groups to leverage their resources to gain community support by reaching varied audiences. The presence of colorful wildflowers can also be a tremendous boost to public relations.

Obstacles

- There may be internal resistance to reducing mowing, due to a culture within DOTs that have a long history of managing vegetation as turf or where misinformation about purported negative effects of reduced mowing prevail.
- Some members of the general public may be resistant to the idea of reduced mowing, viewing unmown roadside vegetation as less attractive than roadsides managed as turf.

Possible Solutions

- Education and training about the long-term cost savings and economic and ecological value of reduced mowing to administrators, State engineers, resident engineers, and district engineers may help increase the comfort level within the transportation agency.
- Implement pilot projects to test reduced mowing regimes on a small scale before adopting widely.
- Communicate with other nearby State DOTs that have implemented reduced mowing regimes and exchange information.
- Community outreach and education, using economic as well as environmental arguments to support the maintenance changes can help to bring the public on board with reduced mowing regimes. Public education opportunities such as signs on roadsides and at rest areas, web resources, and brochures are some ways to spread the word out about the benefits of natural native wildflower habitat.
- Maintain a regularly mown clear zone adjacent to the pavement.
- Aesthetically pleasing native roadside plantings, which often require less mowing, can also increase public support.

Reducing Herbicide Use

Limited resources for training were identified as a constraint to reducing herbicide use. Very few of the States we interviewed provide their maintenance staff with training to identify native vegetation. As a consequence, maintenance staff cannot always recognize the difference between an invasive species such as an introduced thistle and a beneficial native wildflower such as blazing star (*Liatris* spp.). Training to recognize common native plants, as well as noxious and invasive weeds, is needed. Ideally, hands-on training would be conducted in the field, but pocket guides that can be stowed in trucks or tractors, and posters hung in maintenance shops would also be useful. Annual training to support best practices of herbicide use, such as timing applications effectively and using the most efficient equipment available, is an indispensable component of herbicide reduction programs.

Constraints of staff time and resources during busy periods of the season result in applications of herbicides made at non-optimal times, according to States that already make a conscious effort to time applications of herbicides to be most effective. It is recommended that States in this situation do their best to time applications, but at a minimum, treat weeds before the flowering stage.

Obstacles

- Few members of the maintenance staff have the training to recognize native plants, and those who don't have training spray beneficial native plants as well as invasive species.
- Herbicide applications are not always timed effectively due to constraints on maintenance staff time and resources.

Possible Solutions

- Provide training to increase plant identification skills so staff can recognize native plants as well as invasive weeds. If expertise to train staff does not exist within the agency, consider ways to partner with other State agencies or universities to develop a training program. Hold training at least once a year to ensure staff stays informed about any new developments in the vegetation management field. Field identification guides are also helpful tools.
- Establish protocols to time applications as effectively as possible within the given operational constraints of the agency.

Conducting Roadside Vegetation Surveys

The preservation of native plant communities is important for the health of ecosystems as well as for the natural heritage of an area. Identification of native plant communities and locations with invasive species along roadsides is the first step to effective roadside management. If maintenance staff does not currently have the expertise to conduct surveys, there are many public agencies or private organizations that would likely be willing to partner to the mutual benefit of all involved.

Obstacles

- Few DOTs may have internal botanical expertise to conduct roadside vegetation surveys.

Possible Solutions

- Partner with local botanical experts, State agencies, and/or universities to conduct roadside surveys with maintenance staff.

Using Alternative Vegetation Management Tools

Prescribed burns and targeted grazing can be cost-effective and efficient tools for aiding native plant establishment, controlling invasive plants, and managing vegetation over time on roadsides. However, these tools are not used very frequently, even under circumstances for which they might be the most appropriate management tools because of concerns over compromising motorist safety. Prescribed burns and grazing can be executed on some roadsides without endangering motorists or adjacent land. Careful planning to control traffic during a burn or to fence in grazers and proper staff training are needed, however. DOTs can partner with State land management agencies or local conservation organizations to gain training and expertise to conduct prescribed burns or prescribed grazing regimes on appropriate roadside sites.

Obstacles

- Use of prescribed burns and grazing for managing roadsides is limited, though both are effective vegetation management tools and can be valuable for revitalizing roadside plant communities.

Possible Solutions

- Collaborate with State agencies or local conservation organizations to gain training from experienced experts and to implement grazing and prescribed burns.

Obtaining Plant Materials

Increasing the use of native plants in roadside plantings is a key component of managing roadsides to benefit pollinators. Availability of regionally-sourced plant material is a constraint for some States. For example, there are few native seed vendors in Idaho, which limits the plant species that can be used in roadside plantings as well as the scale of plantings. A State may have a number of native species they would like to use for projects but that are not available in sufficient quantities. As a consequence, a DOT may only be able to work with a limited subset of native wildflowers. In practice this could result in mixes that are very costly, have a limited range in bloom times, or do not include key host plants for butterflies.

Photo 6-2: California roadside with native vegetation.

Cost is also an obstacle that is closely tied to issues of availability of native plant material. In some cases, seed can cost over $100 per ounce for certain species of native wildflowers, including species that would otherwise be ideal to include in roadside projects because they establish quickly, contribute to erosion control, fix nitrogen, or support pollinators. But seed for these species are currently typically too expensive for routine use.

There are a number of possible approaches for increasing the availability of regionally sourced seed and transplants. In regions of the country where there is not a developed native seed industry, private nurseries and agencies may to cooperate in pilot projects to develop an industry. Grants, tax benefits, or other incentivized funding tools would help to expand a nascent native seed industry.

DOTs could also consider establishing their own native seed production operations. Indiana's Hoosier Roadside Heritage Program collected seed from remnant prairie habitat in Indiana and established foundation seed plots and eventually production plots (see the Hoosier Roadside Heritage Program's website at http://www.in.gov/indot/2583.htm). Operation Wildflower, a cooperative program between FHWA, State highway agencies, and the National Council of State Garden Clubs, might be an opportunity for some State DOTs to increase their use of native plants or obtain foundation seed for further production. The program encourages garden clubs to contribute to the use of wildflowers in roadside plantings by providing plant material for projects, though the DOT has the final say in what species are used and where they are installed. West Virginia's Donate a Wildflower Site is a similar idea: donors make a financial contribution to support the planting of wildflowers at a particular roadside site, designated by a recognition sign (more information here: http://www.dep.wv.gov/dlr/reap/ow/Pages/DonateASite.aspx). The Transportation Alternatives Program, a competitive grant for State and local organizations other than transportation agencies, is an opportunity to collaborate with transportation agencies to obtain funding and implement vegetation management projects (more information available at http://www.fhwa.dot.gov/environment/transportation_alternatives/guidance/). Several States have specialty wildflower license plates (e.g., Florida, Oklahoma, and Texas), the sales of which support wildflower plantings, research, and education.

Photo 6-3: Iowa's collaborative efforts to grow a local seed industry support the State's efforts to restore roadsides to native prairie vegetation.

In regions of the country where native seed industries are well developed, incentives to existing seed producers can help to increase production and availability. On a State level, State DOTs can commit to increasing the use of native plants when using federal funds. State DOTs can also commit to purchasing and planting State- or region-origin seed. By following through with purchasing regionally sourced seed, DOTs can foster a stable native seed market that will eventually lead to greater production and lower costs. An approach that worked for Arizona DOT was placing a value that was 20-30% above market value on the species they needed most. Working with native seed producers and communicating about species lists and upcoming needs helped to increase availability in Arizona.

However, some States with thriving native seed industries that can offer a large diversity of species for reasonable prices may still face internal push-back about the costs of native plants. In part, resistance to the use of native plants may be a budgetary issue, with limited resources available for roadside planting projects because of other priorities. Resistance may also arise when administrators, State engineers, resident engineers, and district engineers underestimate the long-term economic value and the ecological value of the use of native plants. Among the many duties of a DOT, land management may often be overlooked. Staff education and training can spread awareness. Commissioning additional studies and/or a report on the long term costs of native plantings versus nonnative plantings would allow DOTs to determine if the long term cost savings outweighed the short term costs.

