Yolo Natural Heritage Program (HCP/NCCP)

Pollinator Conservation Strategy

Prepared by
The Xerces Society for Invertebrate Conservation
Portland, Oregon / Sacramento, California

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EXECUTIVE SUMMARY

Pollination is "central to all human beings, livestock, and wildlife" (Kevan 1999). Plant pollination by insects is one of the most widespread and important ecosystem services and is essential in both natural and agricultural landscapes. It is estimated that 60 – 90% of the world's flowering plants depend on animals—most of them insects—for pollination.

Research shows that native bees contribute substantially to the pollination of many crops, including watermelon, canola, sunflower, and tomatoes. The value of crop pollination by native, wild bees in the United States is estimated at $3 billion. In Yolo County, extensive studies demonstrate the significant role of native pollinators in the economic viability of agriculture. In addition, native bees provide incalculable value as pollinators of native plants.

Animal pollinators in North America include bees, butterflies, moths, wasps, flies, beetles, ants, bats, and hummingbirds. Insects make up the vast majority of pollinator species, and bees are the most important pollinators in temperate North America.

There are approximately 4,000 species of native bees in North America. Bee habitat requires two basic components: flowers on which to forage and nest sites. Many pollinators are adapted to forage on particular plants, so a diverse community of pollinators requires a diverse array of flowers. Most native bees are solitary nesting. Around 70% of bee species nest in the ground, excavating shallow tunnels in patches of bare soil, with most of the remaining 30% nesting in cavities in old trees or plant stems. Bumble bees require a small cavity such as an abandoned rodent hole.

Foraging and nesting habitat needs to be within the flight range of a bee. Most solitary wild bees have maximum foraging ranges between 150 and 600 meters. Foraging ranges and species richness are strongly influenced by the landscape structure (habitat area and connectivity) within 250 meters of the location. The presence or absence of seminatural habitat has a dramatic effect on nesting and connectivity between habitats is critical for offspring production.

There is evidence of declines in both managed and wild pollinators. European pollinator monitoring programs have found significant declines in pollinators, and although pollinators have been monitored less intensively outside of Europe, declines of some prominent taxa such as bumble bees have been well-documented. Causes of declines are difficult to pinpoint, but loss of habitat due to increasing urbanization, expansion of intensive agriculture, invasive species, disease, parasites, and the widespread use of pesticides all negatively impact pollinator populations. Protecting, enhancing, or providing new habitat is the best way to conserve native pollinators.

Each of the six major landscapes in Yolo County—agriculture, grasslands, woodlands, shrubland and scrub, riparian and wetland, and urban and barren—are affected to a greater or lesser degree by one or more of these threats.

This paper outlines the importance of pollinators to these landscapes and the threats these animals face. It also identifies strategies that offer ways to halt or reverse pollinator declines.

SECTION 1
INTRODUCTION

Pollination is "central to all human beings, livestock, and wildlife" (Kevan 1999). Plant pollination by insects is one of the most widespread and important ecosystem services on the planet and is essential in both natural and agricultural landscapes. It is estimated that 60 – 90% of the world's flowering plants depend on animals—most of them insects—for pollination (Kremen et al. 2007). Of the 124 most commonly cultivated crops in the world, eighty-seven are animal pollinated (Klein et al. 2007), and insect-pollinated forage plants such as alfalfa and clover also provide feed for the animals that give us dairy and meat products (Richards & Kevan 2002). Calculated by volume, roughly 35% of the food humans consume is dependent on pollination by animals (Klein et al. 2007).

Animal pollinators in North America include bees, butterflies, moths, wasps, flies, beetles, ants, bats, and hummingbirds. Insects make up the vast majority of pollinator species, and bees (Hymenoptera) are the most important pollinators in temperate North America. Although the nonnative honey bee (*Apis mellifera*) provides the bulk of crop pollination in the U.S., native bees are known to provide important pollination services to crops (e.g., Kevan et al. 1990, Ricketts 2004, Klein et al. 2007), and are estimated to contribute $3 billion worth of crop pollination annually to the U.S. economy (Losey & Vaughan 2006). In Yolo County, extensive studies of different crops demonstrate the significant role of native pollinators in the economic viability of those crops (Kremen et al. 2001, Kremen et al. 2002a, Kremen et al. 2002b, Kremen et al. 2004). In addition, native bees provide incalculable value as pollinators of native plants (Kearns et al. 1998, Kremen et al. 2002a).

Of the other orders of pollinating insects, flies (Diptera) 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 (e.g., Frankie et al. 1990, Irvine & Armstrong 1990, Kevan 1999). Most butterfly and moth species (Lepidoptera) visit flowers for nectar, although their contribution to pollination services may be limited (Jennersten 1988, Frankie et al. 1990, Allen-Wardell et al. 1998, Westerkamp & Gottsberger 2000).

Many of these same native pollinator species play a keystone species roll in the health and sustainability of native ecosystems, and are a critical resource for endangered Yolo County plant species such as palmate-bracted bird's-beak, (*Cordylanthus palmatus*) (Saul-Gershenz et al. 2004).

Pollinating insects are necessary for wild plant reproductive success and fitness. Pollinator-plant interactions are seldom completely obligate, instead forming complex pollination webs in which a single plant may receive many visits from different pollinator species and each pollinator may, in turn, visit multiple plants of many different species (Kearns et al. 1998). This pollination web provides a degree of redundancy which may help buffer natural fluctuations in pollinator and/or plant populations. Despite this resiliency, research demonstrates that the loss or decline of pollinator populations can have direct effects on the plants they pollinate and vice versa.

In a review of research addressing the reproductive requirements of twenty-six rare or endangered plant species in the western United States, Tepedino et al. (1997) found that in order to set fruit most of the plants required pollination, usually by native bees. The authors suggest that any management plan hoping to aid in the recovery of an insect pollinated native plant must not only address the requirements of the plant itself, but the native pollinators that enable the plant to reproduce.

1.1 POLLINATORS AND WILDLIFE

The plant communities that pollinators sustain also provide food and shelter for many other animals such as birds, small mammals, and bears. Pollinators are important in wildlife food webs both as an essential step in the availability of seeds, nuts, fruit, and berries and as direct prey. Bears, rodents, small mammals, birds, and many terrestrial invertebrates all have significant dietary components that are attributable directly or indirectly to pollinators.

Pollinators also maintain vegetation communities which provide habitat for wildlife. While pollinator insects perform pollination services only as adults, their larvae are ecologically significant and can shape vegetation communities, provide food for songbirds, decompose detritus, and act as pest control agents. Very little research has been conducted to quantitatively assess the extent to which pollinators and pollination products contribute to the diet of wildlife, but qualitatively it is possible to recognize how important pollinators are in a functional ecosystem.

The following are examples of the importance of pollination to wildlands and wild animals.

- Many migratory songbirds require a diet of berries, fruits, and seeds from insect-pollinated plants, and pollinators (both adults and larvae) are an important component of the diet of many fledglings (Buehler et al. 2002).
- Summerville and Crist (2002) found that forest moths had "important functional roles as selective herbivores, pollinators, detritivores, and prey for migratory passerines."

Given the ecological services insect pollinators perform in natural ecosystems a strong case can be made for pollination being a keystone interaction in nearly all terrestrial ecosystems, necessary not only for plant reproduction, but forming the basis of an energy-rich food web that extends throughout trophic levels (Kearns et al. 1998, Vasquez & Simberloff 2003).

1.2 POLLINATORS AND AGRICULTURE

Honey bees provide the bulk of crop pollination in the U.S., yet the number of managed honey bee hives has declined by 60% in the U.S. since 1950 (Winfree et al. 2007b). In typical year, the U.S. beekeeping industry loses 15 – 20% of hives from a variety of problems, including diseases, pests, pesticide poisoning. Over the last three years, losses of 35% or more have been recorded due to Colony Collapse Disorder. Recent research (much of it in Yolo County) on crop pollination, however, has demonstrated that native bees also make a significant contribution to crop pollination—in some cases providing all of the pollination required when enough habitat is available (Greenleaf & Kremen 2006a, Klein et al. 2007). Today, habitat supporting these native pollinators is increasingly important as honey bee hives become more expensive and difficult to acquire.

Research demonstrates that native bees contribute substantially to the pollination of many crops, including watermelon (Kremen et al. 2002a; Kremen et al. 2004; Winfree et al. 2007b), canola (Morandin & Winston 2005), sunflower (Greenleaf & Kremen 2006b), tomatoes (Greenleaf and Kremen 2006a), and blueberry (Cane 1997; Javorek et al. 2002). The value of crop pollination by native, wild bees in the United States is estimated at $3 billion (Losey & Vaughan 2006).

1.3 POLLINATORS IN NATURAL AREAS: BENEFITS TO AGRICULTURE

The role that adjacent natural habitat plays in providing crop pollination services is increasingly well understood. Proximity to natural or semi-natural non-agricultural land is often an important predictor of pollinator diversity in cropland (Haughton et al. 2003; Bergman et al. 2004; Kim et al. 2006; Kremen et al. 2004; Morandin & Winston 2006; Hendrickx et al. 2007). Natural areas near to farms can also be important sources of pollinators that can recolonize agricultural areas that lost native pollinators due to a pesticide treatment or temporary habitat loss (Öckinger & Smith 2007).

In conjunction with on-farm habitat provided by untilled field margins, hedgerows, bare ground, and non-crop flowers in the agricultural fields, nearby natural habitat is integral to maintaining a long-term population of native pollinators in agricultural landscapes. Pollinators in these areas can provide valuable crop pollination services and add resiliency to the agricultural pollination system. So that natural areas and wildlands close to farms can provide these services, however, it is important that management of those non-arable lands takes into account native pollinators.

1.4 POLLINATORS IN DECLINE

There is ongoing debate in the scientific community as to whether pollinators, and in particular bees which are the most important crop pollinator taxon, are declining at a global scale (Kearns et al. 1998; Steffan-Dewenter et al. 2005; Biesmeijer et al. 2006; NRC 2007). Allen-Wardell et al. (1998) found evidence of declines in both managed and wild pollinators. European pollinator monitoring programs have found significant declines in pollinators as well as the plants they pollinate (Biesmeijer et al. 2006; NRC 2007). Although pollinators have been monitored less intensively outside of Europe, declines of some prominent taxa such as bumble bees have been well-documented (NRC 2007; Evans et al. 2008).

Causes of declines are difficult to pinpoint, but loss of habitat due to increasing urbanization, expansion of intensive agriculture, invasive species, disease, parasites, and the widespread use of pesticides all have negative impacts on pollinator populations (Kearns et al. 1998; Cane & Tepedino 2001; Spira 2001; Goulson 2003; Desneaux et al. 2007; Hendrickx et al. 2007; Steffan-Dewenter & Westphal 2008). As pressure on pollinators increases in developed and agricultural areas, the role that habitat in undeveloped areas can play as long-term refugia for pollinator populations is substantial. Protecting, enhancing, or providing new habitat is the best way to conserve native pollinators (Kremen et al. 2007).

SECTION 2
HABITAT NEEDS, LANDSCAPE STRUCTURE, AND THREATS

2.1 HABITAT NEEDS OF NATIVE POLLINATOR INSECTS

The first step in developing a conservation strategy that will provide for pollinators in Yolo County is to understand the habitat features required by bees and other insect pollinators. These can be divided into two main categories: a diversity of native flowers that will provide nectar and pollen, and egg-laying or nesting sites. Proximity of these resources to each other is also important to consider, as they need to be within the flight range of pollinators.

Diversity of native flowers

A plant community that will support an abundance of diverse pollinators should not only be rich in species but also bloom through a long season. Forage resources are necessary throughout a pollinator's adult life and most species benefit from a succession of blooming plants to provide adequate forage (Bowers 1985; Dramstad & Fry 1995; Kremen et al. 2002a). The wide variety of pollinators and their differing size and body morphology (for example, variations in tongue length between species) means that some species can reach the nectar or pollen in flowers that other pollinators cannot. Many pollinator species have morphological features specific to foraging on certain flower species (Speight 1978; Dramstad & Fry 1995; Thorp 2000; Thorp et al. 2002; Goulson & Darvill 2004). For example, there are short-, medium-, and long-tongued species of bumble bees that preferentially forage on plants with corresponding variations in corolla tube length (Pyke 1982). Flies also have tongues of varying lengths and can be quite specialized foragers (Kearns 2001; Larson et al. 2001). A diverse community of insect pollinators, therefore, requires a diverse array of floral resources (Bowers 1985; Dramstad & Fry 1995; Kremen et al. 2002a; Holzschuh et al. 2008; Wojcik et al. 2008).

Key Points

- *Pollinators need flowers on which to forage.*
- *The plant community should be diverse and bloom through a long season.*
- *Many pollinators are adapted to forage on particular plants.*
- *A diverse community of pollinators requires a diverse array of flowers.*

Nesting or egg-laying sites

Bees

Bees need nest sites. When supporting populations of native bees, protecting or providing nest sites is as important as, if not more important than, providing flowers (Tscharntke et al. 1998; Cane 2001; Potts et al. 2005).

Native bees often nest in inconspicuous locations. For example, many excavate tunnels in bare soil, others occupy tree cavities, and a few even chew out the soft pith of the stems of plants like elderberry or blackberry to make nests (O'Toole & Raw 1999, Michener 2000). It is important to retain as many naturally occurring sites as possible and to create new ones where appropriate.

North America has approximately 4,000 species of native bees (Winfree et al. 2007a). The majority, about 70% or very roughly 2,800 species, are ground nesters. These bees usually need

Table 1. General Habitat Requirements of Native Bees and Butterflies

Pollinator	Food	Shelter
Solitary bees	Nectar and pollen	Most nest in bare or partially vegetated, well-drained soil; many others nest in narrow tunnels in dead standing trees, or excavate nests within the pith of stems and twigs; some construct domed nests of mud, plant resins, saps, or gums on the surface of rocks or trees
Bumble bees	Nectar and pollen	Most nest in small cavities (approx. softball size), often underground in abandoned rodent nests or under clumps of grass, but can be in hollow trees, bird nests, or walls
Honey bees	Nectar and pollen	Hollow trees for feral colonies
Butterflies and Moths – larva	Leaves of larval host plants	Larval hostplants
Butterflies and Moths - pupa	Non-feeding stage	Protected site such as a bush, tall grass, a pile of leaves or sticks or, in the case of some moths, underground
Butterflies and Moths – adult	Nectar; some males obtain nutrients, minerals, and salt from rotting fruit, tree sap, animal dung and urine, carrion, clay deposits, and mud puddles	Protected site such as a tree, bush, tall grass, or a pile of leaves, sticks or rocks

(Adapted from: *Native Pollinators*. Feb. 2006. NRCS Fish and Wildlife Habitat Management Leaflet. No. 34.)

direct access to the soil surface (Potts et al. 2005) to excavate and access their nests. Ground-nesting bees seldom nest in rich soils, so poor quality sandy or loamy soils may provide fine sites. The great majority of ground-nesting bees are solitary, with one female excavating and provisioning her own nest. These may be in large aggregations with hundreds or thousands of bees excavating nests in the same area. Some species, however, will share the nest entrance or cooperate to excavate and supply the nest (Michener 2000).

