

Pollinators in Natural Areas

A Primer on Habitat Management



Anna's northern blue.

Photograph © Kim Davis and Mike Stangeland (www.kimandmikeontheroad.com)

Plant pollination by animals is an essential ecosystem service. It is estimated that 60 to 80 percent of the world's 250,000 flowering plants depend on animals—mostly insects—for pollination (Kremen et al. 2007). Eighty-seven of the world's 124 most commonly cultivated crops are animal pollinated, and insect-pollinated forage plants such as alfalfa and clover provide feed for livestock. Roughly thirty-five percent of global crop production is dependent on pollination by animals (Klein et al. 2006). Pollinators also sustain wildland plant communities that provide food and shelter for myriad other wildlife. As one of the most widespread and important ecosystem services in terrestrial environments, plant pollination by insects is essential to human health, global food webs, and protection of biodiversity.

Despite the recognized importance of pollination services, there is a growing body of evidence that suggests pollinators are at risk. In the United States, the National Research Council (2006) reported that both managed honey bee colonies and wild pollinators showed significant declines. The causes of decline are difficult to pinpoint, but loss of floral diversity and habitat due to increasing urbanization, expansion of intensive agriculture, invasive plants, widespread use of pesticides, climate change, and disease and parasites have all had a negative impact on pollinator populations (National Research Council 2006). As pressure on pollinators increases from human activities and other factors, undeveloped habitat and natural areas can play a substantial role as long-term refugia for these animals.

Written by
Scott Hoffman Black,
Nathan Hodges,
Mace Vaughan, and
Matthew Shepherd



The Xerces Society
for Invertebrate
Conservation

www.xerces.org

POLLINATORS AND THEIR IMPORTANCE

Importance of Natural Areas for Native Pollinators and Agriculture

Native pollinators clearly help with crop pollination, yet many agricultural areas lack the habitat necessary to support native pollinators. The role that natural habitat within the agricultural landscape plays in providing crop pollination services is increasingly well understood. Proximity to natural or seminatural land is often an important predictor of pollinator diversity in cropland (Bergman et al. 2004; Kremen et al. 2004; Morandin & Winston 2006; Hendrickx et al. 2007; Winfree et al. 2007b). For agricultural areas that have lost native pollinators due to habitat modification or pesticide treatments, adjacent natural areas provide two valuable benefits. First, they are a source of pollinators for crop pollination (Kremen et al. 2004). Second, they act as refugia for pollinators that can recolonize degraded agricultural areas (Ockinger & Smith 2007).

Along with on-farm habitat, nearby natural areas are integral to maintaining long-term populations of native pollinators in agricultural landscapes; however, it is important that the management of these natural areas takes native pollinators into account.

Importance of Pollinators to Natural Areas

By aiding in wildland food production, helping with nutrient cycling, and as direct prey, pollinators are important in wildlife food webs. For example, many migratory songbirds require a diet of berries, fruits, and seeds from insect-pollinated plants. Additionally, pollinator larvae are an important component of the diet of many young birds (Buehler et al. 2002). Summerville and Crist (2002) found that forest moths play important functional roles as selective herbivores, pollinators, detritivores, and prey for migratory songbirds. Belfrage et al. (2005) demonstrated that butterfly diversity was a good predictor of bird abundance and diversity, apparently due to a shared requirement for a complex plant community.

Pollinator insects are a diverse component of the wildlife of natural areas. They include butterflies and moths (Lepidoptera), bees and wasps (Hymenoptera), beetles (Coleoptera), and flies (Diptera). There are tens of thousands of pollinator species worldwide representing these different taxonomic groups. Bees alone account for approximately 20,000 of the pollinating species worldwide (Michener 2000), with an estimated 4,000 species in the United States (Winfree et al. 2007a).

Pollinators perform such a range of ecological services in natural ecosystems that they are clearly a keystone group in nearly all terrestrial ecosystems, necessary for plant reproduction and in forming the basis of an energy-rich food web (Kearns et al. 1998).