Case Study: Iowa's Natural Selections Program Increases Iowa Native Seed

The Natural Selections program was formed to build the native seed industry in Iowa to meet the demands for high quality, regionally adapted, and genetically diverse sources of native seed for prairie restorations, including roadside restorations. For native regional seed to be priced to compete with cultivars, it has to be produced in commercial quantities. The Natural Selections program is a collaboration between State and federal agencies, as well as private corporations. Past or present partners include the Iowa Crop Improvement Association, the Living Roadway Trust Fund administered by Iowa DOT, USDA Natural Resources Conservation Service Elsberry Plant Materials Center, the University of Northern Iowa, and independent seed producers. Seed is collected by hand from remnant populations by the project manager and by volunteers throughout the State. Seed is collected from remnant roadsides, natural areas, and private land in three regional zones within Iowa. Iowa's Natural Selections program uses provenance zones large enough to support a market but narrow enough to retain regional distinctiveness. Collectors do not collect seed to intentionally select for certain traits. Foundation seed plots at the University of Northern Iowa's Tallgrass Prairie Center amplify the seed, which is then further increased. Once seed has been increased, it is released to qualified native seed growers with production certified by the Iowa Crop Improvement Association. About 6-8 years after the initial collection, enough seed is available to sell to the public.

Successes of the project include increasing seed of 70 species, with nearly 120 ecotypes of 60 species released for commercial production, and 180,000-200,000 pounds of ecotype source-identified seed produced annually. More information can be found at http://www.tallgrassprairiecenter.org/natural-selections.

Case Study: Establishing Native Plants in Arizona

Arizona DOT (ADOT) has had a long history of effective native plant establishment on roadsides. The transition from use of nonnative species in plantings to use of native species began in earnest in the 1980s. Although prior use of native plants had been sporadic, by 1992, ADOT was using only native species in all roadside revegetation efforts.

State maps of biotic communities were used to draft plant species lists. Using the lists of species grouped by ecoregion, they cross-referenced the lists with commercially available plant material. Over the years, the availability of plant material, particularly seed of native species, has increased greatly. The consistent and sustained use of native grass and wildflower seed for ADOT projects over the years has motivated native seed growers to expand the market and to keep costs affordable. Currently native seed growers are also able to review ADOT's five-year plans, giving them an idea of future demand.

ADOT's roadside plantings are diverse and flower-rich. ADOT has avoided use of single-species mixes, as well as grass-only mixes. In every seeding specification, they emphasize a broad spectrum of species. For example, a typical species mix includes a diversity of 15-25 species, with a mix of annual, biennial, and perennial wildflowers and some shrubs, and 3-5 species of native grasses. After observing in plantings composed of a mix of 50% grass and 50% wildflowers/shrubs that the grasses outcompeted the flowers and even the shrubs over time, ADOT learned from their experiences and scaled back the proportion of grasses to 25% to allow flowers to proliferate.

ADOT is also proactive when it comes to the plant establishment process, controlling weeds that may pose a threat to the establishment of the desired native plants. For example, ADOT includes noxious and invasive species control in construction specifications, the first State to adopt this approach. In practice, this specification means that noxious and invasive weeds are controlled both before an area is disturbed, during construction, and after. To reduce the introduction of unwanted species, ADOT uses clean compost (no manure or biosolids) and certified weed-free straw during the planting process. Seeds are required to be supplied in separate packages for each species rather than pre-mixed. ADOT requires a seed testing certificate showing germination percentage and any contaminant species. ADOT reviews the seed certificates and rejects those that contain undesirable species as contaminants. The specifications also provide a replacement cost for each species to discourage substitutions with seeds of less expensive species. By proactively controlling problematic weeds that can outcompete beneficial plants, these practices help desired species establish quickly and effectively and maintain the long-term integrity of roadside plantings.

Obstacles

- The availability of regionally sourced native plant material varies widely across regions.
- Native plant materials may cost more than nonnative plant materials.

Possible Solutions

- In regions where no native seed industry exists, private nurseries and agencies could cooperate to build an industry. Grants, tax benefits, or other incentivized funding tools would assist the process. DOTs could also consider establishing their own native seed production operations.
- In regions of the country where native seed industries are already developed, DOTs can help to increase production and availability by committing to the use of native plants, purchasing and planting State- or region-origin seed, and communicating needs to seed vendors, which would foster a stable market that will eventually lead to greater production and lower costs.

Training Staff

Education and training were universally mentioned as indispensable by DOT employees and roadside restoration experts. In particular, the people we interviewed expressed a need for DOT staff training to support the use of native plants, including background information about the economic and ecological value of native plants, the process of establishing native plants and the long term management of native plants.

Value of Native Plants

Some State DOT personnel feel that roadside vegetation is not recognized by administrators, engineers, designers, and/or maintenance staff as an important component of the highway system. Training and education about the ecosystem services that roadsides can provide and how to restore and manage roadsides as the natural resources they are, are important for maintenance staff, design staff, engineers, and middle management of State transportation agencies. To balance ecosystem information with fiscal concerns, the potential for cost savings from practices like reduced mowing are good to highlight when discussing the benefits of pollinator-friendly practices with agency managers and leadership. Participation in trainings by other State DOTs, agencies, or local experts may help to build local connections and share expertise.

Internal support for pollinator conservation can be approached directly, citing the value of pollinators to agriculture and ecosystems and the role roadsides can play in pollinator conservation. Or an indirect approach highlighting the multiple benefits of native plant restoration, one of which is pollinator conservation, might be more effective. Managing roadsides to benefit pollinators means managing roadsides to benefit biodiversity. Internal awareness and support can increase communication between functional units within DOTs, increasing efficiency and effective roadside management.

Plant Establishment and Management

"I think there is a lack of expertise especially because there is a perception that roadside revegetation with native plants is easy - just pull seed off the shelf and throw it on the ground. In reality, it is just like being an engineer, with training needed," – Scott Riley, botanist and regional restoration specialist, U.S. Forest Service.

Some States express concern about the process of establishing native plants. States that lack experience and expertise with native plant establishment may need to acquire staff with restoration background. Alternatively, they can work with organizations and partners to learn from existing regional expertise, or learn from DOTs that have histories of successful implementations (examples include Arizona, California, Iowa, Nebraska, and Oregon).

Photo 6-4: Planning ahead and controlling for invasive species before planting can increase the success of roadside revegetation projects.

Tips from an Expert: Planning Ahead Increases Success

"One of the things our team does is get involved with these projects two to three years before they are implemented. This allows us time to collect seed, propagate plants, do soil surveys, look at the climate and work with the engineers to integrate revegetation into their plans. A lot of times when we do our initial study of a site, we often go back to the engineers and let them know what we foresee as challenges so we can try and approach the challenges from a different angle. Time frame is really important. You need to have a minimum of a year to plan how to develop the revegetation project for it to be successful. One of the reasons for our success is having support top-to-bottom internally and from our funding sources that give us the ability to successfully implement projects we are involved with. The other thing that helps our success is one of us from the team being at the site during installation to ensure guidelines are followed. There is a lot of labor and love that goes into this." – David Steinfeld, retired, restoration ecologist, U.S. Forest Service.

Obstacles

- Within DOTs, administrators, State engineers, resident engineers, and/or district engineers may resist using native plants due to initial expense, unfamiliarity with native plants, or because competing priorities overshadow roadside vegetation management concerns.
- There is a lack of expertise in establishing native plants within many DOTs.

Possible Solutions

- Education and training about the long-term economic and ecological value of native plants in roadsides to administrators, State engineers, resident engineers, and district engineers may help increase the comfort level around the use of native plants.
- Education and training about native plants and their establishment would build expertise, as would partnerships with other State land management agencies or conservation experts.

Native Plants, Education, and Public Relations

Effective communication with the public is an important component of roadside restoration programs. The success of roadside restoration programs can hinge on public support. Yet the general public may lack awareness of the ecological and economic values of such a program and are less tolerant of the aesthetics of roadside restorations that are less manicured than traditional turf roadsides. Native plantings can take several years to establish and reach an attractive appearance. Additionally, some adjacent farmers and ranchers see native plants as a threat to their operations. For example, milkweeds, host plants of monarch butterflies, are frequently perceived as problematic roadside plants that will become weeds on a farmer's adjacent land. Landowners may mow down or spray out roadside wildflowers and decrease the quality of the roadside restoration. DOTs may wan to raise awareness and inform the public of the benefits of using native plants along roadsides and other sustainable roadside management practices.

Raising Public Awareness

Aesthetically, roadside restorations are a divergence from traditionally mown turf roadsides. Public awareness of the economic and ecological value of establishing and maintaining native vegetation on roadsides, including the benefits to pollinators, and the processes involved in establishing native vegetation, will help to increase public support.

General recommendations to generate public support for roadside restoration programs include spreading educational information through a number of avenues and producing effective restorations that can serve as examples of successes. Disseminate native plant information via web resources, posters, brochures, signage on roadsides and at rest areas, community meetings, or news articles. Develop a series of native plant public service announcements for local television and radio. Offer promotional items, such as license plates, wildflower handbooks, seed packets, or t-shirts that could be purchased to provide funding for the program.