Approximately 30% (around 1,200 species) of bee species in North America are wood nesters. These are almost exclusively solitary. Generally, these bees nest in abandoned beetle tunnels in logs, stumps, and snags. A few can chew out the centers of woody plant stems and twigs (Michener 2000), such as elderberry, sumac, and in the case of the large carpenter bee, agave or even soft pines. Dead limbs, logs, or snags should be preserved wherever possible. Some wood-nesters also use materials such as mud, leaf pieces, or tree resin to construct brood cells in their nests (O'Toole & Raw 1999).

Bumble bees are the native species usually considered to be social. There are about 45 species in North America (Kearns & Thomson 2001). They nest in small cavities, such as abandoned rodent nests under grass tussocks or in the ground (Kearns & Thompson 2001). Leaving patches of rough undisturbed grass in which rodents can nest will create future nest sites for bumble bees (McFrederick & LeBuhn 2006).

Butterflies

Lepidoptera lay their eggs on or close to the plant on which their larvae will feed once they hatch (Feber et al. 1996; Ries et al. 2001; Croxton et al. 2005). If conserving strong butterfly populations is a management goal, caterpillar hostplants are a necessary part of the habitat (Feber et al. 1996). Some butterflies may rely on plants of a single species or genus for host-plants (the monarch is an example, feeding only on species of milkweed, *Asclepias* sp.), whereas others may exploit a wide range of plants, such as some swallowtails (*Papilio* sp.), whose larvae can eat a range of trees, shrubs, and forbs (Scott 1986). In order to provide egg-laying habitat for the highest number of butterflies and moths, growers should first provide plants that can be used by a number of species. Later those plants can be supplemented with hostplants for more specialized species.

Flies

Several families of flies contain pollinating species. The most important are the families Syrphidae (syrphid or flower flies) and Bombyliidae (bee flies) (Speight 1978; Kearns 2001). Most syrphid flies are aphidophagous as larvae, and therefore require habitat that offers a sufficient abundance of aphids in addition to flowers for the nectar-feeding adults (Gilbert 1986; MacLeod 1999; Sutherland et al. 1999; Colley & Luna 2000). Bee fly larvae are, depending on species, parasites of larvae various insects, including solitary bees and wasps, beetles, moths, grasshoppers, and other flies (Marshall 2006). Larvae of other pollinating flies are predatory, saprophytic, or parasitic, depending on the species (Kearns 2001).

Beetles

The larval food of beetles is extremely variable depending on the species, and is too numerous to list here. The best strategy for attracting or retaining native beetle pollinators is to provide a variety of native plant species that will serve as food for herbivorous beetle larvae, as well as attract a variety of insects that will benefit insectivorous beetle larvae. However, specific requirements of immature stages should be identified when planning to protect the habitat of sensitive species. For example, larvae of the endangered molestan blister beetle (*Lytta molesta*) feed on the provisions and immature stages of ground nesting native bees in or near dried vernal pools (Selander 1960, Halstead & Haines 1992). Therefore, it is important to consider both native plant and bee species associated with their vernal pool habitat when designing a conservation strategy for this beetle.

Key Points

- *There are approximately 4,000 species of native bees in North America; most are solitary nesting.*

- *Nest sites are a key component of bee habitat.*
- *Around 70% of bees nest in the ground, excavating shallow tunnels in patches of bare soil.*
- *Around 30% of bees nest in cavities in old trees or plant stems.*
- *Bumble bees require a small cavity such as an abandoned rodent hole.*
- *Butterflies lay eggs on particular plants that their caterpillars eat.*
- *The egg laying needs of flies and beetles are more diverse, and vary between species.*

2.2 FLIGHT RANGE

How far a pollinator can fly is an important consideration for restoration and management of pollinator habitat. The foraging distance of a bee limits its capacity to move between nesting and foraging habitat. The limitation of foraging distance may be most important for bees. Most insects, including butterflies, flies, and beetles, find egg laying and feeding sites as they move across the landscape. Bees, on the other hand have a fixed location for their nest, collecting pollen and nectar from nearby habitat, and transporting it to that nest. Their nesting success is therefore dependent on the availability of resources within their flight range (Williams & Kremen 2007).

The ideal is to have nesting and forage resources in the same habitat patch, but bees are able to adapt to landscapes in which nesting and forage resources are separated (Cane 2001; Westrich 1996). How far apart habitat patches should be is defined by how far bees can fly on a foraging trip. In general, bigger bees can fly further than smaller bees. Reviewing the literature on sixteen European solitary bee species, Gathman & Tscharntke (2002) found that solitary wild bees generally have maximum foraging ranges between 150 and 600 meters, with the distance correlating positively with body length. They also found that foraging trip duration (6 to 28 minutes) correlated with body length. Foraging flights of bumble bees on a farm in Britain were tracked using harmonic radar by Osborne et al. (1999). In an arable landscape that included woodlands and hedgerows, the bumble bees' outward tracks averaged 275 meters in length, with a maximum recorded of 631 meters, however some flights went further, beyond the range of the radar. More recent work (Greenleaf et al. 2007) established that the best predictor for the foraging range of a bee was a measurement of body size, specifically the distance between the wing bases (intertegular span). However, they also recognize that the theoretical range and actual range differ. The actual foraging range is influenced by landscape factors, such as the density and distribution of flowers and how easy it is to cross other habitats.

The study by Gathmann and Tscharntke (2002) also investigated the distance bees travel between forage and nest sites; they found that the highest probability of a nest site being used was when the nest was less than 260 meters from a species' food plant. Kohler et al. (2008) found similar results for bees and hoverflies in the Netherlands, where both bees and hoverflies were primarily observed no further than 200 meters from their habitat. Considering flight distances does place some limits on how habitat is located in the landscape, but also means it does not need to be in one place. Taken together, a diversity of flowering crops, wild plants on field margins, and plants up to a half mile away on adjacent land can provide the sequentially blooming supply of flowers necessary to support resident populations of pollinators (Winfree et al. 2008)

Key Points

- *Foraging and nesting habitat needs to be within the flight range of a bee.*
- *The flight range of a bee relates directly to body size: larger bees can fly further than small ones.*
- *Most solitary wild bees have maximum foraging ranges between 150 and 600 meters*
- *Habitat patches should be no more than 600 meters from the crop*
    - *Shorter distances—250 to 300 meters— are optimal*
- *Foraging ranges are strongly influenced by the landscape structure.*

2.3 LANDSCAPE STRUCTURE

The work of Greenleaf et al. (2007) highlighted the influence of landscape structure on the flight range of bees, and thus their actual foraging distance. This influence of environmental condition is reinforced by research into how landscape structure influences the species richness of bees in fragmented grassland (Steffan-Dewenter 2003). The author concluded that the species richness of solitary bees at the study sites depended on the landscape structure (habitat area and connectivity) within 250 meters of the site, but that the abundance of honey bees, which have a much longer foraging distance, was influenced by the landscape structure within 3000 meters. In reviewing nearly two dozen studies that investigated crop pollination services and isolation from natural habitat, Ricketts et al. (2008) showed that visitation rates by native bees to crops declined rapidly as the distance from natural habitat increased. On average, visitation rates were at 50% of their maximum at 668 meters from habitat.

It is also likely that the scale of agriculture itself influences the presence and abundance of bees in the crop. Holzschuh et al. (2006) found that bee diversity was greater in organic wheat fields than conventional fields, due to the presence of more flowers. However, the difference between the farming methods was less pronounced in landscapes that had more habitat patches. This is corroborated by work by Winfree et al (2008) conducted in the border of New Jersey and Pennsylvania. In the study region, wild bees made the majority of visits to the four focal crops (watermelon, muskmelon, tomato, and pepper). Crop visitation by bees was not related to farming method (organic or conventional) but was most influenced by the presence of habitat in the landscape surrounding the fields. This landscape has high hetereogeneity with woodlands and other habitat widely dispersed. The woodland cover was 8 – 60% of the landscape within 2 kilometers of the field, which is comparable with the percentage of natural habitat in Yolo County (0 – 62%). The difference is the distance from the field to the nearest woodland. In this study area in New Jersey/Pennsylvania it was no greater than 343 meters, in Yolo County the maximum is 5980 meters. The heterogenous landscape of New Jersey/Pennsylvania, habitat is within the foraging distance of many bees.

Investigating the offspring production and survival of blue orchard bees (*Osmia lignaria*), Williams and Kremen (2007) concluded that the presence or absence of seminatural habitat had a dramatic effect on nesting and that connectivity between habitats is "critical for offspring production." The value of the surrounding landscape for bees depends on degree of habitat specialization of the bees, i.e., if bees have particular needs that are not met by landscape, it doesn't help them (Steffan-Dewenter 2003).

The influence of a mass-flowering crop on bumble bee populations has been studied in Germany. The research compared bumble bee diversity and abundance in agricultural regions growing oil seed rape (*Brassica napus*) and in regions without. Early colony growth of bumble bees was faster where the mass-flowering crop was a resource (Westphal et al 2003), but by the end of the season there was no difference in reproductive success between colonies in areas with the mass-flowering crop and areas without (Westphal et al 2009). Bumble bee colonies have a long season and require foraging resources all season to support them. The mass-flowering crop gave a short-lived abundance of foraging that could not be sustained by alternative sources in the landscape.

In modeling the optimal landscape design to provide crop pollination, Brosi et al (2008) created a framework for habitat creation in agricultural landscapes. The authors suggest that for bees with large foraging distances habitat should be placed in the center of the farm so that the bees are retained on the farm. Bees with short foraging distances require more of the farm to be habitat and for the habitat patches to be more evenly scattered across the farm. The best strategy may be to have a few larger habitat patches with smaller patches across the farm. These may be placed in low-fertility areas of the farm within foraging distance of crops. The authors do not address the size of habitat.

The suggestion that habitat can be in small patches is supported by the finding of Tscharntke et al (2002). They demonstrated that the fragmentation of habitat across an agricultural landscape significantly affects the number of butterfly species. Ten hectares of habitat in many small fragments can support more species of butterflies than the same size of habitat in one or two large patches. The authors concluded that a larger number of small habitat fragments can contain a wider range of conditions than a couple of large patches. However, Krauss et al (2009) found that size of the habitat and the diversity of flowers, not the age of the habitat, most strongly influenced the species richness of bees.

The impact of landscape change differs between bee species and is influenced by life history and habitat requirement. Ricketts et al. (2008) found that declines in visitation rates to flowers were steeper for social bees than solitary bees in the tropics, which was inconsistent with the findings of Steffan-Dewenter et al. (2006) studying bees in temperate grasslands. Social bees in the tropics are mainly stingless bees, which require cavities in mature trees, a feature that is generally missing from agricultural landscapes. Social bees in temperate regions are mainly bumble bees and halictids, which nest in the ground or under grass. These features often can be found in farmland.

Key Points

- *Species richness of solitary bees depends on the landscape structure (habitat area and connectivity) within 250 meters of the location.*
- *Abundance of honey bees influenced by the landscape structure within 3000 meters.*
- *Crop visitation by bees is not related to farming method (organic or conventional) but to the presence of habitat in the landscape surrounding the fields. Although organic farms often have more habitat available due to the lack of herbicide use.*
- *Presence or absence of seminatural habitat has a dramatic effect on nesting and connectivity between habitats is critical for offspring production.*

- *Early colony growth of bumble bees was faster where a mass-flowering crop was a resource but there is no difference in reproductive success between colonies in areas with a mass-flowering crop and areas without.*
- *Data suggests a larger habitat patch surrounded by smaller patches across the farm is more beneficial for pollinators than all smaller patches.*
- *There is not enough data to provide concrete prescriptions for the size or special arrangement of the habitat needed to support native bees.*
- *Recommendations need to be made at the site scale as quality (both nesting and floral resources) of habitat is extremely variable across the landscape.*

2.4 GENERALISTS OR SPECIALISTS?

When managing habitat for pollinators it is important to determine if there are any habitat specialists present. Generalists are considered species of pollinators that can easily find forage resources from a wide diversity of plant sources. Specialists are those species that use limited sources of nectar and pollen. Bees, for example, are usually defined as generalist or specialist based on the range of flowers from which they collect pollen (Michener 2000).

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 and perhaps less standard requirements of specialist species (Swengel 1996, 1998; Winfree et al. 2007a). Unfortunately, there's no single management plan that can provide ideal habitat for all pollinator taxa. Instead, the conservation priority of specific pollinators in the management area should be considered, and since most generalist species can adapt to a broader range of habitat, specialist species are often higher priority.

Key points

- *Habitat specialists such as vernal pool obligate bees need directed management plans for the species/species groups.*
- *Land management should be tailored to specialist species when they are present.*

2.5 THREATS TO NATIVE POLLINATORS

There are many threats to native pollinators, including the loss, degradation, and fragmentation of habitat; introduced species; habitat disruption from grazing, mowing, and fire; the use of pesticides (herbicides and insecticides); and diseases and parasites (Kearns et al. 1998; Spira 2001; Steffan-Dewenter & Westphal 2008). A discussion of each of these threats follows.

Habitat loss, degradation, and fragmentation

In a synthesis of literature about impacts of human disturbances on bees, Winfree et al. (2009) identified habitat loss and fragmentation as the most significant factor in declines of abundance and species richness of bees. Factors causing habitat loss and fragmentation include increasing urbanization, expansion of intensive agriculture, invasive plants, and climate change. These reduce, degrade, and/or eliminate pollinator habitat. In some cases, however, the impact of urban and agricultural expansion can be reduced by providing alternative food resources and nesting sites for bees and other pollinators (Kremen et al. 2002b; McFrederick & LeBuhn 2006; Holzschuh et al. 2008; Rundlof et al. 2008b; Winfree et al. 2008).