Bees and other pollinator insects are not only important for natural areas, but also bring great benefits to nearby farms and gardens. Photograph of mining bee (genus *Andrena*) by Bruce Newhouse.

Habitat Needs of Pollinator Insects

Using pollinator conservation as a framework for managing natural areas will result in diverse plant communities and excellent habitat for all types of wildlife. In managing for insect pollinators, the first step is to understand the habitat needs of bees, butterflies, moths, and other species. These needs can be divided into two main categories: a diversity of native flowers available throughout the season, and egg-laying or nesting sites. Land managers can play a key role in protecting and enhancing pollinator habitat through the careful application of ecosystem management tools. Moreover, they can provide nesting materials for bees, and where appropriate, can increase floral resources through revegetation, as well as provide hostplants for butterflies or moths.

Diversity of native flowers. Flowering plants that benefit from insect pollination produce energy-rich nectar and nutrient-rich pollen to attract pollinators. While foraging for these, insects unwittingly transfer pollen grains within individual flowers, among flowers on the same plant, and between flowers on plants in the same general area, fertilizing the flowers and increasing genetic outcrossing of the species. Forage resources are necessary throughout a pollinator's adult life, and most species benefit from a succession of diverse blooming plants that provide adequate forage (Bowers 1985). A diverse community of insect pollinators, therefore, requires a diversity of native flowers (Dramstad & Fry 1995; Holzschuh et al. 2007).

Nesting and egg-laying resources. In addition to food, insect pollinators require egg-laying sites. For example, butterflies and moths require the appropriate hostplants for laying eggs and for their larvae to eat. The majority of bee species nest in the ground, digging narrow tunnels that lead to a small number of brood cells. Most of the remaining bee species occupy existing tunnels in large, dead, woody vegetation, though some do chew out the center of pithy twigs (Michener 2000). Bumble bees and honey bees are the main exception to this. Bumble bees require a small cavity such as an abandoned rodent nest for their colony (Kearns & Thomson 2001), and feral honey bees usually occupy large cavities, such as a hollow tree (O'Toole & Raw 1999). Some wood-nesting species also need materials such as mud, leaf parts, or tree resin to construct brood cells in their nests (O'Toole & Raw 1999). It is also important that nest sites are close enough to sources of nectar and pollen (Cane 2001).

Generalist and specialist species. The diverse habitat requirements suggested above are most appropriate for conserving generalist pollinator species, those species that can forage from a wide range of plant sources. In contrast, specialist pollinator species use limited sources of nectar and pollen, or have specific hostplants for their young. Some studies have found that management techniques that emphasize the broad habitat requirements of pollinators may preferentially select for generalist species, while ignoring the more specific requirements of specialist species (Swengel 1996; Swengel 1998; Winfree et al. 2007a).

HABITAT MANAGEMENT: GENERAL CONSIDERATIONS

Each of the techniques considered in this primer—grazing, fire, mowing, herbicides, and insecticides—can be used to manage habitat to benefit pollinators. Each can also have damaging, at times severe, impacts on pollinators if they are not used carefully. There's no single management plan that can provide ideal habitat for all pollinator taxa, but there are some general considerations that apply to all situations.

As with any management activity, biological inventories should be done to first identify important plant resources and pollinator habitat. Inventories should pay close attention to occurrences of rare or specialist pollinator species and their life cycle and habitat requirements. In some cases, specialist species, especially those with limited distributions, will become the priority consideration in planning management to ensure that they receive adequate protection.

In all of these management techniques, it is important to leave some patches untreated. Mowing or burning

the entire habitat, for example, could severely impact pollinators and leave them with limited opportunities to recolonize the site. It is generally better to treat separate parts of the site in a multi-year cycle, retaining refugia from which pollinators can spread.