Identify groups that are natural allies or that could provide support for your roadside program, such as native plant societies, local garden clubs, and tourism organizations. Reaching out and presenting to civic groups can garner support too. Partnerships with other State agencies (e.g., Departments of Natural Resources or Fish and Game) or organizations such as native plant societies or land management groups can increase audiences reached. Partnerships with other organizations that work with farmers, or extension services of universities, can help to correct misinformation about native plants while highlighting the importance and value of roadside native plants.

The presence of colorful wildflowers on roadsides, designated by signage, can be a tremendous boost to public relations and to tourism. Wildflower tourism is promoted in several States, including Texas and Florida. West Virginia DOT offers a "Roadsides in Bloom" calendar each year that includes photos of wildflowers on roadsides. WV DOT holds a photography contest to determine the photographs included, and in the process spreads awareness of roadside flowers. Plantings strategically located in visible areas or in regions where farmers will benefit from spillover ecosystem services like pollination can serve as demonstrations.

Staff Awareness

Maintenance staff, as well as any DOT staff that deal with the public, ideally would have training to understand the goals and practices of roadside restoration programs. Such training will benefit staff when they coordinate with the adjacent land owners and address any issues or concerns. Additionally, if staffers are knowledgeable about the practices, they can help to promote the advantages of the program to the public, answer questions (see page 6-11 for example language that could be used when communicating with the public about promoting wildflowers along roadsides to benefit pollinators) and resolve any complaints or problems that arise, all of which can increase public approval. Having a packet or handbook of information available to the staff may be helpful.

Resolving Complaints

Despite the financial and functional arguments for the use of native plants along roadsides, not everyone will be receptive. However, public complaints about weedy roadsides represent a small proportion of the people using the road. DOTs frequently respond to these complaints by increasing mowing, which can be detrimental to restorations. However, complaints may not be the best gauge of public perceptions; public opinion surveys may be more accurate (Guyton et al. 2014).

Photo 6-5: Although pollinators are killed by cars, increasing wildflowers in roadsides actually reduces pollinator road mortality.

Obstacles

- Native plants may be perceived by the general public as weeds or a threat to neighboring land.

Possible Solutions

- Help the public to understand the ecological and economic value of using native plants to manage roadsides.
- Form partnerships with other organizations or agencies to provide education and outreach about native plants.

- Incorporate native plants into tourism campaigns and install showy plantings in visible locations.

Communicating with the Public: Frequently Asked Questions about Roadsides as Habitat for Pollinators

How can roadsides be useful to pollinators?

Roadsides provide several ecological functions for pollinators, including serving as foraging habitat, providing breeding or nesting opportunities, and helping pollinators to move through landscapes by linking fragmented habitats. Not all roadsides are equally beneficial to pollinators. Roadsides with abundant wildflowers, predominately native plants, managed by judicious mowing, herbicides, and other management tools, provide the best roadside habitat. Although roadsides are not a substitute for wildland habitat, as patches of refuge for pollinators in otherwise inhospitable landscapes, roadsides can contribute to the maintenance of healthy ecosystems and the provision of ecological services such as crop pollination.

Sources: Dirig and Cryan 1991; Munguira and Thomas 1992; Ries et al. 2001; Saarinen et al. 2005; Hopwood 2008; Schaffers et al. 2012.

Why use native plants, if they are more expensive than nonnative species?

There are many advantages of using native plants to stabilize roadsides. Native grasses and flowers are best adapted to local growing conditions, require minimal inputs for establishment, and are able to tolerate extreme weather events such as drought. The root systems of native plants can increase water infiltration, which reduces runoff and water pollution and keeps our waters cleaner. A diverse native plant community can reduce soil erosion and resist weed invasions, which can reduce maintenance costs. Although native plants may cost more upfront, they can provide cost savings over time. Native plants can be aesthetically pleasing during the growing season while also acting as snow fences in the winter, trapping and preventing snow from blowing across roads. Native plant communities also support more birds, pollinators, and other wildlife. The use of native plants in roadsides can provide ecological benefits to the surrounding landscape.

Sources: Cramer 1991; Bugg et al. 1997; Harper-Lore and Wilson 2000; Johnson 2000; Ries et al. 2001; Quales 2003; Blumenthal et al. 2005; Tilman et al. 2006; Hopwood 2008; Tallamy and Shropshire 2009; Williams et al. 2011; Harrison 2014; Harper-Lore et al. 2014.

Will any of the wildflowers planted on roadsides spread to my property and become weeds?

Native plants in roadsides are less likely than many nonnative plants to become weed issues and encroach on adjacent land.

Source: Harper-Lore and Wilson 2000.

Are milkweeds present in the roadside a threat to livestock on adjacent land?

Milkweeds present in roadsides are unlikely to be a threat to livestock on adjacent property. Very few milkweeds will spread from their planting site. If milkweeds are present in pastures or rangelands, most livestock take great care to avoid them. Although milkweeds are toxic to herbivores, including livestock, they are highly unpalatable to livestock. Milkweed poisoning typically only occurs when livestock are confined to a barren paddock with no alternate food sources.

Sources: Fulton 1972; Pfister et al. 2002; Borders and Lee-Mader 2014.

Are collisions with vehicles a major source of mortality for pollinators?

Hundreds of thousands of pollinators are killed by vehicles on roads, but, research suggests that the numbers appear to be a small proportion of overall populations. Mortality rates of butterflies on roads, for example, range from 0.6% to a maximum of 10% of the population, depending on the species. Road mortality can be higher for some species of pollinators than others. For example, butterflies appear to be one of the more common groups of insects killed by cars. Some butterflies that are strong fliers have the ability to dodge vehicles, while other less adroit species are more susceptible.

Sources: Munguira and Thomas 1992; McKenna et al. 2001; Ries et al. 2001; Rao and Girish 2007; Zielin et al. 2010; Skórka et al. 2013; Munoz et al. 2015.

If the amount of wildflowers on roadsides increases, will the number of pollinators killed on roads increase too?

Although pollinators and other wildlife are going to be killed by vehicles as long as we have roads, there are ways to reduce pollinator road mortality. Reducing roadside mowing can reduce butterfly mortality, as can enhancing the diversity and abundance of wildflowers on roadsides. Current research suggests that, rather than luring pollinators to their death by vehicle, roadsides with high quality habitat actually reduce pollinator mortality.

Sources: Munguira and Thomas 1992; Ries et al. 2001; Skórka et al. 2013.

If roadsides are mown less frequently, will this impact highway safety, especially collisions with deer?

Frequency of mowing of the entire roadside doesn't appear to influence rates of deer-vehicle crashes. In fact, deer may actually prefer some roadsides that are mowed more frequently because mowing can increase the palatability of some plants. A strip of vegetation adjacent to the pavement that is mown regularly, while letting the rest of the roadside grow to a reasonable height, can help to maintain visibility of drivers and prevent deer-vehicle crashes.

Sources: Mastro et al. 2008; Barnum and Alt 2013; Guyton et al. 2014.

Final Thoughts

With thoughtful management, roadsides can provide our nation's critical pollinators with millions of acres of much-needed habitat. Pollinators will benefit from DOTs that adjust the frequency and timing of vegetation management to augment floral resources, and from the enhancement and restoration of native vegetation to roadside habitat. Some of the obstacles to implementing these changes include skepticism about the value of reduced mowing from DOT staff and the public, the availability and cost of native plant material, and a lack of expertise with native plant identification and establishment within DOTs. In order to successfully implement roadside management regimes that benefit pollinators, State DOTs need training and tools, access to native plant materials and restoration expertise, and a plan for outreach to the public.

Beyond the value to pollinators, roadsides managed with pollinators in mind will broadly benefit wildlife and ecosystem health. Roadsides are also an opportunity to showcase natural beauty and promote tourism, reduce maintenance and thereby provide cost savings to DOTs, and to support a wide range of important ecosystem services including carbon sequestration. Roadsides are an integral part of the highway system and may be valued as important natural resources by the general public, roadside managers, and DOT administrators.

Photo 6-6: The value of native vegetation on roadsides extends beyond regional beauty. Native plants help the air, soil, and wildlife. Roadsides with native plants benefit the larger ecosystem as well as confer economic benefits to DOTs and communities.

This page intentionally left blank.