Habitat loss, degradation, and fragmentation are linked to declines in pollinator diversity and abundance (Frankie et al. 1990; Allen-Wardell et al. 1998) that is followed by a reduction in pollination services (Kremen et al. 2002a). They also can cause decreased population size and/or low population densities of pollinator species (Kearns et al. 1998; Spira 2001) or changes in pollinator community composition (Brosi et al. 2008; Ricketts et al. 2008; Krauss et al. 2009). Diversity and reproduction of native flowering plants may also be affected by decreases in pollinator species diversity and population size (Jennersten 1988; Kearns et al. 1998; Spira 2001). The causes of pollinator declines are often difficult to identify, but are likely due to a combination of factors that include isolation time, isolation distance, size of the fragment, and the surrounding environment (Rathke & Jules 1993).

If habitat becomes fragmented and the distance between patches is greater than the foraging range of pollinators, patches too small to support their own pollinators will suffer from lack of pollination services (Kearns et al. 1998). Williams & Kremen (2007) found that in an agricultural landscape, increasing distance to natural habitat in conventional farms was correlated with decreased reproductive success in wild bees. Small scale experimental fragmentation of alpine meadows in Switzerland altered foraging behavior of bumble bees, with bees visiting the fragments 53.7% less than the control plots (Goverde et al. 2002). Because bumble bees tend to return to foraging sites, habitat fragmentation can result in repeated visits to specific fragments, which potentially limits the genetic diversity of the plant community due to a lack of pollen transfer between fragments (Osborne & Williams 2001). In tropical regions, habitat fragmentation impacts social bees more than solitary bees (Ricketts et al. 2008; Winfree et al. 2009), but in temperate areas solitary bees are more affected (Winfree et al. 2009; Krauss et al. 2009). This is due to differences in life history, especially nest site requirements, of stingless bees, the dominant social bee of the tropics, and bumble bees found in temperate regions.

Key Points

- *Habitat loss and fragmentation is considered to be the most significant threat to bees throughout most of Yolo County.*
- *Solitary and social bees respond differently to habitat fragmentation.*

Introduced plant species

Aside from comparisons of abundance and diversity between sites with nonnative and native plants, there are few studies of the direct effects of nonnative plants on native insects. Introduced nonnative plants compete with native plants for resources as well as alter habitat composition, and some cause significant reductions in the abundance and diversity of pollinators and other herbivorous insects (Samways et al. 1996; Kearns et al. 1998; Spira 2001; Memmott & Wasser 2002; Hopwood 2008; Zuefle et al. 2008,; Burghardt et al. 2009; Wu et al. 2009). There is also evidence that native pollinator insects prefer native plants (Hopwood 2008; Burghardt et al. 2009; Wu et al. 2009), even though many native insects will feed on nonnative plants when few natives are available (Zuefle et al. 2008; Burghardt et al. 2009; Wu et al. 2009).

Key Points

- *Introduced plants alter the habitat composition and can cause reduction in pollinator diversity.*
- *This is a serious threat to pollinators in natural habitat in Yolo County.*

Habitat disruption from grazing, mowing, and fire

The impacts of grazing, mowing, and fire are mixed. They can have damaging impacts on pollinators but when carefully managed, they can be beneficial. Historically, there were sufficient areas in various stages of succession to support populations of habitat specific pollinators. However, now that many of these areas exist only as fragments in larger agricultural or otherwise intensively managed landscapes, and consideration of pollinators is needed to ensure healthy populations.

Grazing

Grazing in natural areas and rangelands is a common practice throughout the United States. If not managed appropriately, the ecological impact of grazing can be severe (Bilotta et al. 2007). Livestock grazing can greatly alter the structure, diversity, and growth habits of the vegetation community, which in turn can affect the associated insect community (Kruess & Tscharntke 2002a). Grazing during periods when floral resources are already scarce (e.g., mid summer) may result in insufficient forage available for pollinators such as bumble bees which, in some areas, forage into late September (Carvell 2002). For example, Hatfield & LeBuhn (2007) found that uncontrolled sheep grazing in mountain meadows in the Sierra Nevada removed enough flowering plants to eliminate bumble bees from some study sites. 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).

Ways that grazing can harm pollinator habitat include: destruction of potential nest sites, destruction of existing nests and contents, direct trampling of adult bees, and removal of food resources (Sugden 1985). Studies of livestock grazing on bees also suggest that increased intensity of livestock grazing negatively affects the species richness of bees (Morris 1967; Sugden 1985; Carvell 2002; Vazquez & Simberloff 2003). In Arizona, Debano (2006) conducted one of the few studies that 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 all greater in the ungrazed sites. The author suggested that since insects in the Southwest had not evolved in the presence of buffalo or another large ungulate, adaptations to grazing pressure had not developed, making them more susceptible to the presence of cattle.

Though only limited research has been done on the impacts of grazing on pollinators in the United States, there is a considerable body of work from other countries on which we can draw. In Argentina, researchers compared insect communities in grazed and ungrazed areas and found that insect diversity, abundance, richness, and biomass were all lowest in intensively grazed areas (Cagnolo et al. 2002). In Australia, Hutchinson & King (1980) studied the impact of sheep grazing on sixteen groups of large invertebrates, and found that for most of them, including butterflies, moths, and flies, abundance and biomass decreased as grazing intensity increased. In a study of four different grazing regimes in Germany that varied from continuously intensively grazed areas to long-term ungrazed grassland, Kruess & Tscharntke (2002a, 2002b) found that the diversity of the invertebrate assemblage decreased as grazing intensity increased. This included pollinators such as butterflies and ground nesting bees. These findings are similar to Balmer & Erhardt (2000) who found that old fallow fields in Switzerland that had not been grazed harbored many more rare and specialist species of butterflies than managed pastures or early fallow land, most likely due to the reduction of nectar resources in grazed pastures.

In a study that directly addressed the usage of light grazing as a method of avoiding succession of grassland into forest, Schtickzelle et al. (2007) investigated the effect on the bog fritillary butterfly (*Proclossiana eunomia*) of the introduction of cattle into a wet meadow system. The study area was monitored for eleven years prior to cattle introduction and four years afterwards with a series of ungrazed controls. The negative effects light grazing had on the butterfly were significant. The butterfly visited grazed areas far less than ungrazed areas, and butterfly emergence in grazed areas was 74% less than in ungrazed areas. These effects are largely attributable to changes in vegetation structure, loss of preferred forage sources, and a decline of the hostplant in grazed plots.

Grazing is not necessarily harmful to a natural area. Many parts of the world have experienced grazing pressure from both domesticated and wild animals for millennia and the indigenous flora and fauna is adapted to grazing. Even in areas where grazing is not historically found, light levels of rotational grazing can have positive effects on maintaining an open, herbaceous-dominated plant community that is capable of supporting a wide diversity of butterflies and other pollinators (Smallidge & Leopold 1997).

Some research suggests that grazing can be beneficial for insect communities, especially by managing invasive plants and succession. Cattle grazing has successfully been used to control invasive plant species on degraded habitat of the Bay checkerspot butterfly (*Euphydryas editha bayensis*) (Weiss 1999). (It must be noted that this is a very site-specific case as the invasive plants were successfully colonizing the site because of excessive nitrogen deposition from automobile exhaust due to its proximity to a large urban area.)

Grazing does need to be carefully planned and implemented to be effective. A Swiss study found that while grazing was an effective management tool for limiting succession, responses to grazing varied greatly among butterfly species (Wettstein & Schmid 1999). The authors suggest that any management regime be attentive to historical and species-specific characteristics of the site, and that a diversity of management techniques be used on a regional scale in order to preserve the greatest diversity of insect pollinator habitat.

Grazing can be a valuable tool for limiting shrub and tree succession, providing structural diversity, encouraging the growth of nectar rich plants, and creating potential nesting habitat. However grazing is usually only beneficial at low to moderate levels and when the site is grazed for a short period followed by ample recovery time—and when it has been planned to suit the local site conditions.

Key Points

- *Grazing can have significant impacts on the habitat quality for bees through the* *destruction of nest sites and removal of forage plants.*

- *Grazing can greatly alters the structure, diversity, and growth habits of the vegetation community.*
- *Grazing can be used to maintain open, forb-dominated plant communities that support a diversity of pollinator insects, but only if the correct combination of timing, intensity of stocking rate are found.*
- *The threat of grazing to pollinators is most severe in grasslands and oak woodlands.*
- *At the most severely impacted sites, cattle should be excluded from the area to allow the habitat time to repair.*
- *Keep grazing periods short, with recovery periods for the habitat relatively long.*
- *Generally grazing that is of short intensity and duration in the fall (when there is less competition for floral resources with pollinators) is best.*

<u>Mowing</u>

Mowing is often used in place of grazing where site access and topography permit equipment access. Like grazing, mowing can alter grassland succession and species composition by suppressing growth of woody vegetation (Forrester et al. 2005). Mowing can have a significant impact on insects through direct mortality, particularly for egg and larval stages that cannot avoid the mower (Di Giulio et al. 2001). Mowing also creates a sward of uniform height and may destroy 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 pollinator insects such as bumble bees. In addition to direct mortality and structural changes, mowing can result in a sudden removal of almost all floral resources for foraging pollinators; therefore it should not be conducted when flowers are in bloom.

Key Points

- *Mowing has significant impacts on the habitat quality.*
- *Mowing will create a sward of uniform height and remove flowering resources.*
- *Mowing can be used to control shrubs and trees to maintain open conditions.*
- *No more than a third of habitat should be mown in one year.*
- *In Yolo County road edges may be an important resource for pollinators. Mowing management could be adapted to the maximum benefit of pollinators.*

<u>Fire</u>

Fire has played an important role in many native ecosystems, and controlled burns are an increasingly common management tool. Effects of fire management on arthropod communities are highly variable. If used appropriately, fire benefits many insect communities through the restoration and maintenance of suitable habitat (Huntzinger 2003; Hartley et al. 2007). Other studies have found a negative or mixed response of invertebrates to fire (e.g., Harper et al. 2000; Ne'eman et al. 2000; Moretti et al. 2006).

In Midwestern U.S. prairie systems, fire as a management tool is based on the supposition that prairie species are adapted to wildfires, and thus can cope with regular burns (e.g., Harper et al. 2000; Swengel 2001; Panzer 2002; Hartley et al. 2007). This is dependent, however, on there being adequate unburned adjacent areas that can provide sources of colonizers into the burned habitat. In small fragments where populations are more isolated, prescribed burning can have much more deleterious effects on the population due to a lack of colonizing capacity. For example, Harper et al. (2000) found that overall arthropod species richness decreased in burned prairie sites, as well as the abundance of all but one of the species measured. Their results suggest that burning a small habitat fragment in its entirety could risk extirpating some species because of limited recolonization from adjacent habitat. A study in Israel compared fruit set and bee visitation to four native plants in an unburned area with those in an area burned five to seven years previously (Ne'eman et al. 2000). They found that fruit set was much lower for the native plants in the burned area than in the adjacent unburned area. The authors ascribe this difference to the loss of pollinators, particularly solitary bees, due to the burn, either directly because of mortality during the fire or indirectly due to a reduction in nectar-rich flowers in the area post-fire. Furthermore, Moretti et al. (2006) found that it can take seventeen to twenty-four years for insect communities in burned areas in southern Switzerland to recover to pre-burn composition.

Fire can have serious impacts on population levels and unless there are adequate refuges from the fire or adjacent habitat, recolonization of a burned site may not be feasible. Timing of burns is also critical and should not be carried out when target pollinators are in a larval or critical foraging stage. Habitat patches should not be burned completely, but rather a mosaic of burned and unburned areas is ideal.

Key Points

- *Fire has played an important role in maintaining many native ecosystems.*
- *Bee populations are significantly lower in years following a burn.*
- *It can take two decades for insect communities to recover from a burn.*
- *Impacts of burning can be reduced if areas of habitat are left unburned.*
- *Fires should not burn more than 1/3 of habitat in any given year.*
- *A program of rotational burning where small sections are burnt every few years will ensure adequate colonization potential for pollinators.*
- *As a fire moves through an area it may leave small patches unburned. These skips should be left intact as potential micro-refuges.*
- *Not all sites within the same complex should be burned.*
- *Care must be taken to avoid actions that could degrade habitat and kill individual pollinators as a result of heavy equipment use or people trampling meadows.*

Pesticides

The use of pesticides, including insecticides and herbicides, is detrimental to a healthy community of pollinators. Insecticides not only kill pollinators (Johansen 1977), but sub-lethal doses can affect their foraging and nesting behaviors (Thompson 2003; Decourtye et al. 2004; Desneux et al. 2007), often preventing pollination. Herbicides can kill plants that pollinators depend on when crops are not in bloom, thus reducing the amount of foraging and egg-laying resources available (Kremen et al. 2002; Tscharntke et al. 2005).

In general, while pesticide labels may list hazards to honey bees, potential dangers to native bees and other pollinators are often not listed. For example, many native bees are much smaller in size than honey bees and are affected by lower doses. Pollinator larvae can also be negatively affected by consuming food contaminated with pesticides (Johansen & Mayer 1990; MacKenzie

1993; Abbott et al. 2008). In agricultural areas, field margins are increasingly cultivated (Dover et al. 1990; O'Toole 1993), and the use of pesticides in these areas can result in loss of native vegetation, fewer nesting areas, and overall loss of diversity and habitat structure, all of which impact bees and other pollinators.

Herbicides

Herbicides can kill plants that pollinators depend on, thus reducing the amount of foraging and egg-laying resources available (Kremen et al. 2002a; Tscharntke et al. 2005; Smallidge & Leopold 1997). Just as pollinators can influence the vegetation community, changes in vegetation can have an impact on pollinators (Kearns & Inouye 1997). A pollinator community requires consistent sources of nectar, pollen, and nesting material during those times adults are active. The broadcast application of a non-selective herbicide can indiscriminately reduce floral resources, hostplants, or nesting habitat (Smallidge & Leopold 1997). Such a reduction in resources can cause a decline in pollinator reproductive success and/or survival rates.

Moreby and Southway (1999) found that invertebrate abundance (notably species of Diptera and Heteroptera) was consistently higher in unsprayed plots than in plots that received a single autumn application of herbicides. Taylor et al. (2006) showed that herbicide applications in field margins reduced the number of arthropods (including Lepidoptera larvae) that were food sources for pheasant and partridge chicks. In a meta-analysis of twenty-three studies, Frampton and Dorne (2007) found that restricting herbicide inputs in the margins of crops benefited arthropod populations, including adult and larval Lepidoptera.