GRAZING

Livestock grazing in natural areas is a common practice throughout the United States. While unmanaged grazing can damage ecosystems (Bilotta & Brazier 2007), there is evidence that carefully managed grazing not only minimizes negative impacts but can provide positive benefits to floral resources in some rangeland settings, especially where shorter flowering plants are suppressed by taller grasses and buildup of thatch. Like many of the management tools discussed in this briefing, there is an ecological cost to introducing grazing into a natural system, especially in areas where herbivory by large ungulates did not occur. In some sites, it is entirely unsuited for protecting pollinators, while in other cases it can be a useful tool. For grazing management to be used effectively, the correct combination of timing, intensity, and duration of grazing, and class of livestock must be found that is best suited for the site. Finding the ideal permutation is not easy, and relies on an in-depth knowledge of the local ecosystem along with well-developed livestock management skills. Developing a com-



While the ecological impact of overgrazing can be severe, moderate levels of rotational grazing may provide some positive benefits. Photograph by Dr. Lloyd Glenn Ingles, California Academy of Sciences.

prehensive grazing and natural resource plan that includes pollinator conservation practices as one of its goals will help protect key communities of both plants and pollinators.

Livestock can greatly alter the structure, diversity, and growth habits of a plant community, which in turn can affect the associated insect community (Kruess & Tscharntke 2002). For example, it has been shown that uncontrolled sheep grazing in mountain meadows removed enough flowering plants to eliminate bumble bees from study sites (Hatfield & LeBuhn 2007). Sugden (1985) hypothesized that sheep grazing harms pollinator habitat in four ways: destruction of potential nest sites, destruction of existing nests and contents, direct trampling of adult bees, and removal of food resources.

In Arizona, Debano (2006) conducted one of the few studies focused explicitly on the impacts of domestic livestock grazing on invertebrate communities in an area that had not been grazed historically. The results clearly show that invertebrate species richness, abundance, and diversity were greater in ungrazed sites. The author suggested that since insects in the Southwest had not evolved in the presence of buffalo or other large ungulates, they had not developed grazing pressure adaptations, which made them more susceptible to being affected by the presence of cattle.

Other research shows that managed grazing can benefit insect communities by managing invasive plants and allowing spring- and summer-blooming flowers to grow. Controlled grazing has been shown to help maintain an open, herbaceous-dominated plant community that is capable of supporting a wide diversity of butterflies and other pollinators (Smallidge & Leopold 1997).

Management Considerations of Grazing: Timing, Duration, and Intensity

A diverse pollinator population requires adequate nectar and pollen sources from early spring to early fall, which makes seasonal timing a key consideration for an effective grazing plan. Ideally, management should be adjusted as needed to maintain the majority of the floral resources in an area throughout the seasons. Grazing during periods when floral resources are already scarce (e.g., mid summer, though this varies between regions) may result in insufficient forage available for pollinators such as bumble bees which, in some areas, forage into late September (Carvell 2002). Likewise, grazing during spring when butterfly larvae are active on hostplants can result in larval mortality or remove important vegetation and nectar resources (Smallidge & Leopold 1997). The most effective time to graze varies from site to site, but would generally be after the majority of the floral resources have died back, or when many pollinators are in diapause (a state of dormancy) or

have successfully laid eggs. This is usually in late summer and fall.

With pollinator conservation as a goal, grazing intensity and duration are also important to consider. Intensive grazing using high livestock numbers has been shown to be detrimental. However, moderate to light stocking levels with herds rotated through the management area to create a mosaic of grazing stages can be a useful method for moderating succession in a targeted vegetation community. The timing and frequency of rotation depends on both the size and type of the herd and the size of the grazed area (Schtickzelle et al. 2007). Generally speaking, grazing periods should be short, with comparatively long recovery periods for the habitat.

FIRE

Due to the importance of fire in many native ecosystems, prescribed burning is a commonly used management tool. Understanding how insects, including pollinators, respond to fire is integral to designing a fire management strategy that protects pollinators.

Many studies have found a negative or mixed response of invertebrates to fire. In a study that examined arthropods in prairies of the American Midwest, Harper et al. (2000) found that overall species richness and the abundance of all but one of the arthropod species measured decreased in burned sites. Their results suggest that burning a small habitat fragment in its entirety could risk extirpating some species because of limited recolonization from adjacent habitat.