Chapter 7
Resources for Roadside Management for Pollinators

Below are some resources for implementing pollinator-friendly roadside management practices. These and other resources may also be available through the Federal Highway Administration's pollinator resource page, found here: https://www.environment.fhwa.dot.gov/ecosystems/vegmgmt_pollinators.asp

Vegetation Management

Guidelines for Vegetation Management

From the American Association of State Highway and Transportation Officials and based on the experience of roadside managers, this manual includes information about weed control, erosion control, native plant establishment, prescribed burning, and other vegetation management techniques.

https://bookstore.transportation.org/item_details.aspx?ID=1752

Vegetation Management: An Ecoregional Approach

This handbook for managers, edited by Bonnie Harper-Lore, Maggie Johnson, and William Ostrum, is one of FHWA's resources for considering ecoregional contexts in roadside vegetation management.

https://www.environment.fhwa.dot.gov/ecosystems/veg_mgmt_rpt/vegmgmt_ecoregional_approach.asp

Roadside Weed Management

Invasive species prevention and control, as well as State-by-State weed lists, and a primer on restoration are included in this book. A portion of the book is available as a pdf from:

http://www.weedcenter.org/store/docs/books-brochures/roadside%20weed%20management.pdf

Introduced, Invasive, and Noxious Plants

Federal and State noxious weed lists, invasive plant lists, and introduced plant lists, with links to more information.

https://plants.usda.gov/java/noxiousDriver

Native Plants and Restoration

Roadside Use of Native Plants

A reference that includes lists of native trees, shrubs, vines, grasses, and forbs for each State.

http://www.environment.fhwa.dot.gov/ecosystems/vegmgmt_rdsduse.asp

***Roadside Revegetation: An Integrated Approach to Establishing Native* Plants**

This manual provides information on native plant establishment from project planning though monitoring after installation. There is also an interactive, multimedia website.

http://www.nativerevegetation.org/

A Manager's Guide to Roadside Revegetation Using Native Plants

This guide is a resource for engineers and managers to implement native revegetation projects.

http://flh.fhwa.dot.gov/about/css/documents/rr-managers-guide.pdf

Restoration, Nurseries, and Genetic Resources

This website, from technical specialists with the U.S. Department of Agriculture, Forest Service, has resources about growing native plants, including a national seed and nursery directory, and many publications about propagation and plant establishment.

http://www.rngr.net/

Lady Bird Johnson Wildflower Center

The Center's Native Plants Database is searchable by plants by State, height, soil moisture, and other characteristics, including value to pollinators.

http://www.wildflower.org/plants/

North American Plant Atlas

From the Biota of North America Program, this searchable plant database also includes county-level species distribution maps.

http://bonap.net/napa

PlantNative

This website includes directories of native plant nurseries and professionals, as well as regional lists of species that are commercially available.

http://www.plantnative.org

Pollinators and Roadsides

Literature Review: Pollinator Habitat Enhancement and Best Management Practices in Highway Rights-of-Way.

This literature review was developed to inform this Best Management Practices document, and provides a detailed account of the research relating to use of roadsides by pollinators and vegetation management practices.

http://www.environment.fhwa.dot.gov/ecosystems/documents/pollinators_BMPs_in_highway_ROW.asp

What's the Buzz about Pollinators and Roadsides?

Produced by Minnesota's Department of Natural Resources, this poster focuses on pollinators and the role roadsides can play in their conservation.

http://files.dnr.state.mn.us/assistance/nrplanning/community/roadsidesforwildlife/beesforroadsides.pdf

Pollinators and Roadsides: Guidelines for Managing Roadsides for Bees and Butterflies

This publication provides an overview of the conservation potential of roadsides and steps to take to maximize the value of these areas to pollinators.

http://www.xerces.org/guidelines/pollinators-and-roadsides/

Pollinator Plant Resources

Regional Pollinator Plant Lists

A resource for finding native plants that are highly attractive to pollinators such as native bees, honey bees, butterflies, moths, and hummingbirds, and are well-suited for small-scale plantings in gardens, on business and school campuses, in urban greenspaces, and in farm field borders.

http://www.xerces.org/pollinator-conservation/plant-lists/

Pollinator Habitat Installation Guides

These regional guides describe how to install and maintain foraging and nesting habitat for pollinators and include region-specific plant recommendations.

http://www.xerces.org/pollinator-conservation/agriculture/pollinator-habitat-installation-guides/

Attracting Native Pollinators

A guide to pollinators, including profiles of commonly encountered bee genera and more than 50 pages of fully-illustrated plant lists.

http://www.xerces.org/announcing-the-publication-of-attracting-native-pollinators/

Lady Bird Johnson Wildflower Center

The Special Collections section of the Native Plants Database includes lists of plants that are attractive to native bees, honey bees, and other beneficial insects. The lists can also be narrowed down by criteria such as State, soil moisture, and other characteristics.

https://www.wildflower.org/collections/

Pollinator Biology and Conservation

Pollinator Conservation Resource Center

The Resource Center includes regional information on plants for pollinator habitat enhancement, habitat conservation guides, nest management instructions, bee identification and monitoring resources, and directories of native pollinator plant nurseries.

www.xerces.org/pollinator-resource-center/

Attracting Native Pollinators

A guide to pollinators, including profiles of commonly encountered bee genera and more than 50 pages of fully-illustrated plant lists.

http://www.xerces.org/announcing-the-publication-of-attracting-native-pollinators/

Bee Monitoring Tools

Designed for conservationists, farmers, land managers, and restorationists, these guides provide instructions for assessing pollinator habitat quality and diversity by monitoring native bees.

http://www.xerces.org/xerces-bee-monitoring-tools/

How to Reduce Bee Poisoning from Pesticides

From Pacific Northwest Extension, this publication includes common agricultural pesticides and their known effects on bees.

http://ir.library.oregonstate.edu/xmlui/bitstream/handle/1957/42829/PNW%20591.pdf?sequence=3

Inside Agroforestry – Windbreaks

From the National Agroforestry Center, this publication describes how to design windbreaks with pollinators in mind.

http://nac.unl.edu/documents/insideagroforestry/vol20issue1.pdf

This page intentionally left blank.

Chapter 8
Contributors

Prepared by: The Xerces Society for Invertebrate Conservation in collaboration with ICF International.

Authors: Jennifer Hopwood[1], Scott Hoffman Black[1], and Scott Fleury[2]

Editor/Contributor: Deirdre Remley[3]

[1] Xerces Society for Invertebrate Conservation

[2] ICF International

[3] Federal Highway Administration

This page intentionally left blank.

Chapter 9
References Cited

Ahern, J., C. A. Niedner, and A. Barker. 1992. Roadside wildflower meadows: Summary of benefits and guidelines to successful establishment and management. *Transportation Research Record* No. 1334: 46–53.

Alaux, C., F. Ducloz, D. Crauser, and Y. Le Conte. 2010. Diet effects on honeybee immunocompetence. *Biology Letters*: rsbl20090986.

Allen-Wardell, G., P. Bernhardt, R. Bitner, A. Burquez, S. Buchmann, J. Cane, P. Cox, V. Dalton, P. Feinsinger, M. Ingram, D. Inouye, C. E. Jones, K. Kennedy, P. Kevan, H. Koopowitz, R. Medellin, S. Medellin-Morales, G. Nabhan, B. Pavlik, V. Tepedino, P. Torchio, and S. Walker. 1998. The potential consequences of pollinator declines on the conservation of biodiversity and stability of food crop yields. *Conservation Biology* 12(1):8–17.

Altizer S. M., and K. S. Oberhauser. 1999. Effects of the protozoan parasite *Ophryocystis elektroscirrha* on the fitness of monarch butterflies (*Danaus plexippus*). *Journal of Invertebrate Pathology* 74:76–88.

Ament, R., J. Begley, S. Powell, and P. Stoy. 2014. Roadside Vegetation and Soils on Federal Lands-Evaluation of the Potential for Increasing Carbon Capture and Storage and Decreasing Carbon Emissions. Report for the Federal Highway Administration, # DTFH68-07-E-00045. Available: http://www.westerntransportationinstitute.org/documents/reports/4W3748_Final_Report.pdf. Accessed: September 2015.

Barnum, S. A., and G. Alt. 2013. The Effect of Reduced Roadside Mowing on Rate of Deer-Vehicle Collisions. Transportation Research Board 92nd Annual Meeting Compendium of Papers. Available: http://docs.trb.org/prp/13-5041.pdf. Accessed: October 2015.

Barton, S., R. Darke, and G. Schwetz. 2009. Enhancing Delaware Highways: Roadside Vegetation Establishment and Management Manual. Delaware Department of Transportation. Available: http://www.deldot.gov/information/pubs_forms/manuals/edh/pdf/edh_establishment_management.pdf. Accessed: September 2015.