Other studies have addressed herbicide use and its effects on pollinators in general. In a review suggesting that pollinators are useful bioindicators, Kevan (1999) found that herbicides reduced Asteraceae and Lamiaceae flowers in France, contributing to a decline in bumble bee populations. Kevan (1999) also finds that herbicide applications have reduced the reproductive success of blueberry pollinators by limiting alternative food sources that can sustain the insects when the blueberries are not in bloom. Kearns et al. (1998) state "herbicide use affects pollinators by reducing the availability of nectar plants. In some circumstances, herbicides appear to have a greater effect than insecticides on wild bee populations … Some of these bee populations show massive declines due to the lack of suitable nesting sites and alternative food plants." In contrast, Russell et al. (2005) and Forrester et al. (2005) both found that the use of selective herbicide when combined with mechanical removal of shrubs and small trees was an effective method of maintaining power line corridors as effective pollinator habitat. In both studies, however, non-selective broadcast herbicides were prohibited as they not only suppressed management target plants, but important nectar resources as well.

While the majority of the effects herbicides have on pollinators are mediated through changes in vegetation, there is evidence that some herbicides such as paraquat, the organic arsenicals, and phenoxy materials can have lethal effects in bees, either through direct application or exposure by feeding (Johansen & Mayer 1990). There is also the potential for sub-lethal effects such as a decreased ability to fly and an increase in flower handling time. For example, hormonal herbicides alter the chemistry of plant secretions such as nectar which in turn may cause harmful effects to pollinators foraging on that contaminated nectar. Ingestion of herbicides by other insects, such as species of Coleoptera and Lepidoptera, has varying effects depending on the species, life stage of the species, and the chemical (Brown 1987; Kegal 1989; Kjaer and Elmegaard 1996; Kjaer and Heimbach 2001; Kutlesa and Caveney 2001; Russell and Schultz 2009). For example, in a laboratory study, Russell and Schultz (2009) showed that sethoxydim and fluazifop-p-butyl herbicides both reduce development time of Puget blue (*Plebejus icarioides blackmorei*) butterflies from the date of treatment to eclosure, and reduce survival, pupal weight, and wing size of cabbage white butterflies. A similar study by Kutlesa and Caveney (2001) found that glufosinate-ammonium is highly toxic to larvae of the Brazilian skipper (*Calpodes ethlius*).

Key Points

- *Herbicides kill plants on which pollinators depend for foraging or egg laying.*
- *Some herbicides can be lethal to bees by direct application or exposure during foraging.*
- *In crop fields, limiting herbicide applications in field margins benefits insect populations in field borders and adjacent habitats.*
- *During vegetation management, treat only the minimum area necessary for the control of weeds. Take care to minimize overspray to habitat around the weeds.*

<u>Insecticides</u>

Insecticides are widely used on agricultural lands and in natural areas throughout the United States to control both native and non-native species. In rangelands, native grasshoppers are targeted with a variety of pesticides (Alston & Tepedino 2000). In addition overspray and drift of agricultural insecticides can affect non-target organisms in field borders (Çilgi & Jepson 1994).

There are two general categories of effects that native pollinators may experience as a result of coming into contact with insecticides or insecticide residues, lethal and sub-lethal.

Lethal effects are most easily recognized: the dosage is sufficient to result in near immediate mortality of the insect. While there are reports of native pollinator die-offs in non-laboratory conditions, many such poisonings are assumed to go unreported because the bees are unmanaged and do not gather in large aggregations (Thompson & Hunt 1999). Low fecundity rates mean it can take many years for a native pollinator population to recover from a large reduction. For example, native bees in laboratory conditions were found to produce 15 – 20 offspring per year (Tepedino 1979). In a natural setting this number is expected to be less due to competition, predation and parasites (Kearns & Inouye 1997). Lethal effects on honey bees are often the primary focus of regulatory procedures for assessing the safety of a new insecticide for pollinators despite the enormous diversity of bees, butterflies, and other pollinating insects that may have a wide variation in their response to the same insecticide (Abramson et al. 2004; Morandin et al. 2005; Abbott et al. 2008). As a result, a pesticide that has been deemed safe for honey bees when used according to the bee label may not be safe for native bees or other pollinators.

Sub-lethal effects refer to a suite of impacts that may inhibit or degrade pollinator function and/or life history, possibly across multiple generations (Desneux et al. 2007). Sub-lethal effects are often difficult to measure and little work has been done to thoroughly investigate their significance in native pollinator populations (Alston & Tepedino 2000). Existing studies show sub-lethal effects impact native pollinator communities in many ways. These include a decrease in forage efficiency, decline of reproductive success and fitness, increase in immunological disorders, and a decrease in learning ability (Decourtye et al. 2004, 2005; Desneux et al. 2007; Morandin et al. 2005; Thomson 2003). Despite the long-term repercussions that these symptoms may have on an ecosystem few pesticides are tested for sub-lethal effects prior to regulatory approval.

One of the most robust case studies of ecosystem effects of insecticide use details the effects of forestry insecticides on pollinators, illustrating how the use of fenitrothion to control spruce budworm in Canadian forests devastated native bee populations. As summarized in Kevan (1999) and Kevan and Plowright (1989), the reduction of native pollinators due to fenitrothion caused a series of effects to ripple through the ecosystem. Similar effects were discussed by Alston and Tepedino (2000) for the application of broad spectrum insecticides in rangelands to control grasshoppers. The insecticides used, due to their high toxicity, are not permitted on blooming crops being visited by bees yet they were allowed to be sprayed on rangelands while native pollinators were foraging on wildflowers. The grasshopper spraying campaigns (generally from mid-April to late May) coincide with the flowering period of several endemic rangeland plants that grow among the grasses, a number of which are listed as endangered or threatened. This time period also overlaps the period of emergence and active foraging of many native bee species (Kearns & Inouye 1997). The usage of broadband insecticides in wild areas may potentially result in a number of ecosystem shifts due to pollinator limitation. These include "changes in future vegetation patterns via plant competition, reduction in seed banks, and influences on the animals dependent upon plants for food" (Alston & Tepedino 2000).

Key Points

- *Insecticides can be lethal to bees or have sublethal effects such as reducing foraging efficiency or reproductive success.*
- *A pesticide that has been deemed safe for honey bees may not be safe for native bees, even when applied according to label requirements.*
- *Pesticides not allowed on blooming crops due to high toxicity may be allowed to be used on rangeland while pollinators forage.*
- *Pesticide impacts are most severe within the agricultural matrix although spraying for mosquitoes or other insects may impact pollinators in a wide range of landscapes.*

Disease and parasites

Effects of pathogens and parasites on honey bees are well documented but there is less known about the impact on native pollinators (Kevan 1999).

The most studied group of native bees are bumble bees. In 2007, the National Research Council stated that a major cause of decline in several native bumble bees appears to be recently introduced nonnative fungal and protozoan parasites, including *Nosema bombi* and *Crithidia bombi*. A recent status review of three bumble bee species from both the eastern and western U.S. found that their decline is most likely caused by introduced diseases from commercial bee rearing and movement (Evans et al. 2008). These pests were probably introduced in the early 1990s when colonies of North American bumble bees were taken to Europe for rearing and then reimported to the U.S. for commercial greenhouse pollination. These pathogens were likely spread to wild populations of bumble bees in the late 1990s as commercial bumble bees were transported throughout the U.S. for pollination of greenhouse tomatoes and a variety of other crops. Commercially reared bees frequently harbor pathogens and their escape from greenhouses can lead to infections in native species (Colla et al. 2006; Otterstatter and Thomson 2008).

Currently, commercial bumble bee rearing facilities in North America breed just one species, the common eastern bumble bee (*Bombus impatiens*). These facilities are in Michigan. California state regulations only allow their importation into the state for use in glasshouses. Open-field pollination by these colonies is illegal. Limiting commercially reared colonies to glasshouses provides some control over the spread of pathogens. California regulations require the use of queen excluders on glasshouse bumble bee colonies to prevent the escape of queens and the possibility of them becoming established in the wild. Using colonies in glasshouses also protects them from vandalism and much accidental damage, two ways in which the bees can escape from the colony boxes.

Key Points

- *Diseases and parasites of native bees are less well studied than those of honey bees.*
- *Bumble bee populations have experienced serious declines, probably due to pathogens spread by commercially reared bumble bee colonies.*
- *Commercially reared bumble bees are used in glasshouses and should not be used for open-field pollination.*

Table 2: Summary of threats to pollinators in different landscapes of Yolo County

Landscape	Threats
Agriculture	1. Habitat loss and fragmentation 2. Pesticide use 3. Grazing, mowing, and fire 4. Disease and parasites from non-native commercially reared bees
Grassland	1. Habitat loss and fragmentation 2. Invasive exotic plants 3. Pesticide use 4. Grazing, mowing, and fire 5. Disease and parasites from non-native commercially reared bees used in agricultural areas
Woodland	1. Fragmentation by both agricultural and urban development 2. Over grazing in the understory 3. Fire, especially when fire suppression allows a build up in fuel loads and increased tree densities 4. Disease and parasites from non-native commercially reared bees used in agricultural areas
Shrubland & Scrub	1. Commercial livestock grazing 2. Burning, mowing and pesticides 3. Habitat fragmentation 4. Disease and parasites from non-native commercially reared bees used in agricultural areas
Riparian & Wetland	1. Livestock grazing in and near riparian and wetland areas can significantly damage stream banks and wetlands 2. Invasive species; management methods can cause further damage to pollinator populations if not used carefully 3. Pesticides are a significant threat, especially in areas with intensive agriculture 4. Disease and parasites from non-native commercially reared bees used in agricultural areas 5. Conversion of vernal pool landscapes to agriculture (primarily rice fields) and urban areas
Urban & Barren	1. Habitat loss and fragmentation are the most significant threats to pollinators 2. Invasive species 3. Use of pesticides.

SECTION 3
HABITAT CONSERVATION AND RESTORATION

This section focuses on pollinators in the Yolo County landscapes described on the Yolo Natural Heritage Program website, with special emphasis on wetland, grassland, and agricultural habitat types. For each landscape, we describe 1) how to recognize pollinator habitat, 2) potential threats to pollinators, and 3) actions to reduce or mitigate threats.

3.1 AGRICULTURE

Agricultural land is the predominant landscape type in Yolo County, covering 347,900 acres of the valley. Crops include over 138,000 acres of pasture, grain and hay, nearly 113,300 acres of field/truck/nursery/berry crops, over 45,000 acres of rice, 36,300 acres of fruit, nut, and citrus orchards, and 15,000 acres of vineyards. Agriculture is very important to Yolo County, contributing well over a billion dollars to its economy (Yolo County 2007 Agricultural Crop Report). Processing tomatoes is the most valuable crop in Yolo County ($100,012,325 in 2007). Field-grown tomatoes are generally considered to be self-pollinating (Delaplane & Meyer 2000; Greenleaf & Kremen 2006a), but a number of native bees visit the flowers and contribute to pollination (Greenleaf & Kremen 2006a). Other crops in Yolo County that rely on insect pollinators for all or some of their pollination include sunflower (seed crop: $9,355,318; field crop: $10,590,093), almonds ($28,914,985), miscellaneous melons and vegetables ($12,220,033), and organic crops ($19,475,512). Many studies show that native bees are more effective pollinators or can enhance pollination by honey bees in many crops, including tomatoes (Greenleaf & Kremen 2006a, Hogendoorn et al. 2006), watermelon (Kremen et al. 2002b), squash (Shuler et al. 2005), raspberries (Willmer et al. 1994), hybrid sunflower (Greenleaf & Kremen 2006b), and cherries (Bosch et al. 2006). In Yolo County, native pollinators can provide complete pollination for some crops in fields that offer proximity to sufficient natural habitat (Kremen et al. 2002b, Kremen et al. 2004).

Published research—much of it conducted in Yolo County—identifies ways in which native bees benefit pollination (e.g., Greenleaf & Kremen 2006a, b; Winfree et al 2008) and connects the presence of native bees to the proximity of natural habitat (e.g., Kremen et al 2004; Williams & Kremen 2007), but generally does not discuss the size of habitat required, nor the ratio of foraging habitat to nesting habitat. Kremen et al (2004) demonstrated that the pollen deposition by native bees in watermelon crops in California's Central Valley was significantly related to the proportion of riparian or upland habitat in the landscape. The authors estimated that complete pollination of watermelon by native bees could be achieved if at least 40% of the land within 2.4 kilometers (1½ miles) of the field or at least 30% of the land within 1.2 kilometers (¾ mile) of the field is habitat. They suggested that 10% of the landscape as habitat might be feasible if areas such as field margins, trackways, equipment areas, and ditchsides were enhanced.

Modeling of landscapes for their capacity to support bees by Lonsdorf et al (2009) can predict the relative abundance and richness of native pollinators in the landscape. This modeling does take into account an estimate of nest and floral resources provided by each habitat type. For each land parcel, the authors estimate the proportion of the parcel that is habitat and what type of nesting resources that habitat offers (cavity, ground). While this offers an estimate of the current nesting habitat (and from that a prediction of the pollinator abundance in a land parcel), it does not say how much of the habitat should be nesting to provide adequate pollination. The model cannot predict bee abundance over time (i.e., population fluctuations) or the pollination benefit (crop yield).

I. Recognizing pollinator habitat

Many growers may already have habitat for native pollinators on or near their land. Having semi-natural or natural habitat available significantly increases pollinator populations (Kremen et al. 2004, Williams & Kremen 2007). Marginal lands such as field edges, hedgerows, sub-irrigated areas, and drainage ditches mimic natural early successional habitat and can offer both nesting and foraging sites (Carvell 2002). Woodlots, conservation areas, utility easements, farm roads, and other untilled areas may also contain good habitat. Often, poor quality soils, unfit for crops, may be useful as pollinator habitat (Morandin and Winston 2006).

II. Potential threats to pollinators

The principal threats to pollinators in agricultural areas of Yolo County are:

1. Habitat loss and fragmentation,
2. Pesticide use,
3. Mowing, grazing, and burning, and
4. Disease and parasites.

Habitat loss including agricultural intensification is thought to be a primary cause of pollinator decline (Winfree et al. 2009). In Yolo County agricultural areas often lack the habitat resources necessary for native pollinators to exist because of intensive land use practices that are detrimental to pollinators (Kremen et al. 2002b; Kremen et al. 2004). Agricultural practices that harm pollinators include leaving no area of the farm uncultivated, treatment of field margins with herbicides and pesticides, and extensive cultivated regions where crops are large distances from natural habitat. Large scale cultivation in Yolo County has reduced pollinator habitat and increased the distance pollinators must travel between foraging and nesting resources (Kremen et al. 2002b; Kremen et al. 2004).