Reviewing the literature associated with the effects of various management techniques on insects, Swengel (2001) found that fire is more detrimental than grazing, mowing, or haying. Due to the loss of more than 99 percent of the native tall-grass prairie, managing the existing remnants based on historical fire disturbance regimes may not be appropriate. Instead, Swengel advocates an approach based on individual site characteristics and assessment of how the plants and insects at that site will respond to fire.

Many other studies have found that fire benefits insect communities. Hartley et al. (2007) found that fire was an excellent management tool in prairies for decreasing woody plants and simultaneously encouraging higher arthropod diversity. The authors suggested, however, that recolonization of the burned plots from nearby refugia is an important factor in the recovery of insect populations.

In researching prescribed burns in western forests, Huntzinger (2003) found that there was greater butterfly species richness in areas where fire had been reintroduced. The burns created large sunlit openings in the forest canopy that were favorable for herbaceous plant growth, which in



Fire can be an important management tool for managing or restoring native prairies. Photograph courtesy of Jeff Vanuga/USDA-NRCS.

turn encouraged butterflies. The author recommends a cautious approach to prescribed burning to ensure that a range of habitat heterogeneity is maintained or restored.

Management Considerations of Fire: Scale and Refugia

Prescribed burning as a management tool is a two-edged sword. It clearly has a role to play in long-term maintenance of pollinator habitat, but can have catastrophic impacts on pollinator populations. To avoid undue loss of insects, a number of considerations should be integrated into fire management protocols.

A single prescribed fire should not burn an entire area of pollinator habitat. A program of rotational burning in which small sections—30 percent of a site or less—are burned every few years will ensure adequate colonization potential and refugia for insects. In addition, as a fire moves through an area, skips—small, unburned patches—should be left intact as potential micro-refuges. Periods between managed burns over the same patch should be conservative. Based on a variety of studies cited above, it appears that three to ten years allows adequate recovery of pollinator populations, depending on the ecosystem and specific management goals.

Unless the objective for a prescribed fire is for brush or tree removal, (e.g., pinyon-juniper, chamise, or mesquite), high-intensity (hot) fires should be avoided. Low-intensity prescribed burns conducted early or late in the day, or from late fall to early spring, are not only preferable for pollinators but also reduce impacts on other wild-life species such as reptiles and ground nesting birds.

MOWING

Mowing is commonly used in areas where site access and topography permit equipment access, such as road margins and powerline corridors, and is often used in place of grazing or fire to manage vegetation. Like grazing, mowing can alter grassland succession and species composition by suppressing the growth of woody vegetation (Forrester et al. 2005). Mowing can have a significant impact on insects through direct insect mortality, particularly for egg or larval stages that can't avoid the mower (Di Giulio et al. 2001). Mowing also creates a sward of uniform height and may destroy smaller topographical features—such as grass tussocks (Morris 2000)—when care is not taken to avoid these features or the mower height is too low. Such features provide structural diversity to the habitat and offer potential nesting sites for pollinators such as bumble bees.

Yet, there are some instances when mowing is beneficial for pollinators. In a large-scale survey of prairie and barrens butterfly species, Swengel (1998) found that mowing benefited specialist butterflies.

Management Considerations of Mowing: Technique, Timing, and Scale

The differences between an ultimately beneficial mowing regime and a detrimental one are technique, timing, and scale. Because mowing can completely remove floral resources from the treated area, it should generally not be conducted when flowers are in bloom. An exception to this would be in a weed management program where there is a

narrow window of opportunity for optimum control of the target species. Wherever possible, management areas should be mowed during seasons when flowers have died back or are dormant, such as in fall or winter (Munguira & Thomas 1992). Mowing at these times will also reduce disruption to nesting bumble bees.