Baum, K. A., and E. Mueller. 2015. Grassland and roadside management practices affect milkweed abundance and opportunities for monarch recruitment. Pages 197–202 in K. S. Oberhauser, K. R. Nail, and S. M. Altizer (eds.), *Monarchs in a Changing World: Biology and Conservation of an Iconic Butterfly*. Ithaca, NY: Cornell University Press.

Bawa, K. S. 1990. Plant-pollinator interactions in tropical rain forests. *Annual Review of Ecology and Systematics*: 399–422.

Bee Informed Partnership. 2014. Bee Informed Partnership | Using beekeepers' Real World Experience to Solve Beekeepers' Real World problems. Available: http://beeinformed.org/. Accessed: April 2014.

Biesmeijer J. C., S. P. M. Roberts, M. Reemer, R. Ohlemüller, M. Edwards, T. Peeters, A. P. Schaffers, S. G. Potts, R. Kleukers, C. D. Thomas, J. Settele, and W. E. Kunin. 2006. Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. *Science* 313:351–354.

Billings, C. H. 1990. Wildflowers: Municipal field reports. *Public Works* 121(3):106.

Black, S. H., M. Shepherd, and M. Vaughan. 2011. Rangeland management for pollinators. *Rangelands* 33(3):9–13.

Blumenthal, D. M., N. R. Jordan, and E. L. Svenson. 2005. Effects of prairie restoration on weed invasions. *Agriculture, Ecosystems and Environment* 107:221–230.

Borders, B., and E. Lee-Mader. 2014. *Milkweeds: A Conservation Practitioner's Guide*. 146 pp. Portland, OR: The Xerces Society for Invertebrate Conservation.

Bosch, J., and W. P. Kemp. 2001. *How to Manage the Blue Orchard Bee as an Orchard Pollinator.* Available: http://agris.fao.org/agris-search/search.do?recordID=US201300072439. Accessed: March 31, 2014.

Brandt, J., K. Henderson, and J. Uthe. 2011. *Integrated Roadside Vegetation Management Technical Manual*. Available: http://www.uni.edu/irvm. Accessed: November 2014.

Brosi, B. J., and H. M. Briggs. 2013. Single pollinator species losses reduce floral fidelity and plant reproductive function. *Proceedings of the National Academy of Sciences* 110(32):13044–13048.

Brown, D. L., J. Laird, W. Sommers, and A. Hamilton. 1999. Methods used by the Arizona Department of Transportation to reduce wildlife mortality and improve highway safety. In *International Conference of Wildlife Ecology and Transportation, Florida*.

Bugg, R. L., C. S. Brown, and J. H. Anderson. 1997. Restoring native perennial grasses to rural roadsides in the Sacramento Valley of California: Establishment and evaluation. *Restoration Ecology* 5:214–228.

Burrows, G. E., and R. J, Tyrl. 2013. Table 9.2: Toxicity and cardenolide content of species of *Asclepias. Toxic Plants of North America, 2nd Edition*. Wiley-Blackwell, 1,390 pp.

Cackowsky, J.-M., and J.L. Nasar. 2003. Restorative effects of roadside vegetation: implications for automobile driver anger and frustration. *Environment and Behavior* 35(6):736–751.

Calder, W. A. 2004. Rufous and broad-tailed hummingbirds—Pollination, migration, and population biology. Pages 59–79 in G. P. Nabhan (ed.), *Conserving Migratory Pollinators and Nectar Corridors in Western North America*. Tucson: University of Arizona Press.

Calderone, N. W. 2012. Insect pollinated crops, insect pollinators and US agriculture: Trend analysis of aggregate data for the period 1992–2009. *PLOS One* 7:e37235.

Cameron, S. A., J. D. Lozier, J. P. Strange, J. B. Koch, N. Cordes, L. F. Solter, and T. L. Griswold. 2011. Patterns of widespread decline in North American bumble bees. *Proceedings of the National Academy of Sciences* 108(2):662–667.

Carvell, C. 2002. Habitat use and conservation of bumble bees (*Bombus* spp.) under different grassland management regimes. *Biological Conservation* 103:33–49.

Chaplin-Kramer, R., M. E. O'Rourke, E. J. Blitzer, and C. Kremen. 2011. A meta-analysis of crop pest and natural enemy response to landscape complexity. *Ecology Letters* 14(9):922–932.

Colla, S. R., M. C. Otterstatter, R. J. Gegear, and J. D. Thomson. 2006. Plight of the bumble bee: pathogen spillover from commercial to wild populations. *Biological Conservation* 129:461–467.

Collins, K. L., N. D. Boatman, A. Wilcox, and J. M. Holland. 2003. Effects of different grass treatments used to create overwintering habitat for predatory arthropods on arable farmland. *Agriculture, Ecosystems & Environment* 96:59–68.

Collins, S. L., A. K. Knapp, J. M. Briggs, J. M. Blair, and E. M. Steinauer. 1998. Modulation of diversity by grazing and mowing in native tallgrass prairie. *Science* 280:745–747.

Cramer, C. 1991. Tougher than weeds: native prairie plants, better management trim roadside spraying 90%. *The New Farm* 13:37–39.

Croxton, P. J., J. P. Hann, J. N. Greatorex-Davis, and T. H. Sparks. 2005. Linear hotspots? The floral and butterfly diversity of green lanes. *Biological Conservation* 121:579–584.

Dana M. N., R. D. Kemery, and B. S. Boszor. 1996. *Wildflowers for Indiana's Highways.* Purdue University Joint Highway Research Project, Project No: C-36-48N, File No: 9-5-14.

Davies, Z. G., R. J. Wilson, T. M. Brereton, and C. D. Thomas. 2005. The re-expansion and improving status of the silver-spotted skipper butterfly (*Hesperia comma*) in Britain: A metapopulation success story. *Biological Conservation* 124:189–198.

Di Pasquale, G., M. Salignon, Y. Le Conte, L.P. Belzunces, A. Decourtye, A. Kretzschmar, S. Suchail, J-L Brunet, and C. Alaux. 2013. Influence of pollen nutrition on honey bee health: Do pollen quality and diversity matter. *PLOS One* 8(8):e72016.

Dirig, R., and J. F. Cryan 1991. The status of silvery blue subspecies (*Glaucopsyche lygdamus lygdamus* and *G. l. couperi*: Lycaenidae) in New York. *Journal of the Lepidopterists' Society* 45(4):272–290.

Eilers, E. J., C. Kremen, S. Smith Greenleaf, A. K. Garber, and A-M Klein. 2011. Contribution of pollinator-mediated crops to nutrients in the human food supply. *PLOS One* 6(6):e21363.

Evans, E., R. Thorp, S. Jepsen, and S. Hoffman Black. 2008. *Status Review of Three Formerly Common Species of Bumble bee in the Subgenus /Bombus/.* The Xerces Society. 63 pp. Available: http://www.xerces.org/wp-content/uploads/2009/03/xerces_2008_bombus_status_review.pdf.

Falk, A. D., T. E. Fulbright, F. S. Smith, L. A. Brennan, A. J. Ortega-Santos, and S. Benn. 2013. Does seeding a locally adapted native mixture inhibit ingress by exotic plants? *Restoration Ecology* 21(4):474–480.

Fallon, C., S. Hoffman Black, and M. Shepherd. 2014. Butterflies and moths as pollinators. *Wings* 37(2). The Xerces Society for Invertebrate Conservation.

Feber, R. E., H. Smith, and D. W. Macdonald. 1996. The effects on butterfly abundance of the management of uncropped edges of arable fields. *Journal of Applied Ecology* 33:1191–1205.

Federal Highway Administration. 2008. A Guide for Local Highway and Street Maintenance Personnel. *http://safety.fhwa.dot.gov/local_rural/training/fhwasa07018/*.

Fiedler, A. K., D. A. Landis, and M. Arduser. 2012. Rapid shift in pollinator communities following invasive species removal. *Restoration Ecology* 20(5):593–602.

Fischer, S. J., E. H. Williams, L. P. Brower, and P. A. Palmiotto. 2015. Enhancing monarch butterfly reproduction by mowing fields of common milkweed. *The American Midland Naturalist* 173(2):229–240.

Fontaine, C., I. Dajoz, J. Meriguet, and M. Loreau. 2005. Functional diversity of plant–pollinator interaction webs enhances the persistence of plant communities. *PLOS Biology* 4(1):e1. DOI: 10.1371/journal.pbio.0040001.