Pesticide use in intensively cropped agricultural areas is always a concern for pollinator populations. Pesticides applied to crops or fields in which bees are foraging, as well as drift over field margins and adjacent natural areas can have both lethal and sublethal impacts.

Mowing, grazing, and burning are common agricultural land management practices and are significant threats to pollinators. Use of these practices in field margins, along roads and adjacent to ditches have reduced pollinator habitat in the county (personal observation).

If open-field pollination by commercially reared bumble bees imported from east of the Rockies, native bumble bee populations may be put at greater risk through the spread of disease or pathogens.

III. Actions to reduce or mitigate threats

<u>A. Protect existing pollinator habitat</u>

The first priority in the Yolo County agricultural landscape should be to identify and protect existing pollinator habitat. When assessing pollen and nectar resources, it is important to look at all of the potential plant resources on and around a landowner or farmer's property, and which plants are heavily visited by bees and other pollinators. These plants include insect-pollinated crops, as well as the flowers – even "weeds" – in buffer areas, forest edges, hedgerows, roadsides, natural areas, fallowed fields, and other vegetated areas. Insect-pollinated crops may supply abundant forage for short periods of time, and such flowering crops should be factored into an overall farm plan if a grower is interested in supporting wild pollinators (Banaszak 1992). However, for pollinators to be most productive, nectar and pollen resources are needed outside the period of crop bloom.

As long as a plant is not a noxious weed species that should be removed or controlled, producers might consider allowing some of the native or nonnative forbs that are currently present onsite to bloom prior to their crop bloom, mow them during crop bloom, and then let them bloom again afterward. For example, dandelions, clover, and other nonnative plants are often good pollinator plants (Free 1968, Mosquin 1971). Growers may also allow some unharvested salad and cabbage crops to bolt. In addition to pollinators, the predators and parasitoids of pests are attracted to the flowers of arugula, chervil, chicory, mustards and other greens, supporting pest management.

When evaluating existing plant communities on the margins of cropland, a special effort should be made to conserve very early and very late blooming plants. Early-flowering plants provide an important food source for bees emerging from hibernation, and late-flowering plants help bumble bees build up their energy reserves before entering winter dormancy (Pywell et al. 2005).

<u>B. Habitat restoration</u>

Landowners intending to increase their pollinator populations may need to do more than simply curtail or alter current management practices that negatively impact pollinators or existing foraging or nesting sites. High quality foraging habitat may be limited, so action may be needed to increase the available foraging habitat and include a range of plants that bloom and provide abundant sources of pollen and nectar throughout spring, summer, and fall. Such habitat can take the form of designated pollinator meadows ("bee pastures"), demonstration gardens, orchard understory plantings, hedgerows and windbreaks with flowering trees and shrubs, riparian and rangeland re-vegetation efforts, flowering cover crops and green manures, and countless other similar efforts.

Where possible, planting local native plants is preferred for their ease of establishment, greater wildlife value, and their evolutionary mutualism with native pollinators (Kearns et al. 1998). Nonnative plants may be suitable, however on disturbed sites, for specialty uses such as cover cropping, and where native plants are not available. Mixtures of native and nonnative plants are also possible, as long as nonnative species are naturalized and not invasive.

Providing pollinator habitat in large cultivated regions of Yolo County will reduce the distance pollinators must travel to find suitable food and nesting resources. If managed properly, these habitat patches will not only protect native pollinators from population declines, but will also help maintain their crop pollination services (Kremen et al. 2002a). Plans to enhance existing habitat or develop new habitat for pollinators should include considerations for both forage and nesting resources. Establishing a diverse mix of plant species will ensure available floral resources through the foraging season of pollinator insects, as well as resources for larval butterflies, moths, and other foliage feeders. The size of restored habitat patches should be at least one-half acre area in size, with two acres or more providing even greater benefits (Morandin & Winston 2006; Kremen et al. 2004).

C. Protect Ground Nesting Bees

In order to protect nest sites of ground-nesting bees, avoid tilling (Shuler et al. 2005) and flood-irrigating (Vaughan et al. 2007) areas of bare, or partially bare ground that may be occupied by nesting bees. Grazing such areas can also disturb ground nests (Gess & Gess 1993; Vinson et al. 1993). Similarly, using fumigants like Chloropicrin for the control of soilborne crop pathogens (such as *Verticillium* wilt), or covering large areas with plastic mulch could be detrimental to ground nesting bees.

Weed control alternatives to tillage include the use of selective crop herbicides, flame weeders, and hooded sprayers for between row herbicide applications.

D. Protect Tunnel-Nesting Bees

Tunnel-nesting bees will make their homes in the abandoned tunnels of wood-boring beetles and the pithy centers of many woody plant stems. Allowing snags and dead trees to stand, as long as they do not pose a risk to property or people, and protecting shrubs with pithy or hollow stems, such as elderberry, blackberry, and box elder, will go a long way towards supporting these solitary bees.

E. Management considerations of pesticides

Given the risk of harm to pollinators the use of pesticides should be greatly reduced. Farmers who encourage native plants for pollinator habitat will inevitably be providing habitat that also will host many beneficial insects that help control pests naturally, and may come to depend less on pesticides. Studies show that organic crops support a higher abundance and diversity of pollinators than areas under conventional management, primarily because of the greater flower abundance in field margins that results from less disturbance and herbicide use (Kremen et al. 2002b; Belfrage et al. 2005; Holzschuh et al. 2008; Rundlof et al. 2008a, 2008b). In some of these cases, native pollinators provide most or all of the pollination services (Kremen et al. 2002b). When pesticide applications are necessary, they should be applied when pollinators are the least active: either in fall or winter months, or at night. Applications can also be scaled to target specific areas and avoid field margins and other areas of pollinator habitat.

F. Management considerations of mowing, grazing and burning

Only a portion of pollinator habitat should be burned, mowed, grazed, or hayed at any one time in order to protect overwintering pollinators and foraging larvae and adults (Black et al. 2008). This will allow for recolonization of the disturbed area from nearby undisturbed refugia, an important factor in the recovery of pollinator populations after disturbance (Hartley et al. 2007). In order to maximize foraging and egg-laying opportunities, maintenance activities should be avoided while plants are in flower (Smallidge & Leopold 1997).

[For more information on habitat restoration for pollinators in agricultural landscapes please see Vaughan and Black (2006) the NRCS technical Note: Pollinator Biology and Habitat in CA.]

IV. Conservation principles for agricultural landscapes

Pollinators are an essential part of Yolo County's agricultural landscape. Several major crops, including sunflowers, almonds, melons, and vegetables, require pollination for full harvests. In the west of the county, the Capay Valley retains many habitat features and is close to shrublands and woodlands in the hills above. However, much of the agricultural area is stripped of habitat, leaving riparian areas as the principal habitat type. There are also areas of wetlands and vernal pools. In these regions, conservation efforts should have a dual focus: protecting and retaining any pollinator habitat that remains, and creating or restoring habitat. Marginal areas like roadsides, ditches, field margins and fencerows, even barren lands have potential as pollinator habitat. Hedgerows rich in flowering shrubs and forbs can be planted and ditchsides restored with wide swathes of flowering plants. These linear habitats can connect with riparian areas and larger habitat patches to create a network of pollinator habitat across farmland.

The principal threats to pollinators in agricultural areas of Yolo County are habitat loss and fragmentation, pesticide use, mowing, grazing, and burning, and disease and parasites.

To maintain pollinator (especially native bee) populations within the agricultural landscape:

- Identify and protect existing pollinator habitat:
    - Areas of natural or seminatural habitat such as riparian areas, wetlands, species-rich grasslands, and vegetated roadside verges.
    - Areas supporting flowers such as buffer areas, forest edges, hedgerows, roadsides, ditchsides, and fallowed fields.
    - Potential bee nesting sites such as areas of untilled bare soil, snags, and pithy-stemmed shrubs.
- Create or restore habitat:
    - Such habitat can take the form of hedgerows, pollinator meadows ("bee pastures"), orchard understory plantings, riparian and rangeland re-vegetation, and flowering cover crops.
    - Have at least three plants blooming in each season (spring, summer, and fall).
    - Use native plants wherever possible.
    - Nonnative plants may be suitable on disturbed sites and for specialty uses such as cover cropping.
    - Include bee nest sites in habitat patches.
    - Restored patches should be a half-acre or more in size.
    - If crop pollination is the focus habitat patches should be no more than 600 meters from the crop (or from each other); shorter distances—250 to 300 meters—would be optimal.
    - Create linear habitats along roads and tracks, ditches, and field margins to increase connectivity across the landscape.
- Pesticide use should be minimized, especially adjacent to natural areas or known pollinator habitat:
    - Pesticides should not be applied when bees are actively foraging on flowers.
    - IPM principals should be followed when planning pest management.
    - If possible applications should be done in fall or winter, or at night.
    - Select the formulation and application method that will minimize overspray or drift into pollinator habitat.

    - Reduce spraying near field margins.
- Grazing, mowing, or the use of fire should be carefully planned in any pollinator habitat.
- Imported bumble bee colonies must be fitted with queen excluders and only used in glasshouses.
- Commercially reared bumble bees should not be used for open-field pollination.

3.2 GRASSLAND

Grassland is the second largest landscape type in Yolo County, and consists of over 93,000 acres of annual grasslands and serpentine habitat. Grasslands are scattered throughout the county, but the majority are located in the western half. The vernal pool complex is also a type of grassland, but will be discussed under the wetlands landscape section. Grassland is a valuable landscape because natural grassland habitat is often in close proximity to agricultural land in Yolo County, it can provide a reservoir of pollinators that provide additional pollination services to crops. The role that adjacent natural habitat plays in providing crop pollination services is increasingly well understood. Proximity to natural or semi-natural non-agricultural land is often an important predictor of pollinator diversity in cropland (Haughton et al. 2003; Bergman et al. 2004; Kim et al. 2006; Kremen et al. 2004; Morandin & Winston 2006; Hendrickx et al. 2007). Natural areas near to farms can also be important sources of pollinators that can recolonize agricultural areas that lost native pollinators due to a pesticide treatment or temporary habitat loss (Öckinger & Smith 2007).

I. Recognizing pollinator habitat

A diverse native grassland comprising of a variety of native grasses and forbs will provide habitat for native pollinators. Solitary ground nesting bees are likely the most common pollinators in grassland but flies, beetles, and butterflies are also likely prevalent. Most of North America's native bee species (about 70%) are ground nesters. These bees usually need direct access to the soil surface (Potts et al. 2005) to excavate and access their nests, which may sometimes be in huge aggregations of hundreds or thousands of nests. Ground-nesting bees seldom nest in rich soils, so poor quality sandy or loamy soils may provide fine sites. Bumble bees are also found in grasslands. They nest in small cavities, such as abandoned rodent nests under grass tussocks or in the ground (Kearns & Thompson 2001).

II. Potential threats to pollinators

The principal threats to pollinators in grasslands of Yolo County are:

1. Loss and fragmentation of grassland,
2. Exotic invasive species can reduce floral diversity,
3. Overgrazing, mowing, and burning, and
4. Pesticide use.

III. Actions to reduce or mitigate threats

<u>A. Protect existing pollinator habitat</u>

Protecting intact species-rich grassland habitats will provide resources for pollinators. Protecting existing nesting sites is also important. For instance, patches of rough undisturbed grass in which rodents can nest will create future nest sites for bumble bees (McFrederick & LeBuhn 2006). Management should be carefully planned and applied to minimize impacts on these species.

B. Habitat restoration

Removal of invasive species and restoration with native grasses and forbs will benefit pollinators. Emphasis should be placed on restoration to historic condition not on pollinator plants specifically. Nesting needs of ground nesting bees and bumble bees should be taken into consideration during restoration (also wood nesting bees if there is an appropriate place to include shrubs).

C. Management considerations of pesticides

Herbicide and insecticide applications in grasslands can be useful in controlling invasive species, but should be planned and carefully managed to avoid negative effects on native pollinators and other species. Targeted spraying should be used instead of broadcast spraying whenever possible, to avoid affecting pollinator species. Areas that are in bloom or have high densities of native pollinators should be avoided, or sprayed at times when the pollinators are not active, such as late fall, winter, and early spring. Timing applications to minimize spray drift is also important, and includes spraying on calm days with low temperatures.

[See Black et al. 2007 for more information.]

D. Management considerations of mowing, grazing and burning

Only a portion of pollinator habitat should be burned, mowed, grazed, or hayed at any one time in order to protect pollinators (Black et al. 2008). This will allow for recolonization of the disturbed area from nearby undisturbed refugia, an important factor in the recovery of pollinator populations after disturbance (Hartley et al. 2007). In order to maximize foraging and egg-laying opportunities, maintenance activities should be avoided while plants are in flower (Smallidge & Leopold 1997).

Mowing is an effective tool at limiting succession of shrubs and trees in grasslands (Forrester et al. 2005) and can be used in areas where other management options such as grazing or prescribed burning are impractical. With careful attention to timing and scale, mowing can be a successful management tool for insuring the long-term stability of pollinator populations and the plants and animals that depend on them. Mowing should not be conducted while flowers are in bloom, to avoid affecting pollinators both through direct mortality from the mower, and through the loss of their food source. Ideally, mowing should be done in the fall and winter to reduce effects on pollinators (Munguira & Thomas 1992). If mowing during spring and summer is necessary to control target weed species, mowing some patches and leaving others is the best method to reduce impacts on pollinators.

Grazing management should be adjusted as needed to maintain the majority of floral resources in an area throughout the seasons. The most effective time to graze varies depending on the site, but should be limited to times of low or no pollinator activity. Moderate levels of rotational grazing minimize negative impacts on pollinators and other native species.

In grassland regions, fire suppression can lead to invasion and maturation of shrubs and trees and an increase in invasive plant species. Eventually, continued succession results in the degradation and loss of the grasslands (Schultz & Crone 1998; Panzer 2003). Prescribed burning is therefore a useful tool for restoring and maintaining grassland habitat. Precautions for avoiding impacts on pollinators include only burning small sections of grassland, and rotating burned areas over several years, to allow sufficient time for the habitat to recover and pollinators to recolonize the burned sites.

[See Black et al. 2007 for more information on mowing, grazing and fire management.]

IV. Conservation principles for grasslands
The native grasslands in Yolo County could provide a valuable source of pollinators; a diverse native grassland comprising a variety of grasses and forbs will provide habitat for pollinators. As with agricultural areas, conservation should have a dual focus, protecting existing areas of good habitat and restoring degraded areas.

The principal threats to pollinators in grasslands of Yolo County are the loss and fragmentation of grassland; invasive species reducing floral diversity; overgrazing, mowing, and burning; and pesticide use.