To minimize these effects and allow sufficient space and time for pollinator populations to recover, mowing a mosaic of patches over several years is better than mowing an entire site; no single area should be mowed more than once a year (Di Giulio et al. 2001). If weed management is the short-term objective, it may be necessary to mow more frequently. In this case, try to limit mowing only to patches of weeds. As with all management, carefully consider the impact of mowing on the life cycle of known rare or specialist species in the management area. Other techniques that will benefit pollinators as well as other terrestrial wildlife are: use a flushing bar on mower/swather, use a high minimum mower/swather height (twelve to sixteen inches), use reduced mower speed (less than eight miles per hour), and avoid mowing at night (Green 2007).

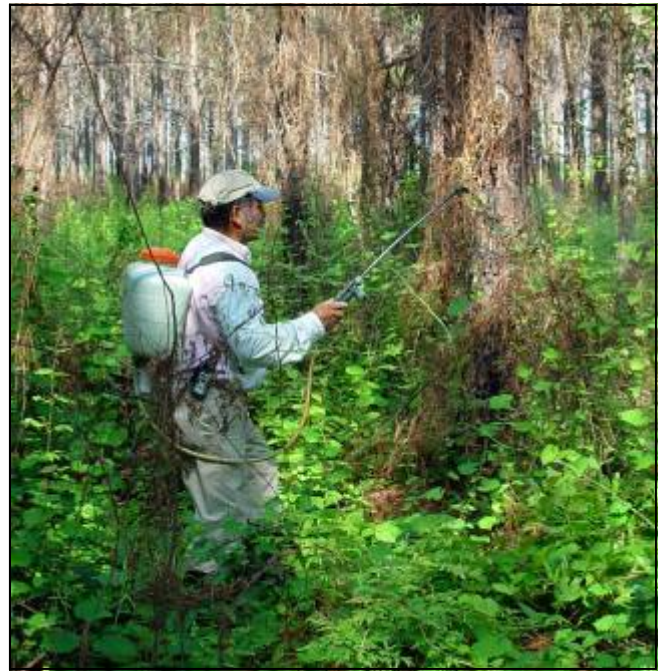
HERBICIDES

Herbicides are used to manage vegetation structure and composition, especially in controlling invasive plants, and thinning of small trees and shrubs (Miller & Miller 2004). When applied with care, herbicides can be a useful management tool. However, they can also dramatically change plant communities and decrease the usability of habitat for pollinators. For example, broadcast applications of non-selective herbicides can indiscriminately reduce important floral resources (Smallidge & Leopold 1997), leading to a decline in pollinator reproductive success and survival rates.

Management Considerations of Herbicides: Application Method and Active Ingredients

To avoid herbicide damage to nontarget plants and associated pollinators, some simple precautions should be taken. In general, avoid broadcast spraying or pellet dispersal because large numbers of larval hostplants or adult forage plants could be destroyed. Instead, spot treat with a backpack sprayer, weed wipe, or similarly well-targeted technique, allowing for selective control of undesirable plants while avoiding nontarget species. In at least one study, targeted spraying, combined with mechanical removal of larger shrubs, was found to be effective in maintaining butterfly habitat. At the same time, long-term management costs were reduced because fewer visits were required to suppress undesirable vegetation (Russell et al. 2005).

Herbicide applications should be specific enough to avoid spraying nontarget forage plants and hostplants.



Wherever herbicides or insecticides are applied, use the most targeted method possible. Photograph by Chris Evans, River to River CWMA; Bugwood.org.

INSECTICIDES

Insecticides can severely impact pollinator populations. Nevertheless, insecticides are widely used in natural areas throughout the United States to control both native and non-native species. Many forestry insecticides have been found to have lethal or sublethal effects on native pollinators (Helson et al. 1994), and broad-spectrum insecticides used for grasshopper control in rangelands impact nontarget insects (Alston & Tepedino 2000). On farms, overspray and drift of insecticides can also affect nontarget organisms in field borders (Çilgi & Jepson 1995) or adjacent natural areas.

Management Considerations of Insecticides: Application Method, Product Formulation, and Timing

In situations where insecticides must be used, there are a number of things that can be done to minimize negative effects on native pollinators (Riedl et al. 2006).