Forister, M. L., J. P. Jahner, K. L. Casner, J. S. Wilson, and A. M. Shapiro. 2011. The race is not to the swift: Long-term data reveal pervasive declines in California's low-elevation butterfly fauna. *Ecology* 92(12):2222–2235.

Forman, R. T. T., D. Sperling, J. A. Bissonette, A. P. Clevenger, C. D. Cutshall, V. H. Dale, L. Fahrig, R. France, C. R. Goldman, K. Heanue, J. A. Jones, F. J. Swanson, T. Turrentine, and T. C. Winter. 2003. *Road Ecology: Science and Solutions*. Washington, D.C.: Island Press.

Frankie, G. W., S. B. Vinson, L. E. Newstrom, J. F. Barthell, W. A. Haber, and J. K. Frankie. 1990. Plant phenology, pollination ecology, pollinator behaviour and conservation of pollinators in Neotropical dry forest. Pages 37–47 in K. S. Bawa and M. Hadley (eds.), *Reproductive Ecology of Tropical Forest Plants*. Paris: The Parthenon Publishing Group.

Fulton, D. H. (ed). 1972. *Poisonous Plant Groups*. Technical Note: Range No. 1. USDA SCS: Boise, ID.

Garibaldi, L. A., I. Steffan-Dewenter, R. Winfree, M. A. Aizen, R. Bommarco, S. A. Cunningham, C. Kremen. 2013. Wild pollinators enhance fruit set of crops regardless of honey bee abundance. *Science* 339(6127):1608–1611.

Gerell, R. 1997. Management of roadside vegetation: Effects on density and species diversity of butterflies in Scania, south Sweden. *Entomologisk Tidskrift* 118:171–176.

Grant, V. 1994. Historical development of ornithophily in the western North American flora. *Proceedings of the National Academy of Sciences* 91:10407–10411.

Grixti, J. C., L. T. Wong, S. A. Cameron, and C. Favret. 2009. Decline of bumble bees (*Bombus*) in the North American Midwest. *Biological Conservation* 142:75–84.

Gustafson, D. J., D. J. Gibson, and D. L. Nickrent. 2005. Using local seeds in prairie restoration—data support the paradigm. *Native Plants Journal* 6(1):25–28.

Guyton, J., J. C. Jones, and E. Entsminger. 2014. *Alternative Mowing Regimes' Influence on Native Plants and Deer*. Report No. FHWA/MDOT-RD-14-228

Hansen, M. J., and A. P. Clevenger. 2005. The influence of disturbance and habitat on the presence of non-native plant species along transport corridors. *Biological Conservation* 125(2):249–259.

Hanula, J. L., and S. Horn. 2011. Removing an invasive shrub (Chinese privet) increases native bee diversity and abundance in riparian forests of the southeastern United States. *Insect Conservation and Diversity* 4(4):275–283.

Harper-Lore, B., and M. Wilson (eds.). 2000. *Roadside Use of Native Plants*. Washington, DC: Island Press. 665 pp.

Harper-Lore, B., M. Johnson, and W. F. Ostrum. 2014. *Vegetation Management: An Ecoregional Approach*. United States Department of Transportation Federal Highway Administration.

Harrison, G. L. 2014. *Economic Impact of Ecosystem Service Provided by Ecologically Sustainable Roadside Right of Way Vegetation Management Practices.* Florida Department of Transportation Contract Number BDK75-977-74. Available: http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_EMO/FDOT-BDK75-977-74-rpt.pdf. Accessed: September 2014.

Hartzler, R. G. 2010. Reduction in common milkweed (*Asclepias syriaca*) occurrence in Iowa cropland from 1999 to 2009. *Crop Protection* 29:1542–1544.

Hatfield, R. G., and G. LeBuhn. 2007. Patch and landscape factors shape community assemblage of bumble bees, *Bombus* spp. (Hymenoptera: Apidae), in montane meadows. *Biological Conservation* 139:150–158.

Hatfield, R., S. Jepsen, E. Mader, S. H. Black, and M. Shepherd. 2012. *Conserving Bumble Bees, Guidelines for Creating and Managing Habitat for America's Declining Pollinators*. 32 pp. Portland, OR: The Xerces Society for Invertebrate Conservation.

Hatfield, R. G., S. R. Colla, S. Jepsen, L. L. Richardson, and R. W. Thorp. 2014. In Prep. International Union for the Conservation of Nature (IUCN) Assessments for North American *Bombus* spp. for the North American IUCN Bumble Bee Specialist Group. Portland, OR: The Xerces Society for Invertebrate Conservation.

Hopwood, J. L. 2008. The contribution of roadside grassland restorations to native bee conservation. *Biological Conservation* 141:2632–2640.

Hopwood, J., L. Winkler, B. Deal, and M. Chivvis. 2010. Use of roadside prairie plantings by native bees. Living Roadway Trust Fund. Available: http://www.iowalivingroadway.com/ResearchProjects/90-00-LRTF-011.pdf. Accessed: October 2014.

Houseal, G., and D. Smith. 2000. Source-identified seed: The Iowa roadside experience. *Ecological Restoration* 18(3):173–183.

Huijser, M. P., and A. P. Clevenger. 2006. Habitat and corridor function of rights-of-way. Pages 233–254 in J. Davenport and J. L. Davenport (eds.), *The Ecology of Transportation: Managing Mobility for the Environment*. Springer Netherlands.

Humbert, J-Y., J. Ghazoul, G. J. Sauter, and T. Walter. 2010. Impact of different meadow mowing techniques on field invertebrates. *Journal of Applied Entomology* 134(7):592–599.

Irvine, A. K, and J. E. Armstrong. 1990. Beetle pollination in tropical forests of Australia. Pages 135–149 in K. S. Bawa and M. Hadley (eds.), *Reproductive Ecology of Tropical Forest Plants*. Paris: The Parthenon Publishing Group.

Jablonski, B., Z. Koltowski, J. Marcinkowski, H. Rybak-Chmielewska, T. Szczesna, and Z. Warakomska. 1995. Zawartosc metali ciezkich [Pb, Cd, i Cu] w nektarze, miodzie i pylku pochodzacym z roslin rosnacych przy szlakach komunikacyjnych [The content of heavy metals (Pb, Cd and Cu) in the nectar, honey and pollen collected from roadside plants]. *Pszczelnicze Zeszyty Naukowe* 39:129–144.

Jacobsen, R. L., N. J. Albrecht, and K. E. Bolin. 1990. Wildflower routes: Benefits of a management program for Minnesota right-of-way prairies. *Proceedings of the Twelfth North American Prairie Conference,* 153–158.

Javorek, S. K., K. E. Mackenzie, and S. P. Vander Kloet. 2002. Comparative pollination effectiveness among bees (Hymenoptera: Apoidea) on lowbush blueberry (Ericaceae: *Vaccinium angustifolium*). *Annals of the Entomological Society of America* 95:345–351.

Jennersten, O. 1988. Pollination in *Dianthus deltoides* (Caryophyllaceae): Effects of habitat fragmentation on visitation and seed set. *Conservation Biology* 2(4):359–366.

Jepsen, S., D. F. Schweitzer, B. Young, N. Sears, M. Ormes, and S. H. Black. 2015. *Conservation Status and Ecology of Monarchs in the United States*. 36 pp. NatureServe, Arlington, Virginia, and the Xerces Society for Invertebrate Conservation, Portland, Oregon.

Johnson, A. M. 2000. *Best Practices Handbook on Roadside Vegetation Management*. Technical Report N. Mn/DOT 2000-19.

Johst, K., M. Drechsler, J. Thomas, and J. Settele. 2006. Influence of mowing on the persistence of two endangered large blue butterfly species. *Journal of Applied Ecology* 43(2):333–342.

Kearns, C. A. 2001. North American dipteran pollinators: Assessing their value and conservation status. *Conservation Ecology* 5(1):5. Available: http://www.consecol.org/vol5/iss1/art5/.

Kearns, C. A., and J. D. Thompson. 2001. *The Natural History of Bumble Bees. A Sourcebook for Investigations*. Boulder: University Press of Colorado.

Kearns, C. A., D. A. Inouye, and N. M. Waser. 1998. Endangered mutualisms: The conservation of plant–pollinator interactions. *Annual Review of Ecology and Systematics* 29:83–113.

Kevan, P. G. 1975. Forest application of the insecticide fenitrothion and its effect on wild bee pollinators (Hymenoptera: Apoidea) of lowbush blueberries (*Vaccinium* spp.) in Southern New Brunswick, Canada. *Biological Conservation* 7(4):301–309.