To maintain pollinator (especially native bee) populations within the grassland landscape:

- Identify and protect existing pollinator habitat:
    - Areas of natural or seminatural grassland that support a diverse native flora.
    - Potential bee nesting sites such as areas of bare soil, snags, and pithy-stemmed shrubs.
- Restore degraded grasslands and create new grasslands:
    - Control and remove invasive weeds
    - Use native forbs to enhance diversity of grasslands.
- Use grazing, mowing, or fire carefully to avoid harming pollinators:
    - Treat only part of the area in one year.
    - Leave areas untreated as refugia for pollinators.
    - Time grazing to avoid periods of major bloom.
    - Rotate grazing to allow all patches to bloom.
    - Do not mow while flowers are in bloom.
    - Burning can be used to suppress shrubs and trees.
    - Allow habitat to recover fully between burns.
- Reduce spraying on grasslands and protected from drift from adjacent fields:
    - Pesticides that are not allowed on blooming crops may be allowed on grassland, despite the fact that they are no less damaging to bees.

3.3 WOODLAND AND FOREST

Woodlands and forests are primarily found in western Yolo County, and include several oak alliances, as well as foothill pine, knobcone pine, eucalyptus, cypress, and juniper alliances.
The open forest and woodland in Yolo County can provide significant habitat for pollinators. If managed properly they can provide a resource for nearby agricultural crops.

Oak woodlands, when relatively intact, contain a diverse flora interacting with a diverse pollinator fauna (Dobson 1993). In a study on the Greek Island of Lesvos, oak woodlands, pine forests and managed olive groves had the highest diversity of bees and oak woodlands had the highest levels of pollination from generalist species. In recent times, California's oak woodlands have experienced profound changes that have led to significant fragmentation of these habitats. These changes involve various combinations of grazing, conversion to agriculture, altered fire regimes, and fragmentation due to development. Although our understanding of the effects of fragmentation on vertebrate species in oak woodlands is increasing, we know very little about the effect of these changes on invertebrate communities (Block and Morrision 1998; Knapp et al. 2001). Recent work on solitary bees in oak woodlands suggests that there is a decrease in species diversity and number of species in habitats dominated by vineyards (LeBuhn, in prep) but other work showed little influence of this habitat fragmentation on bumble bees (LeBuhn and Fenter 2008).

I. Recognizing pollinator habitat

A diverse set of native plants in the understory of forests and woodlands can provide habitat for a variety of native bees. These will include ground nesting solitary bees. These bees usually need direct access to the soil surface (Potts et al. 2005) to excavate and access their nests. Ground nesting bees seldom nest in rich soils, so poor quality sandy or loamy soils may provide fine sites. Bumble bees are also found in forests and woodlands. They nest in small cavities, such as abandoned rodent nests under grass tussocks or in the ground (Kearns & Thompson 2001). Tunnel nesting bees will make their homes in the abandoned tunnels of wood-boring beetles in both conifers and a variety of deciduous trees and in the pithy centers of many woody plant stems.

II. Potential threats to pollinators

The principal threats to pollinators in woodlands of Yolo County are:

1. Fragmentation by both agricultural and urban development,
2. Over grazing in the understory is a significant threat to pollinators (personal observation), and
3. Fire also poses a threat, especially when fire suppression allows a build up in fuel loads and increased tree densities (Huntzinger 2003), both of which can lead to hotter and more widespread wildfires.

III. Actions to reduce or mitigate threats

A. Protect existing pollinator habitat

Providing a diverse understory of native grasses and native flowering forbs will provide significant habitat for a variety of native pollinators. Leaving patches of rough undisturbed grass in which rodents can nest will create future nest sites for bumble bees (McFrederick & LeBuhn 2006). Allowing snags and dead trees to stand, as long as they do not pose a risk to property or people, and protecting shrubs with pithy or hollow stems, such as elderberry, blackberry, and box elder, will go a long way towards supporting bees.

B. Habitat restoration

Removal of invasive species and restoration with native grasses forbs and shrubs will benefit pollinators. Emphasis should be placed on restoration to historic condition not on pollinator plants specifically. Nesting needs of ground nesting bees and bumble bees should be taken into consideration when restoring this habitat. Snags and other resources should be left for wood nesting bees.

C. Management considerations of pesticides

As in the other landscape types of Yolo County, herbicides are beneficial for invasive plant control, but should be used carefully to avoid harming native pollinators. The use of pesticides, particularly of insecticides, should be limited to small areas or applied at times when pollinators are inactive.

D. Grazing and fire

Only a portion of pollinator habitat should be burned, mowed, grazed, or hayed at any one time in order to protect pollinators (Black et al. 2008). This will allow for recolonization of the disturbed area from nearby undisturbed refugia, an important factor in the recovery of pollinator populations after disturbance (Hartley et al. 2007). In order to maximize foraging and egg-laying opportunities, maintenance activities should be avoided while plants are in flower (Smallidge & Leopold 1997).

Grazing management should be adjusted as needed to maintain the majority of floral resources in an area throughout the seasons. The most effective time to graze varies depending on the site, but should be limited to times of low or no pollinator activity. Moderate levels of rotational grazing minimize negative impacts on pollinators and other native species.

Fire is an important natural disturbance in the Yolo County forest and woodland landscape. Prescribed fire can help maintain these forest and woodland ecosystems, and if conducted regularly, can control the buildup of fuel loads and increased tree densities, as well as reduce the intensity and frequency of uncontrolled wildfires (Huntzinger 2003). Huntzinger (2003) evaluated adult butterfly species diversity in three types of prescribed burn treatments (forest burns, fuel breaks, and riparian burns) in formerly fire-suppressed forests in the Rogue River National Forest and Yosemite National Park. Butterfly species were higher in each of the treatments compared to the controls, with two to three times more species in forest burns, thirteen times more species in fuel breaks, and two times more species in riparian burns (Huntzinger 2003). However, several studies indicate that pollinators are negatively affected by fire (Harper et al. 2000; Swengel 2001; Potts et al. 2003). As with all potentially harmful management activities, care must be taken when using prescribed fire.

[See Black et al. 2007 for more information on grazing and fire management.]

IV. Conservation principles for woodland and forest

The open woodlands and forests of Yolo County can provide significant habitat for pollinators. The diversity of ground conditions combined with mixed ages of trees provides a rich nesting resource suited to ground-, wood-, and cavity-nesting bees. In addition, the ground flora can offer abundant flowers for foraging. These habitats are largely restricted to the hills and mountains in the west of the county, so any pollinator benefit to agricultural land is limited to farms in the Capay Valley and those close to the eastern fringe of the uplands.

The principal threats to pollinators in woodland and forest of Yolo County are fragmentation by both agricultural and urban development, overgrazing in the understory, and fire.

To maintain pollinator (especially native bee) populations within woodlands and forests:

- Reduce or prevent fragmentation of woodland and forest areas.
- Grazing should be adjusted to reduce the impact on flowering plants:
  - The best time to graze varies with the site but should be limited to periods of low pollinator activity.
  - Establish exclosures and rotate grazing to allow recovery of the vegetation community.
- Control invasive species.
- Fire is an important natural disturbance and prescribed fire can be used to manage the habitat:
  - Burn only small areas at one time.
  - Do not burn the same area more frequently than five years.
  - During burns, leave skips as refugia from which pollinators can recolonize.
- If pesticides are required for pest management:
  - Do not apply to significant patches of foraging flowers.
  - Do not apply while pollinators are active.
  - Choose least toxic option, such as pheromone traps.
- Habitat restoration should be done with native species only.

3.4 Shrubland and Scrub

Shrubland and scrub habitats are primarily located in western Yolo County and include various chamise and mixed chaparral alliances. In studies by Kremen et al. (2004), a common factor influencing native bee distribution appears to be areas of nearby natural habitat, particularly, in their study chaparral and oak woodland. Shrubland and scrub habitat offers a variety of flowering plants and nesting sites and can be very valuable habitat for native pollinators. Surveys of pollinators in different California plant communities show that the chaparral community has the largest diversity of bees per unit area (Moldenke 1976, as cited in Dobson 1993). Dobson (1993) recorded 73 bee species from six families visiting 11 shrub species in a Napa County, CA shrubland habitat, with *Ceanothus* sp. attracting the greatest diversity of bees.

I. Recognizing pollinator habitat

Bees are the most significant pollinators in chaparral communities (Moldenke 1976, as cited in Dobson 1993). Shrubland and scrub habitat provides the variety of dead, woody vegetation necessary for bees that nest in twigs and holes in shrubs and trees. The ground also provides good nesting habitat, in comparison to frequently disturbed soil in agricultural and urban areas. Flowering shrubs are the principle food source of bees in this habitat although some bees did visit other plants with low frequency (Dobson 1993). Most chaparral shrub species are self incompatible and depend on insects for pollination (Keeley and Keeley 1988, as cited in Dobson 1993). In mature chaparral flowering shrubs compromise the major food source for bees although herbaceous plants growing in shrub openings or adjacent habitats appear to play a role in maintaining populations of certain bee species (Dobson 1993).

II. Potential threats to pollinators

The principal threats to pollinators in shrubland and scrub of Yolo County are:

1. Commercial livestock grazing is common in this landscape type,

2. Burning, mowing and pesticides, and
3. Habitat fragmentation from conversion of the land to agriculture and urban areas.

III. Actions to reduce or mitigate threats

A. Protect existing pollinator habitat

Existing pollinator habitat should be identified and protected to help maintain native pollinator species and help supplement nearby agricultural and urban areas, as well as to protect threatened and endangered plant and animal species. Management should be carefully planned and applied to minimize impacts on these species.

B. Habitat enhancement and restoration

The value of the shrubland and scrub landscape, both to pollinator survival and as a source of pollinators for other landscapes, makes the enhancement and restoration of habitat important in pollinator conservation in Yolo County. In areas where habitat enhancement or restoration is planned, management practices such as pesticide use and grazing should be carefully managed.

C. Management considerations of pesticides

Insecticides should be avoided if at all possible, and herbicides should be applied at times and scales to minimize harmful effects on pollinators.

E. Management considerations of grazing and fire

Low to moderate levels of grazing can help maintain shrubland and scrub habitat. Some studies indicate that grazing has a beneficial effect on pollinator species (Smallidge & Leopold 1997; Vulliamy et al. 2006). However, if not managed carefully, livestock can severely damage the nests of ground nesting bees, as well as destroy floral and foliage resources of pollinators such as bees and butterflies (Kruess & Tscharntke 2002b; Debano 2006; Hatfield & LeBuhn 2007). Grazing should be limited to times when pollinators are not actively foraging or nesting, and should be rotated through areas in sufficient time intervals to allow recovery of grazed areas.

Fire is an important natural disturbance in the shrubland and scrub landscape. Prescribed burning can prevent the spread of large wildfires. A balanced plan for fire management should include reducing excess fuel loads and controlling vegetative succession, while allowing time between burns for the recovery of plant and wildlife populations.

[See Black et al. 2007 for more information on grazing and fire management.]

IV. Conservation principles for shrubland and scrub

Shrubland may support the richest and most diverse community of bees in Yolo County. Surveys done elsewhere in California identified chaparral as the plant community with the largest diversity of bees. Shrublands provide a diversity of nesting sites (twigs, stems, bare ground) as well as an abundance of flowering shrubs and forbs. Disturbance from fire is important to maintain the open conditions and diverse plant community. Like the woodlands and forest, shrublands are restricted to the western part of the county. Scrub habitat close to farms provides pollinators for crops.

The principal threats to pollinators in shrublands and scrub of Yolo County are commercial livestock grazing, burning, mowing, and pesticides, and habitat fragmentation.

To maintain pollinator (especially native bee) populations within shrublands and scrub:

- Protect existing shrublands and scrub to avoid loss or fragmentation.
- Manage grazing to avoid over grazing and damage to floral resources:
  - Keep grazing at low to moderate levels.
  - Establish exclosures and rotate grazing to allow recovery of grazed areas.
  - Avoid grazing when pollinators are active.
- Prescribed burning can lessen the chance of catastrophic wildfire by reducing the fuel load as well as control vegetation succession:
  - Burning should be done in small units to ensure that areas of scrub remain unburned.
  - During burns, leave skips as refugia from which pollinators can recolonize.
- If pesticides are required for pest management:
  - Do not apply to significant patches of foraging flowers.
  - Do not apply while pollinators are active.
  - Choose least toxic option, such as pheromone traps.

3.5 RIPARIAN AND WETLAND

Riparian and wetland habitat in Yolo County consists of fresh emergent wetland, saline emergent wetland, valley foothill riparian, alkali sink, and vernal pool complex.

Vernal pools

Vernal pools support many threatened and endangered species, and are of primary concern for restoration and conservation in this landscape. Areas that are seasonally flooded, such as the vernal pool complex, offer rich food and nesting resources for pollinators and other wildlife. The vernal pools of California provide critical habitat for a relatively large number of threatened and endangered species, many of which are quite specialized (Keeler-Wolf et al. 1998). The vernal pool region of Solano, Yolo, and Colusa counties hosts 16 sensitive plant species and 7 sensitive animal species (Keeler-Wolf et al. 1998). Several native solitary bee species are specialist pollen foragers on endemic vernal pool plants (Thorp & Leong 1995; Thorp & Leong 1998; Thorp 2007). Some species of vernal pool plants, many of which are threatened or endangered, are solely dependent upon specialized solitary bees for pollination (Thorp & Leong 1995).

For vernal pools in particular, many plants have bees that are specialists on that plant and have life cycles very closely associated with the host plant. Some vernal pool plants and their associated pollinators are listed in Table 2 below.

Many of the bees listed in Table 2 are oligolectic, i.e., they collect pollen from a limited range of flowers, and thus have a close association with the plants. Emergence and flight period of these bees is tightly synchronized with the bloom period of their host flower (Thorp 2007). Most of these species nest in upland areas next to the pools (rarely as far as 100 meters from the host plants) and some nest even closer in pool margins. At least one—a *Panurginus* associated with

Downingia—nests in the bottom of dried up pools. Females tend to forage in a single patch of flowers and nest near to their natal nest.