The easiest and simplest way to avoid large pollinator die-offs as a result of insecticide application is to completely avoid treatment of areas that have flowers in bloom. Because pollinators utilize pollen and nectar as a food source, often exclusively, they will be active primarily in and around areas where flowers are abundant (Johansen & Mayer 1990). By avoiding applications in blooming areas, the risk to pollinators will be reduced, but not eliminated. Pollinators often travel through or complete some part of their reproductive process in areas where there are

no blooms. For example, leafcutter bees harvest small leaf pieces to construct their nests and can be exposed to insecticide residues on contaminated foliage, butterfly caterpillars will continue to feed on contaminated leaves, and many bees nest in the ground where they may be oversprayed.

Another key method for reducing insecticide effects on native pollinators is to choose the insecticide formulation and application method that is the least harmful. Generally, dusts and microencapsulated insecticides are the most dangerous formulations for bees, and aerial spraying is the most harmful method of application (Riedl et al. 2006). Dusts are difficult to control, can easily be blown out of the target area, and readily adhere to the small hairs that cover the bodies of pollinators such as bees. Micro-encapsulated insecticides are of a similar size and electrostatic charge as pollen grains, making them easily ingested or transported back to the nest by foraging insects. Both dusts and microcapsules are collected along with pollen and used to provision brood, which can result in lethal or sublethal effects on larvae in the nest (Johansen & Mayer 1990; MacKenzie 1993). In comparison, sprayed solutions and large granules are not as readily incorporated into the foraging of pollinators, and negative effects that do occur are more likely to be limited to the adult bee. Aerial spraying almost always results in some degree of unintended drift into nontarget areas. Methods that increase the accuracy of targeted application are recommended, such as ground application and coarse sprays (Zhong et al. 2004).

Those applying insecticide should be aware of butterfly hostplants in the management area and avoid spraying on or around them. If a managed area is known to host rare or specialist pollinators, ensure that adequately buffered habitat refugia are available during and after insecticide application.



Pollinators are a vital component of our ecosystems. Planning management with them in mind will help create a healthy environment. Photograph of bumble bee (genus *Bombus*) by Mace Vaughan.

FOR MORE INFORMATION

To learn more about providing habitat for pollinators, please see our *Pollinator Conservation Handbook*. In addition, check the publications page of our website (www.xerces.org) for detailed guidelines for wildland managers, as well as guidelines for restoring and creating pollinator habitat on farms, parks, and golf courses.