Kevan, P. G. 1999. Pollinators as bioindicators of the State of the environment: Species, activity and diversity. *Agriculture Ecosystems & Environment* 74(1-3):373–393.

Klein, A.-M., B. E. Vaissière, J. H. Cane, I. Steffan-Dewenter, S. A. Cunningham, C. Kremen, and T. Tscharntke. 2006. Importance of pollinators in changing landscapes for world crops. *Proceedings of the Royal Society Series B: Biological Sciences* 274:303–313.

Klein, A.-M., C. Brittain, S. D. Hendrix, R. Thorp, N. Williams, and C. Kremen. 2012. Wild pollination services to California almond rely on semi-natural habitat. *Journal of Applied Ecology* 49:723–732.

Kremen, C., N. M. Williams, and R. W. Thorp. 2002. Crop pollination from native bees at risk from agricultural intensification. *Proceedings of the National Academy of Sciences* 99(26):16812–16816.

Krupke, C. H., G. J. Hunt, B. D. Eitzer, G. Andino, and K. Given. 2012. Multiple routes of pesticide exposure for honey bees living near agricultural fields. *PLOS One* 7(1):e29268. DOI: 10.1371/journal.pone.0029268.

Larson, B. M. H., P. G. Kevan, and D. W. Inouye. 2001. Flies and flowers: taxonomic diversity of anthophiles and pollinators. *The Canadian Entomologist* 133:439–465.

Linsley, E. G. 1958. The ecology of solitary bees. *Hilgardia* 27:543–599.

Lippit, L., M. W. Fidelibs, and D. A. Bainbridge. 1994. Native seed collection, processing, and storage for revegetation projects in the western United States. *Restoration Ecology* 2:120–131.

Losey, J. E., and M. Vaughan. 2006. The economic value of ecological services provided by insects. *Bioscience* 56:311–323.

Louda, S. M., C. Kendall, J. Connor, and D. Simberloff. 1997. Ecological effects of an insect introduced for the biological control of weeds. *Science* 277:1088–1090.

Macdonald, E., R. Sanders, and P. Supawanich. 2008. *The Effects of Transportation Corridors' Roadside Design Features on User Behavior and Safety, and Their Contributions to Health, Environmental Quality, and Community Economic Vitality: A Literature Review*. University of California Transportation Center, Research Report 878.

Mader, E., J. Hopwood, L. Morandin, M. Vaughan, and S. H. Black. 2014. *Farming with Native Beneficial Insects: Ecological Pest Control Solutions*. Storey Publishing, 272 pp.

Marks, R. 2006. *Native Pollinators*. U.S. Department of Agriculture Natural Resources Conservation Service. Fish and Wildlife Habitat Management Leaflet. No. 34.

Marrs, R. H., A. J. Frost, R. A. Plant, and P. Lunnis. 1993. Determination of buffer zones to protect seedlings of non-target plants from the effects of glyphosate spray drift. *Agriculture, Ecosystems & Environment* 45(3):283–293.

Mastro, L. L., M. R. Conover, and S. N. Frey. 2008. Deer-vehicle collision prevention techniques. *Human-Wildlife Conflicts* 2(1): 80–92.

McGregor, S. E. 1976 Insect pollination of cultivated crop-plants. *U.S.D.A. Agriculture Handbook No. 496*, 93–98. Version with updated information for some crop species available: http://gears.tucson.ars.ag.gov/book/.

McKenna, D. D., K. M. McKenna, S. B. Malcom, and M. R. Berenbaum. 2001. Mortality of Lepidoptera along roadways in central Illinois. *Journal of the Lepidopterists Society* 55(2):63–68.

Memmott, J. and N. M. Waser. 2002. Integration of alien plants into a native flower–pollinator visitation web. *Proceedings of the Royal Society of London Series B: Biological Sciences* 269:2395–2399.

Michener, C. D. 2007. *The Bees of the World, 2nd edition*. 992 pp. Baltimore: John Hopkins University Press.

Mok, J-H, H. C. Landphair, and J. R. Naderi. 2006. Landscape improvement impacts on roadside safety in Texas. *Landscape and Urban Planning* 78(3):263–274.

Monroe, M., D. Frey, and S. Stevens. 2014. *Western Monarch Thanksgiving Count Data from 1997–2013*. Available: http://www.xerces.org/western-monarch-thanksgiving-count/.

Morandin, L. A., and C. Kremen. 2013. Hedgerow restoration promotes pollinator populations and exports native bees to adjacent fields. *Ecological Applications* 23(4):829–839.

Morse, R. A. and N. W. Calderone. 2000. The value of honey bees as pollinators of US crops in 2000. *Bee Culture* 128:1–15.

Munguira, M. L., and J. A. Thomas. 1992. Use of road verges by butterfly and burnet populations, and the effect of roads on adult dispersal and mortality. *Journal of Applied Ecology* 29:316–329.

Munoz, P. T., F. P. Torres and A. G. Megias. 2015. Effects of roads on insects: A review*. Biodiversity and Conservation* 24(3):659–682.

Nabhan, G. P., R. C. Brusca, and L. Holter (ed.). 2004. *Conserving Migratory Pollinators and Nectar Corridors in Western North America*. Tucson: University of Arizona Press.

National Research Council. 2007. *Status of Pollinators in North America*. Washington, DC: National Academies Press.

NatureServe. 2014. *Conservation Status*. Available: http://explorer.natureserve.org/ranking.htm.

Nebraska Department of Roads. 2014. *Roadside Vegetation Establishment and Management*. Available: http://www.transportation.nebraska.gov/environment/guides/veg-manual.pdf. Accessed: July 2015.

Ne'eman, G., A. Dafni, and S. G. Potts. 2000. The effect of fire on flower visitation rate and fruit set in four core-species in east Mediterranean scrubland. *Plant Ecology* 146:97–104.

Nelson, Carmelita. Water Supply Plans and Conversation, Minnesota Department of Natural Resources. Personal Communication.

Noordijk, J., K. Delille, A. P. Schaffers, and K. V. Sýkora. 2009. Optimizing grassland management for flower-visiting insects in roadside verges. *Biological Conservation* 142:2097–2103.

Norcini, J. G. 2014. *Madison County Energy Conservation Study 2012-2013 Survey of Roadside Vegetation*. Final Report to Florida Department of Transportation. Available: http://ntl.bts.gov/lib/51000/51400/51440/FDOT-PR6365252-rpt.pdf. Accessed: June 11 2015.

Norcini, J. G., J. H. Aldrich, M. Thetford, K. A. Klock-Moore, M. L. Bell, and B. K. Harbaugh. 2001. Growth, flowering, and survival of black-eyed susan from different regional seed sources. *HortTechnology* 11(1):26–30.

O'Dell, R. E., S. L. Young, and V. P. Claassen. 2007. Native roadside perennial grasses persist a decade after planting in the Sacramento Valley. *California Agriculture* 61(2):79–84.

Oakley, C. and J. Knox. 2013. Plant species richness increases resistance to invasion by non-resident plant species during grassland restoration. *Applied Vegetation Science* 16:21–28.

Ollerton, J., R. Winfree, and S. Tarrant. 2011. How many flowering plants are pollinated by animals? *Oikos* 120:321–326.

Ouin, A., S. Aviron, J. Dover, and F. Burel. 2004. Complementation/supplementation of resources for butterflies in agricultural landscapes. *Agriculture, Ecosystems & Environment* 103:473–479.

Panzer, R. 2002. Compatibility of prescribed burning with the conservation of insects in small, isolated prairie reserves. *Conservation Biology* 16:1296–1307.

Parr, T. W., and J. M. Way. 1988. Management of roadside vegetation: the long-term effects of cutting. *Journal of Applied Ecology* 25:1073–1087.

Pfister, J. A., F. D. Provenza, K. E. Panter, B. L. Stegelmeier, and K. L. Launchbaugh. 2002. Risk management to reduce livestock losses from toxic plants. *Journal of Range Management* 55:291–300.

Pisa, L. W., V. Amaral-Rogers, L. P. Belzunces, J. M. Bonmatin, C. A. Downs, D. Goulson, D. P. Kreutzweiser, C. Krupke, M. Liess, M. McField, C. A. Morrissey, D. A. Noome, J. Settele, N. Simon-Delso, J. D. Stark, J. P. Van der Sluijs, H. Van Dyck, and M. Wiemers. 2015. Effects of neonicotinoids and fipronil on non-target invertebrates. *Environmental Science and Pollution Research* 22(1):68–102.