Table 3: Vernal pool plants and their flower visitors

Vernal pool plant	Specialist bee(s)	Other insect visitors
Blennosperma (stickyseed)	*Andrena blennospermatis*	Generalist visitors, including empidid and syrphid flies
Lasthenia (goldfields)	Six *Andrena* spp. (*puthua*, *submoesta*, *baeriae*, *duboisi*, *lativentris*, *leucomystax*)	Generalist bees and other visitors
Limnanthes (meadowfoam)	*Andrena puvlerea* *Panurgnius occidentalis*	
Downingia (calicoflower)	*Panurginus* sp.	Small sweat bees (Halictidae), and *Bombus vosnesenskii* (which buzzes flowers to gather pollen but doesn't pollinate)

(Pollinator information is from Thorp & Leong 1995 and Thorp 2007. Common plant names are from USDA-NRCS PLANTS database; accessed 10/12/09.)

In addition to nesting close to their host plants, these bees have limited ability to disperse to new sites. Thorp & Leong (1995) report a study conducted in a newly constructed vernal pool in which *Blennosperma* plants had been introduced. Over a period of two growing seasons, no specialist bees (*Andrena blennospermatis*) visited flowers of *Blennosperma*, though the blooms were visited by generalist sweat bees (*Halictus*) and empidid and syrphid flies.

For these specialist bees, protection of the existing vernal pool habitat, including upland areas, is the key to conservation (Thorp & Leong 1995, Thorp 2007). Do not excavate new pools in upland areas. The surrounding agricultural land provides little opportunity for ground nests (Lonsdorf et al 2009), and it is unlikely that flowering crops will contribute to conservation of these specialist bees.

The presence of flowering crops is likely to offer more foraging resources to the generalist visitors of vernal pool flowers. Unfortunately, there is little specific information published about these generalist insects which makes it difficult to assess the benefit that could accrue from crop flowers. Commercial crops of meadowfoam (*L. alba*) use honey bees and the blue orchard bee for pollination (Thorp 2007). It can be assumed that these bees must have some benefit as pollinators of vernal pool populations of *Limnanthes*. However, this is not true for all vernal pool flowers. Thorp (2007) also reports that *Downingia* growing in gardens rarely sets seeds, indicating that the generalist flower visitors are not effective.

The larvae of endangered molestan blister beetles (*Lytta molesta*) feed on the provisions and immature stages of ground nesting native bees, while the adults are flower feeders and potential pollinators (Selander 1960; Halstead & Haines 1992), and have only been collected on vernal pool vegetation, although records are limited. Conservation of native plant and bee species associated with vernal pools should be central to the conservation of this blister beetle, and will potentially benefit other plant and animal species as well.

Key Points

- *Important pollinators of vernal pool plants are mainly specialist, ground-nesting bees.*
- *These bees have a very close association with the plants, including life cycles synchronized with bloom of flowers, pollen collection from flowers, and nesting sites close to flower patches.*
- *These bees probably will not forage on crop flowers.*
- *Generalist pollinators such as bumble bees may use crops, but are not efficient pollinators of vernal pool plants.*
- *Conservation of vernal pool pollinators is best served by focusing on protecting existing vernal pools and the surrounding upland areas.*
- *There is not enough research on these systems to provide a proportion or ratio of pollinator habitat for rare plants.*
- *Generally the larger the upland area the more beneficial of pollinators.*

Riparian areas

The importance of riparian areas as pollinator habitat has been underscored by several studies, each of which identified the proximity of riparian areas as an important influence on the availability of native bees as crop pollinators (Kremen et al. 2002a, 2002b; Kremen et al. 2004) or influencing the reproduction of bees nesting on farms (Williams & Kremen 2007). Lonsdorf et al (2009) identify riparian as offering floral resources in spring but not summer. During this season, the main contribution of riparian zones may be in offering nest sites. Maximizing plant diversity along riparian corridors will result in more pollinators and other terrestrial insects to feed fish in the streams. In the agricultural areas of Yolo County, riparian areas may be the only significant areas of habitat.

I. Recognizing pollinator habitat

Most species of bees that rely on vernal pool habitat are solitary ground nesters. Most of these species nest in uplands close to vernal pools, while some species nest in the margins and sometimes the bottoms of evaporated vernal pools (Thorp & Leong 1995; Thorp 2007). Some of these species are also known to nest in stream banks (Saul-Gershenz et al. 2004). These bees have short flight ranges usually less than half a mile and are therefore often restricted to only a few vernal pools (Thorp & Leong 1995). Some species such as bumble bees also use vernal plants and may fly long distances from their nest to forage on vernal pool flowers (Thorp personal communication), underscoring the importance of landscape-wide conservation of pollinators.

II. Potential threats to pollinators

The principal threats to pollinators in riparian areas and wetlands of Yolo County are:

1. Habitat loss (vernal pools, in particular),
2. Grazing in or near riparian and wetland areas,
3. Pesticide use, and

4. Invasive exotic plants.

Livestock grazing in and near riparian and wetland areas can significantly damage stream banks and wetlands, affecting native species associated with this landscape type. Saunders and Fausch (2007) found that reduction of grazing intensity increased invertebrate inputs into streams which in turn increased trout biomass by more than 100%. Overgrazing can also reduce or eliminate plant species, and in habitat such as vernal pools, this can lead to the extirpation or extinction of specialized plants and animals.

Invasive species also threaten pollinators and other native species in these habitats, and management methods can cause further damage to pollinator populations if not used carefully.

Pesticides are a significant threat to native pollinators and other species in or near riparian areas and wetlands, especially in areas with intensive agriculture, where pesticides can build up in the water system, directly and indirectly affecting pollinators and their food plants.

Conversion of the landscape to agriculture (primarily rice fields) and urban areas has led to a significant loss of vernal pool habitat, which not only threatens pollinators, but other native species as well.

III. Actions to reduce or mitigate threats

A. Protect existing pollinator habitat

As in other landscapes, the first priority in pollinator conservation is to identify and protect existing pollinator habitat. This is especially important for the vernal pool complex, which is severely threatened by fragmentation and habitat loss, and is home to many species that are threatened or endangered in California.

B. Habitat restoration and conservation

Restoring and protecting vernal pool habitat and other sensitive riparian and wetlands areas is critically important for the survival of many threatened and endangered species in Yolo County. Vernal pools that are primarily impacted by overgrazing have the highest potential for habitat restoration, while restoration of agricultural areas such as rice fields is possible but not as feasible (Keeler-Wolf et al. 1998). Restoration of riparian and wetland habitat should include reintroduction of native plants associated with each site. As stated in the assessment of vernal pools in California done by Keeler-Wolf et al. (1998), conservation efforts should focus on the entire vernal pool complex, which includes the pools and their associated uplands, as well as considerations for both the wet and dry phases of the pools. Several native solitary bees are specialist pollinators of vernal pool plants, and have certain requirements that should be incorporated in conservation strategies for vernal pools. These bees primarily nest in uplands near vernal pools, although some species have been found nesting in the bottom of evaporated pools (Thorp 2007). These bees also have short foraging ranges and are therefore limited in how far they can travel to find forage plants (Gathmann & Tscharntke 2002, Thorp 2007). Restoration and conservation of vernal pools should also take into consideration the significant variation in the plant and animal species composition between individual pools (Keeler-Wolf et al. 1998). Management of riparian and wetland areas should use low-impact, targeted practices, and avoid grazing and pesticides.

C. Management considerations of pesticides

Pesticides should be used as little as possible in riparian and wetland areas to avoid compounding negative effects on plants and animals from the buildup of chemicals in the water system. Because so many threatened and endangered plant and animal species are associated with vernal pools, particular care should be taken when pesticide applications are necessary.

D. Management considerations of grazing and fire

Although grazing can be a beneficial disturbance, riparian and wetland areas are extremely sensitive to it and any grazing should be carefully managed. Grazing in wetlands can cause destruction of vegetation through trampling and consumption, high nutrient additions from manure that can alter plant composition in the wetlands, negatively impacting native plant and animal species, including pollinators, trampling nests of ground nesting bees and consuming and trampling foliage feeding larvae of pollinators such as butterflies and moths. But some studies have shown that some grazing can be beneficial to vernal pool habitats. One study on grazing of vernal pools in California (Marty 2005) showed that continuous grazing from October to June resulted in the highest cover of native plants compared to either no grazing or grazing for shorter periods. Grazing also affected the number of days for which the pools held water, which in turn influenced whether or not vernal pool flowers could complete their life cycle.

When burning is prescribed for areas with vernal pools, it should be carefully timed to avoid the key weeks when specialist bee species are active and threatened flower species are blooming. Other wetlands and riparian areas have longer bloom periods and corresponding pollinator activity, so burns in these areas should be timed to avoid these periods.

[See Black et al. 2008 for more information on grazing and fire management.]

IV. Conservation principles for riparian and wetland areas

This habitat category in Yolo County consists of a variety of wetland types, as well as riparian zones flanking many watercourses. This category also includes vernal pools, which support many threatened and endangered species, and are of primary concern for restoration and conservation. In the eastern part of the county, where the landscape is dominated by agriculture, riparian and wetland areas may be the only significant areas of seminatural habitat. As such, they form an important resource for pollinators and should be at the center of conservation efforts. In addition to the flowers and nesting opportunities they hold, riparian areas cross land holdings and ownership boundaries and provide valuable corridors. Pollinator habitat created in hedgerows or along ditchsides and field margins should connect with riparian areas to create a network of habitat.

The principal threats to pollinators in riparian areas and wetlands of Yolo County are habitat loss (vernal pools, in particular), grazing in or near riparian and wetland areas, pesticide use in adjacent fields, and invasive exotic plants.

To maintain pollinator (especially native bee) populations within riparian and wetland:

- Protect existing areas from habitat loss or fragmentation:
    - This is particularly important for vernal pools.
- Enhance current habitat or create new habitat:

    - Use native plants.
- Monitor and control invasive species.
- Manage grazing to avoid over grazing and damage to floral resources:
    - Keep grazing at low levels to reduce trampling and consumption.
- Pesticide use in riparian and wetland areas should be avoided:
    - Monitor pesticide use in adjacent fields.
    - Reduce spraying along field margins close to riparian zones.

For vernal pools in particular:

- Protect existing vernal pool habitat, including upland areas.
- Do not excavate new pools in upland areas.
- Carefully managed grazing may help maintain native plant communities and retain longer flooding periods.
- Avoid pesticide drift or overspray from adjacent crops.
- A buffer of 500 feet around the pools should be adequate to protect the specialist bees.
- A wider buffer (1 kilometer) should be used for aerial spraying of insecticides especially during the active flight period of the specialist bees (which coincides with bloom of the plants).

3.6 URBAN AND BARREN

Developed land in Yolo County is defined as urban. All other areas of unvegetated or vacant land are defined as barren, and include gravel bars, sand bars, and rock outcroppings. Major highways and associated verges are also included. Urban and barren areas are distributed throughout the county.

Pollinators are essential in urban areas for fruit and vegetable production of home and market gardeners, as well as for ensuring the continuation of flowering plants in gardens and parks, and the production of seeds for birds (Cane 2005). The need for pollinators in other urban and barren landscapes such as roadsides includes contributions to crops, especially in Yolo County where a majority of the county is agricultural land.

I. Recognizing pollinator habitat

Natural barren land such as gravel and sand bars can provide nesting sites to native bees. It has been demonstrated that some barren lands, particularly those due to human activities such as quarrying, can offer valuable habitat for pollinators (Benes et al. 2003; Krauss et al. 2009). Roadsides can also offer valuable habitat to pollinators if managed carefully and restored with native plants (Hopwood 2008). Roadside habitat is especially important for pollinators in areas of intensive agriculture with very little available habitat (Hopwood 2008). Urban gardens and parks also provide important habitat for pollinators in a fragmented landscape, and can serve as pollinator reservoirs if managed properly (e.g., McIntyre & Hostetler 2001; Tommasi et al. 2004; Wojcik et al. 2008). Studies of arthropods in Phoenix, Arizona indicate that while bees and other arthropods are often abundant in urban settings, the abundance and community composition differs depending on urban land use, such as residential and industrial use (McIntyre et al. 2001, Faeth et al. 2005). Ground-nesting bees are often more sensitive to urbanization because of degraded nesting habitat, compared to cavity-nesting bees that can adapt to nesting in cavities in houses, fences, and woody landscape vegetation (Cane et al. 2006).

II. Potential threats to pollinators

The principal threats to pollinators in urban and barren areas of Yolo County are:

1. Habitat loss and fragmentation are the most significant threats to pollinators,
2. Invasive species, and
3. Use of pesticides. According to some studies more types of pesticides are detected in urban streams than in agricultural streams (Bortleson and Davis 1997) and more pounds of pesticides were applied in urban than in agricultural areas (Tetra Tech Incorporated, 1988) but urban use of pesticides are hard to track and no one has completed any analysis for Yolo County (http://agis.ucdavis.edu/pur/pdf/FlintPUR.pdf).

III. Actions to reduce or mitigate threats

A. Protect existing pollinator habitat

Existing pollinator habitat should be identified and protected to help maintain native pollinator species and provide patches of habitat in a highly fragmented and disturbed landscape. Management should be carefully planned and applied to minimize impacts on these species.

B. Habitat restoration

Restoration of roadside vegetation to native grasses can provide low-maintenance ground cover (Booze-Daniels et al. 2000; O'Dell et al. 2007). A survey of such restoration in Yolo County found that establishing native perennial grasses along roads was highly successful, with the grasses persisting under minimal maintenance for over ten years (O'Dell et al. 2007). Native broadleaf plants such as lupine and California poppy also colonized the restored roadsides (O'Dell et al. 2007), making these strips of land even more suitable for pollinator habitat. Restoration in urban areas should include establishing native flowering herbaceous plants and providing nesting materials for bees, as well as reducing pesticide use, to encourage bees and other insect pollinators to colonize parks, gardens, and other urban areas. Pavement, buildings, and turf eliminate habitat for ground nesting bees, as well as reduce the area available for flowering plants. If gardens and other potential habitat are too fragmented and widely spaced, they may not be able to support many pollinator species due to flight range restrictions.

C. Management considerations of pesticides

Pesticides are frequently used in urban areas, both to control weeds and insect pests. Pesticide use should be significantly reduced to lower the threat to pollinators and their host plants.

D. Management considerations of mowing

Mowing is a common practice in urban areas, usually to maintain the height of grasses in parks and lawns. Mowing should be avoided in areas where bees are actively foraging or nesting, or can be conducted in the evening when pollinators are less active.

IV. Conservation principles for urban and barren areas

This landscape category includes all developed land in Yolo County and any areas of unvegetated or vacant land, including gravel bars, sand bars, and rock outcroppings. Major highways and associated verges are also included. While these may not seem to be particularly attractive as pollinator habitat, the disturbed and marginal areas can be valuable as they often include a variety of flowering plants and range of ground conditions suited for bee nests. These areas are found throughout the county, offering small patches of habitat scattered across the landscape. In intensively cultivated agricultural areas, roadsides or abandoned land may be a significant habitat resource.