REFERENCES

- Alston, D. G., and V. J. Tepedino. 2000. Direct and indirect effects of insecticides on native bees. In *Grasshopper Integrated Pest Management User Handbook* (Technical Bulletin No. 1809), edited by G. L. Cuningham and M. W. Sampson. Washington, DC: United States Department of Agriculture Animal and Plant Health Inspection Services.
- Belfrage, K., J. Björklund and L. Salomonsson. 2005. The effects of farm size and organic farming on diversity of birds, pollinators, and plants in a Swedish landscape. *Ambio* 34:582–588.
- Bergman, K. O., J. Askling, O. Ekberg, H. Ignell, H. Wahlman, and P. Milberg. 2004. Landscape effects on butterfly assemblages in an agricultural region. *Ecography* 27:619–628.
- Bilotta, G. S., and R. Brazier. 2007. The impacts of grazing animals on the quality of soils, vegetation, and surface waters in intensively managed grasslands. *Advances in Agronomy* 94:237–280.
- Bowers, M. A. 1985. Bumble bee colonization, extinction, and reproduction in subalpine meadows in northeastern Utah. *Ecology* 66:914–927.
- Buehler, D. M., D. R. Norris, B. J. M. Stutchbury, and N. C. Kopysh. 2002. Food supply and parental feeding rates of hooded warblers in forest fragments. *The Wilson Bulletin* 114:122–127.
- Cane, J. H. 2001. Habitat fragmentation and native bees: a premature verdict? *Conservation Ecology* 5(1):3 [online] URL: <http://www.consecol.org/vol5/iss1/art3>.
- Carvell, C. 2002. Habitat use and conservation of bumblebees (*Bombus* spp.) under different grassland management regimes. *Biological Conservation* 103:33–49.
- Çilgi, T., and P. C. Jepson. 1995. The risks posed by deltamethrin drift to hedgerow butterflies. *Environmental Pollution* 87:1–9.
- Debano, S. J. 2006. Effects of livestock grazing on above ground insect communities in semi-arid grasslands of southeastern Arizona. *Biodiversity and Conservation* 15:2547–2564.
- Di Giulio, M., P. J. Edwards, and F. Meister. 2001. Enhancing insect diversity in agricultural grasslands: The roles of management and landscape structure. *Journal of Applied Ecology* 38:310–319.
- Dramstad, W., and G. Fry. 1995. Foraging activity of bumblebees (*Bombus*) in relation to flower resources on arable land. *Agriculture, Ecosystems & Environment* 53:123–135.
- Forrester, J. A., D. J. Leopold, and S. D. Hafner. 2005. Maintaining critical habitat in a heavily managed landscape: Effects of power line corridor management on Karner blue butterfly (*Lycæides melissa samuelis*) habitat. *Restoration Ecology* 13:488–498.
- Green, C. 2007. *Reducing Mortality of Grassland Wildlife During Haying and Wheat-Harvesting Operations*. Oklahoma Cooperative Extension Fact Sheet NREM-5006. Stillwater, OK: Oklahoma State University.
- Harper, M. G., C. H. Dietrich, R. L. Larimore, and P. A. Tessene. 2000. Effects of prescribed fire on prairie arthropods: An enclosure study. *Natural Areas Journal* 20:325–335.
- Hartley, M. K., W. E. Rogers, E. Siemann, and J. Grace. 2007. Responses of prairie arthropod communities to fire and fertilizer: Balancing plant and