Pleasants, J. M., and K. S. Oberhauser. 2012. Milkweed loss in agricultural fields because of herbicide use: Effect on the monarch butterfly population. *Insect Conservation and Diversity* 6:135–144.

Potts, S. G., B. Vulliamy, A. Dafni, G. Ne'eman, and P. G. Willmer. 2003. Linking bees and flowers: How do floral communities structure pollinator communities? *Ecology* 84:2628–2642.

Potts, S. G., B. Vulliamy, S. Roberts, C. O'Toole, A. Dafni, G. Ne'eman, and P. G. Willmer. 2005. Role of nesting resources in organizing diverse bee communities in a Mediterranean landscape. *Ecological Entomology* 30(1):78–85.

Potts, S. G., J. C. Biesmeijer, C. Kremen, P. Neumann, O. Schweiger, and W. E. Kunin. 2010. Global pollinator declines: trends, impacts and drivers. *Trends in Ecology and Evolution* 25(6):345–353.

Procter, M., P. Yeo, and A. Lack. 1996. *The Natural History of Pollination*. Portland: Timber Press.

Quales, W. 2003. Native plants and integrated roadside vegetation management. *IPM Practitioner* 25(3-4):1–9.

Rao, R. S. P., and M. K. S. Girish. 2007. Road kills: Assessing insect casualties using flagship taxon. *Current Science* 92(6):830–843.

Rendón-Salinas, E. and G. Tavera-Alonso. 2014. Monitoreo de la superficie forestal ocupada por las colonias de hibernación de la mariposa Monarca en diciembre de 2013. Alianza WWF-Telcel / CONANP. 5 pp. Available: http://www.wwf.org.mx/que_hacemos/ mariposa_monarca/publicaciones/.

Ries, L., D. M. Debinski, and M. L. Wieland. 2001. Conservation value of roadside prairie restoration to butterfly communities. *Conservation Biology* 15:401–411.

Robins P., R. B. Holmes, and K. Laddish (eds.). 2001. Bring farm edges back to life! *Landowner Conservation Handbook*. Yolo County Resource Conservation District. Woodland, CA. Available: www.yolorcd.ca.gov. 101 p.

Saarinen, K., A. Valtonen, J. Jantunen, and S. Saarnio. 2005. Butterflies and diurnal moths along road verges: Does road type affect diversity and abundance? *Biological Conservation* 123:403–412.

Saunders, D. A., R. J. Hobbs, and C. R. Margules. 1991. Biological consequences of ecosystem fragmentation – A review. *Conservation Biology* 5:18–32.

Schaffers, A. P., I. P. Raemakers, and K. V. Sykora. 2012. Successful overwintering of arthropods in roadside verges. *Journal of Insect Conservation* 16(4):511–522.

Simmons, M., M. Bertelsen, S. Windhager, and H. Zafian. 2011. The performance of native and non-native turfgrass monocultures and native turfgrass polycultures: An ecological approach to sustainable lawns. *Ecological Engineering* 37:1095–1103.

Skórka, P., M. Lenda, D. Moroń, K. Kalarus, and P. Tryjanowski. 2013. Factors affecting road mortality and the suitability of road verges for butterflies. *Biological Conservation* 159:148–157.

Smallidge, P. J., and D. J. Leopold. 1997. Vegetation management for the maintenance and conservation of butterfly habitats in temperate human-dominated habitats. *Landscape and Urban Planning* 38:259–280.

Speight, M. C. D. 1978. Flower-visiting flies. Pages 229–236 in A. Stubbs, P. Chandler, and P. W. Cribb, *A Dipterist's Handbook*. The Amateur Entomologists' Society.

Spira, T. P. 2001. Plant-pollinator interactions: a threatened mutualism with implications for the ecology and management of rare plants. *Natural Areas Journal* 21(1):78–88.

Stark, J.D., X. D. Chena, and C. S. Johnson. 2012. Effects of herbicides on Behr's metalmark butterfly, a surrogate species for the endangered butterfly, Lange's metalmark. *Environmental Pollution* 164:24–27.

Steffan-Dewenter, I., and C. Westphal. 2008. The interplay of pollinator diversity, pollination services and landscape change. *Journal of Applied Ecology* 45(3):737–741.

Steinfeld, D., S. Riley, K. Wilkinson, T. Landis, and L. Riley. 2007. *Roadside Revegetation: An Integrated Approach to Establishing Native Plants*. Federal Highway Administration. Western Federal Lands Highway Division. Report No. FHWA-WFL/TD-07-005

Sugden, E. A. 1985. Pollinators of *Astragalus monoensis* Barneby (Fabaceae): New host records; potential impact of sheep grazing. *Great Basin Naturalist* 45:299–312.

Svensson, B., J. Lagerlöf, and B. G. Svensson. 2000. Habitat preferences of nest-seeking bumble bees (Hymenoptera: Apidae) in an agricultural landscape. *Agriculture, Ecosystems & Environment 77*(3):247–255.

Tallamy, D. W., and K. J. Shropshire. 2009. Ranking lepidopteran use of native versus introduced plants. *Conservation Biology* 23(4):941–947.

Tepedino, V. J. 1981. The pollination efficiency of the squash bee (*Peponapis pruinosa*) and the honey bee (*Apis mellifera*) on summer squash (*Cucurbita pepo*). *Journal of the Kansas Entomological Society*:359–377.

Tilman, D., P. B. Reich, and J. M. H. Knops. 2006. Biodiversity and ecosystem stability in a decade-long grassland experiment. *Nature* 441:629–632.

Tinsley, J. M., M. T. Simmons, and S. Windhager. 2006. The establishment success of native versus non-native herbaceous seed mixes on a revegetated roadside in Central Texas. *Ecological Engineering* 26:231–240.

Topp, H. H. 1990. Traffic safety, usability and streetscape effects of new design principles for major urban roads. *Transportation* 16:297–310.

Trombulak, S. C., and C. A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology* 14(1):18–30.

Tyser, R. W. and C. A. Worley. 1992. Alien flora in grasslands adjacent to road and trail corridors in Glacier National Park, Montana (USA). *Conservation Biology* 6(2):253–262.

U.S. Fish and Wildlife Service. 2006. *Lesser Long-Nosed Bat (*Leptonycteris curasoae yerbabuenae*) 5-Year Review: Summary and Evaluation.* U.S. Fish and Wildlife Service, Phoenix, Arizona.

U.S. Fish and Wildlife Service. 2014. *Environmental Conservation Online System. Listed Animals.* Available: http://www.fws.gov/ecos/ajax/tess_public/pub/listedAnimals.jsp. Accessed: October 2014.

Valiente-Banuet, A., F. Molina-Freaner, A. Torres, M. C. Arizmendi, and A. Casas. 2004. Geographic differentiation in the pollination system of the columnar cactus *Pachycereus pecten-aboriginum*. *American Journal of Botany* 91:850–855.

Valtonen, A., and K. Saarinen. 2005. A highway intersection as an alternative habitat for a meadow butterfly: effect of mowing, habitat geometry and roads on the ringlet (*Aphantopus hyperantus*). *Annales Zoologici Fennici* 42(5):545–556.

Valtonen, A., K. Saarinen, and J. Jantunen. 2006. Effect of different mowing regimes on butterflies and diurnal moths on road verges. *Animal Biodiversity and Conservation* 29:133–148.

Westbrooks R. G. 1998. *Invasive Plants: Changing the Landscape of America: Fact Book*. Federal Interagency Committee for the Management of Noxious and Exotic Weeds. Washington, DC. 109 pp.

Westerkamp, C., and G. Gottsberger. 2000. Diversity pays in crop pollination. *Crop Science* 40:1209–1222.

Williams, N. M., D. Cariveau, R. Winfree, and C. Kremen. 2011. Bees in disturbed habitats use, but do not prefer, alien plants. *Basic and Applied Ecology* 12(4):332–341.

Winfree, R., N. M. Williams, H. Gaines, J. S. Ascher, and C. Kremen. 2008. Wild bee pollinators provide the majority of crop visitation across land-use gradients in New Jersey and Pennsylvania, USA. *Journal of Applied Ecology* 45(3):794–802.

Zielin, S., C. E. de Rivera, S. Jacobson, and W. P. Smith. 2010. *Exploring Mitigation Options to Reduce Vehicle-Caused Mortality of a Threatened Butterfly.* Transportation Research Board Annual Meeting. Available: http://itre.ncsu.edu/ADC30/11_TRB_Winter_Conference/ Presentations/Paper_11-2834.pdf. Accessed: October 2014.

This page intentionally left blank.