The principal threats to pollinators in urban and barren areas of Yolo County are habitat loss and fragmentation, invasive species, mowing, and the use of pesticides.

To maintain pollinator (especially native bee) populations within urban and barren areas:

- Identify and protect existing pollinator habitat:
  - Areas of natural or seminatural grassland that support a diverse native flora.
  - Species-rich hedgerows or scrub habitat.
  - Potential bee nesting sites such as areas of bare soil, snags, and pithy-stemmed shrubs.
- Restore degraded habitat (especially grasslands) and create new habitat patches:
  - Control and remove invasive weeds
  - Use native forbs and grasses to enhance diversity of grasslands.
  - Use flowering shrubs to create hedgerows.
  - In urban parks and gardens, flower borders, ecolawns, and ornamental plantings can be created that feature native plants.
- Use mowing carefully to avoid harming pollinators:
  - Mow only part of the area in one year.
  - Leave areas unmown as refugia for pollinators.
  - Time mowing to avoid periods of major bloom.
  - Allow habitat to recover fully between mowing.
- Reduce spraying on sites such as roadside verges and protect from drift from adjacent fields:
  - Pesticides that are not allowed on blooming crops may be allowed on verges, despite the fact that they are no less damaging to bees.

SECTION 5
RARE AND COVERED PLANTS

The issue with conserving the pollinators of rare plants is two-fold: often the pollinator of a particular plant is not known, and if it is, the biology and particular habitat needs of that pollinator may not be known.

A literature search for information about the pollination and pollinators of the covered plants in the Yolo HCP/NCCP yielded very little specific information. In some cases, for example, adobe-lily (*Fritillaria pluriflora*), pollinator information is only available for the genus or a different species, not the covered species itself. Given this it is difficult to make plant-specific suggestions or recommendations on management.

Table 4 (pages 50 – 54) summarizes what is known of the pollinators (or possible pollinators) of the covered plant species and their habitat needs.

There is limited published research on conserving pollinators related to rare plants. One exception is a paper by Sipes and Tepedino (1995) discussing the conservation of Ute lady's tresses (*Spiranthes diluvialis*), a rare orchid found in Colorado and Utah. The authors found that bumble bees were the most important pollinators, even though they visited for nectar only; the orchids' pollinaria were attached while the bees nectared. The authors recommended that management of the orchid must include consideration of bumble bees, particularly avoiding disturbance to habitat, protecting and retaining nest sites, providing flowers throughout bumble bee season (nectar and pollen when orchid not blooming, pollen while it is), and establishing an insecticide-free buffer during grasshopper control spraying. This last recommendation, obviously, is specific to the location of the orchid. Grasshopper control is likely not an issue for Yolo County, but pesticide use in the area adjacent to rare plants certainly is.

Key Points

- *Little is known about the pollinators of rare plants.*
- *Specific conservation strategies are hard to prepare without detailed information on the habitat needs of pollinators.*

Table 4. Yolo HCP/NCCP: Notes on pollinators of covered plant species

Plant	Likely pollinator	Source	Habitat notes
Adobe-lily, *Fritillaria pluriflora*	Bees	Krombein et al (1979) list *Fritillaria* as a pollen source for three spp. of Andrena. USFWS (2003) recovery plan for Gentner's fritillary mention *Lasioglossum* covered in pollen and "andrenid" bees visiting.	*Andrena* (mining bees): active in spring; solitary; excavates nests in sand or sandy loam; max foraging distance c. 300m. *Lasioglossum* (sweat bees): subsocial or solitary; excavates nests in sandy or silty loams; max foraging distance c. 150-200m.
Alkali milk-vetch, *Astragalus tener* var. *tener*	butterfly?, bees, moth?	Liston (1992) suggested butterflies due to flower morphology but there doesn't seem to be butterflies on the wing during bloom period. Also, *Astragalus* is generally pollinated by bees. Krombein et al (1979) list *Anthidium collectum*, *Hoplitis hypocrita*, and *Synhalonia tricinctella* as visitors to *A. tener*. Report on pollination of Lane Mountain milk-vetch prepared for Dept of Defense (2003) identified syrphid fly (*Eupeodes volucris*), *Anthophora* sp. (digger bees), and white-lined sphinx (*Hyles lineata*) as pollinators.	*Anthidium collectum* (carder bee): nests in abandoned burrows in the ground; lines cells with down from the leaves and stem of *Artemisia tridentata*; foraging distance likely to be 2-300m. *Hoplitis hypocrita*: nests in dead dry stems and also pre-existing tunnels in wood; likely foraging distance c. 200m. *Synhalonia tricinctella*: active in spring; solitary; ground nesting. *Anthophora* (digger bees): solitary; nests in loam or sandy loam soils; likely foraging distance 3-500m. Syrphid fly (*Eupeodes volucris*): larvae feed on aphids; adults drink nectar. White-lined sphinx (*Hyles lineata*): larvae feed on willow weed (*Epilobium*), four o'clock (*Mirabilis*), apple (*Malus*), evening primrose (*Oenothera*), elm (*Ulmus*), grape (*Vitis*), tomato (*Lycopersicon*), purslane (*Portulaca*), and fuschia.
Baker's navarretia, *Navarretia leucocephala* ssp. *bakeri*	Bees, bee flies, flower flies?	Grant (1965) lists many genera of bees visiting other species of *Navarretia*, also bee flies to two species and flower flies to one. The bee genera listed are *Andrena*, *Ancylandrena*, *Ashmeadiella*, *Anthophora*, *Exomalopsis*, *Osmia*, *Oreopasites*, and *Perdita*. Bee fly genera include *Anastoechus*, *Bombylius*,	See above for *Andrena* and *Anthophora*. *Ancylandrena*: similar to *Andrena* in nesting habitats and flight range. *Ashmeadiella*: solitary; different species nest in a variety

		Lepidanthrax, and *Lordotus*.	of substrates, including pre-existing tunnels in wood, spaces under rocks, and burrows in the ground; cells are lined with chewed leaf or petal pieces; foraging range unknown, but probably 3-500m. *Osmia* (mason bees, metallic leafcutter bees): solitary; most species nest in pre-existing tunnels in wood or crevices in rocks, divided with mud or chewed leaf pieces; likely foraging distance 150-600m. *Oreopasites*: cleptoparasites in nest of various species in the andrenid subfamily Panurginae. *Perdita*: solitary; nests in sandy soils, creating unlined cells; foraging range likely to be no more than 100m. Bee flies (Bombyliidae): egg laying needs vary between genera, but several, including *Bombylius*, lay eggs near ground-nesting bees; their larvae area external parasites of bee larvae.
Bent-flowered fiddleneck, *Amsinckia lunaris*	Bees, butterfly?	Krombein et al (1979) list numerous species from the following genera as pollen collectors from *Amsinckia*: *Andrena*, *Anthidium*, *Anthophora*, *Chelostoma*, *Duforea*, *Emphoropsis*, *Synhalonia*. Erhardt and Baker (1990) identify *A. lunaris* as an important nectar source for pipevine swallowtails.	See above for *Andrena*, *Anthophora*, and *Synhalonia*. *Anthidium* (carder bees): nests in pre-existing cavities in wood, rocks, walls, or in the ground; cells lined with down from the leaves and stem hairy plants; foraging distance likely to be 2-300m. *Chelostoma*: solitary; nests in abandoned beetle-tunnels in wood or hollow stems, divided into brood cells with soil or sand; likely foraging distance 150-300m. *Duforea*: solitary; nests in ground, lining cells with waxy substance. *Emphoropsis*: solitary; excavates nests in ground.
Brittlescale, *Atriplex depressa*	Wind	Freeman et al (2007): *Atriplex* are wind-pollinated, a feature common to most members of the Chenopodiaceae (goosefoot) family.	N/A
Colusa grass, *Neostapfia colusana*	Wind	Colusa grass is a member of the Poaceae. (USDA-PLANTS database; last accessed 10/16/09.) Grasses	N/A

		are all wind pollinated.	
Colusa layia, *Layia septentrionalis*	Bees?	Krombein et al (1979) list numerous species from the following genera as pollen collectors from *Layia*: *Colletes*, *Andrena*, *Nomadopsis*, *Perdita*, *Duforea*, *Augochlorella*, *Chelostoma*, *Osmia*, *Synhalonia*, and *Anthophora*	See above for *Andrena*, *Perdita*, *Duforea*, *Chelostoma*, *Osmia*, *Synhalonia*, and *Anthophora*. *Colletes* (polyester bees): solitary; excavates nests in sand or loamy sand, lines brood cells with cellophane-like material; likely foraging distance 3-400m. *Nomadopsis* (now a subgenus of *Calliopsis*): solitary; nests in sandy loam soils.
Delta tule pea, *Lathyrus jepsonii* var. *jepsonii*	Bees	No specific information. Nature Serve profile states "Zygomorphic flowers are probably adapted to bee pollination." Godt & Hamrick (1993) state that bumble bees are primary pollinator of *L. latifolius*.	N/A
Drymaria-like western flax, *Hesperolinon drymarioides*	small bees?, flies?	No specific information. Jepson manual (http://ucjeps.berkeley.edu/cgi-bin/get_JM_treatment.pl?4965,4966,4975; accessed 10/16/09) states that dwarf flax (*Hesperolinon*) is "Generally self-pollinated."	N/A
Ferris's milk-vetch, *Astragalus tener* var. *ferrisiae*	Bees	Liston (1992) suggested butterflies due to flower morphology but there doesn't seem to be butterflies on the wing during bloom period. Also, *Astragalus* is generally pollinated by bees. Krombein et al (1979) list *Anthidium collectum*, *Hoplitis hypocrita*, and *Synhalonia tricinctella* as visitors to *A. tener*. Report on pollination of Lane Mountain milk-vetch prepared for the U.S. Army (Charis Professional Services Corp 2003) identified syrphid fly (*Eupeodes volucris*), *Anthophora* sp., and white-lined sphinx (*Hyles lineata*) as pollinators.	See above (alkali milk-vetch) for notes.
Hall's harmonia, *Harmonia hallii*	Insect?	No information. Flower structure suggests it is visited by insects, probably small bees and flies.	N/A
Heckard's pepper-grass, *Lepidium latipes* var.	Bees, syrphid flies?	No information on this species or subspecies.	N/A

heckardii		Robertson & Klemash (2003) recorded insects from 25 families visiting slickspot peppergrass (*Lepidium papilliferum*). Bees in the families Colletidae, Halictidae, Apidae, and Anthophoridae (now a subfamily of Apidae) were considered to be the most significant pollinators. Syrphid flies (Syrphidae) were also recorded carrying pollen.	
Mason's lilaeopsis, *Lilaeopsis masonii*	Reproduction is primarily vegetative (ramets).	No information on this species. COSEWIC (2004) report on eastern lilaeopsis (*Lilaeopsis chinensis*) states: "Most plants are thought to arise from a rhizome through vegetative reproduction, which is thought to be the main means of reproduction necessary for maintaining populations. Self-pollination of flowers is also known to occur in a controlled environment, without artificial manipulation (Affolter 1985). Mechanisms of cross-pollination are not known."	N/A
Morrison's jewelflower, *Streptanthus morrisonii* spp. *morrisonii*	Bees, beefly	Krombein et al (1979) list many *Osmia* as visitors to *Streptanthus*, also *Anthidium* and *Dianthidium*. Dieringer (1991) says *Megachile comata* is effective pollinator of *S. bracteatus*.	See above for *Osmia* and *Anthidium*. *Dianthidium*: solitary; nests made of pebbles stuck together with resin, usually on the surface of a rock or twig; some species make nests in hollow twigs or under ground. *Megachile* (leafcutter bees): generally active in late-spring - summer; solitary; most species nest in pre-existing tunnels in wood, a few in loose soil; brood cells made from carefully cut leaf pieces; likely foraging distance 200-1000m.
Palmate-bracted bird's beak, *Cordylanthus palmatus*	Bees	Saul-Gershenz et al (2002): *Bombus vosnesenskii*, *Halictus tripartitus*, *Lasioglossum* sp.	See above for *Lasioglossum*. *Bombus vosnesenskii* (yellow-faced bumble bee): social, living in colonies of dozens of bees; nests in abandoned rodent nests under tussocky grass or in ground; colony founded in late winter by single female, grows through several generations during summer; workers active Feb - Oct; likely foraging distance 500-1500m. *Halictus* (sweat bee): solitary or subsocial; excavates nest

			in ground (sandy loam or loamy sand).
Rose mallow, *Hibiscus lasiocarpus*	Bees?	Krombein et al (1979) list *Melissodes agilis* as *Hibiscus* visitor with range to West Coast. *Melissodes bimaculata bimaculata* visits *H. lasiocarpus*, but is not found west of North Dakota. On the East Coast, *Ptilothrix bombiformis* and *Svastra atripes atrimitra* visit *Hibiscus*.	*Melissodes*: solitary; excavates nest in ground. *Ptilothrix*: solitary; excavates nests in sandy loam. *Svastra*: solitary; excavates nest in ground.
San Joaquin spearscale, *Atriplex joaquiniana*	Wind	Freeman et al (2007): *Atriplex* are wind-pollinated, a feature common to most members of the Chenopodiaceae (goosefoot) family.	N/A
Snow Mountain buckwheat, *Eriogonum nervulosum*	Bees, flies?	*Eriogonum* are widely recognized as important bee plants. Panjabi (2004) recorded bees (*Halictus*, *Lasioglossum*), flies (Bombylidae, Tachinidae), and wasps (*Euceceris*) visiting *Eriogonum brandegei* (Brandegee wild buckwheat).	See above for *Lasioglossum* and *Halictus*.
Solano grass, *Tuctoria mucronata*	Wind	Solano grass is a member of the Poaceae. (USDA-PLANTS database; last accessed 10/16/09.) Grasses are all wind pollinated.	N/A

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SECTION 5
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The Xerces Society for Invertebrate Conservation

The Xerces Society for Invertebrate Conservation is a nonprofit organization that protects wildlife through the conservation of invertebrates and their habitat. Established in 1971, the Society is at the forefront of invertebrate protection worldwide, harnessing the knowledge of scientists and the enthusiasm of citizens to implement conservation programs. Our work focuses on three principal issues: endangered species, healthy waters, and pollinator conservation.

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Cover photos
Main: pollinator habitat created on farmland in Yolo County; top left: yellow-face bumble bee approaching tomato flower; lower left: foraging sweat bee. (All photos by Mace Vaughan/Xerces Society.)