- arthropod conservation. *American Midland Naturalist* 157:92–105.
- 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.
- Helson, B. V., K. N. Barber, and P. D. Kingsbury. 1994. Laboratory toxicology of six forestry insecticides to four species of bee (Hymenoptera: Apoidea). *Archives of Environmental Contamination and Toxicology* 27:107–114.
- Hendrickx, F., J.-P. Maelfait, W. Van Wingerden, O. Schweiger, M. Speelmans, S. Aviron, I. Augenstein, R. Billeter, D. Bailey, R. Bukacek, F. Burel, T. Diekötter, J. Dirksen, F. Herzog, J. Liira, M. Roubalova, V. Vandomme, and R. Bugter. 2007. How landscape structure, land-use intensity and habitat diversity affect components of total arthropod diversity in agricultural landscapes. *Journal of Applied Ecology* 44:340–351.
- Holzschuh, A., I. Steffan-Dewenter, D. Kleijn, and T. Tscharntke. 2007. Diversity of flower-visiting bees in cereal fields: Effects of farming system, landscape composition and regional context. *Journal of Applied Ecology* 44:41–49.
- Huntzinger, M. 2003. Effects of fire management practices on butterfly diversity in the forested western United States. *Biological Conservation* 113:1–12.
- Johansen, C. A., and D. F. Mayer. 1990 *Pollinator Protection. A Bee and Pesticide Handbook*. Chesire, CT: Wicwas Press.
- Kearns, C. A., D. W. Inouye, and N. Waser. 1998. Endangered mutualisms: The conservation of plant–pollinator interactions. *Annual Review of Ecology and Systematics* 29:83–112.
- Kearns, C. A., and J. D. Thomson. 2001. *The Natural History of Bumblebees*. 130 pp. Boulder: University Press of Colorado.
- 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)* 274:303–313.
- Kremen, C., N. M. Williams, M. A. Aizen, B. Gemmill-Herren, G. LeBuhn, R. Minckley, L. Packer, S. G. Potts, T. Roulston, I. Steffan-Dewenter, D. P. Vázquez, R. Winfree, L. Adams, E. E. Crone, S. S. Greenleaf, T. H. Keitt, A.-M. Klein, J. Regetz, and T. H. Ricketts. 2007. Pollination and other ecosystem services produced by mobile organisms: a conceptual framework for the effects of land-use change. *Ecology Letters* 10:299–314.
- Kremen, C., N. M. Williams, R. L. Bugg, J. P. Fay, and R. W. Thorp. 2004. The area requirements of an ecosystem service: Crop pollination by native bee communities in California. *Ecology Letters* 7:1109–1119.
- Kruess, A., and T. Tscharntke. 2002. Contrasting responses of plant and insect diversity to variation in grazing intensity. *Biological Conservation* 106:293–302.
- MacKenzie, K. E. 1993. Honey bees and pesticides: a complex problem. *The Vector Control Bulletin of the North Central States* 1:123–136.
- Michener, C. D. 2000. *The Bees of the World*. 913 pp. Baltimore: Johns Hopkins University Press.
- Miller, K. V., and J. H. Miller. 2004. Forestry herbicide influences on biodiversity and wildlife habitat in southern forests. *Wildlife Society Bulletin* 32:1049–1060.
- Morandin, L. A., and M. L. Winston. 2006. Pollinators provide economic incentive to preserve natural land in agroecosystems. *Agriculture Ecosystems & Environment* 116:289–292.
- Morris, M. G. 2000. The effects of structure and its dynamics on the ecology and conservation of arthropods in British grasslands. *Biological Conservation* 95:121–226.
- 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.
- National Research Council. 2006. *Status of Pollinators in North America*. 307 pp. Washington, DC: National Academies Press.
- Ockinger, E., and H. G. Smith. 2007. Semi-natural grasslands as population sources for pollinating insects in agricultural landscapes. *Journal of Applied Ecology* 44:50–59.
- O'Toole, C., and A. Raw. 1999. *Bees of the World*. 192 pp. London: Blandford.
- Riedl, H., E. Johansen, L. Brewer, and J. Barbour. 2006. *How to Reduce Bee Poisoning From Pesticides*. Pacific Northwest Extension Publication PNW 591. Corvallis, OR: Oregon State University.
- Russell, K. N., H. Ikerd, and S. Droege. 2005. The potential conservation value of unmowed powerline strips for native bees. *Biological Conservation* 124:133–148.
- Schtickzelle, N., C. Turlure, and M. Baguette. 2007. Grazing management impacts on the viability of the threatened bog fritillary butterfly *Proclossiana eunomia*. *Biological Conservation* 136:651–660.
- 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.
- Sugden, E. A. 1985. Pollinators of *Astragalus monoensis* Barneby (Fabaceae): New host records; potential impact of sheep grazing. *Great Basin Naturalist* 45:299–312.
- Summerville, K. S., and T. O. Crist. 2002. Effects of timber harvest on forest Lepidoptera: Community, guild, and species responses. *Ecological Applications* 12:820–835.
- Swengel, A. B. 1996. Effects of fire and hay management on abundance of prairie butterflies. *Biological Conservation* 76:73–85.
- Swengel, A. B. 1998. Effects of management on butterfly abundance in tallgrass prairie and pine barrens. *Biological Conservation* 83:77–89.
- Swengel, A. B. 2001. A literature review of insect responses to fire, compared to other conservation managements of open habitat. *Biodiversity and Conservation* 10:1141–1169.
- Winfree, R., T. Griswold, and C. Kremen. 2007a. Effect of human disturbance on bee communities in a forested ecosystem. *Conservation Biology* 21:213–223.
- Winfree, R., N.M. Williams, J. Dushoff, and C. Kremen. 2007b. Native bees provide insurance against ongoing honey bee losses. *Ecology Letters* 10:1105–1113.
- Zhong, H., M. Latham, S. Payne, and C. Brock. 2004. Minimizing the impact of the mosquito adulticide naled on honey bees, *Apis mellifera* (Hymenoptera: Apidae): Aerial ultra-low-volume application using a high-pressure nozzle system. *Journal of Economic Entomology* 97:1–7.

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