Conservation and Management of North American Bumble Bees

By

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This version corrects an error in Figure 1 that appears in the print version. Nunavut has been distinguished from Northwest Territories and the geographic projection has been changed to better depict northern North America.

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Executive Summary

This document provides a brief overview of the diversity, natural history, conservation status, and management of North American bumble bees, genus *Bombus*. The spring to late summer period of colony founding, build up, and production of reproductive individuals, followed by the overwintering of new queens provide the natural history basis for management considerations of the approximately 46 North American species. Most bumble bee species are currently not threatened or documented as declining except in areas of intensive agriculture. Eight species from three subgenera, however, have declined drastically during the last 15-20 years. These include three species that are obligate parasites on other declining species. The pathogen spillover hypothesis, which proposes that diseases from infected commercial colonies imported from Europe are infecting native populations of closely related species, may explain the sharp declines of most species. Other threats to bumble bees include climate change, loss of nesting and foraging habitats and pesticide use.

Management recommendations center on providing suitable nesting and foraging habitat in close proximity during the annual period of bumble bee activity. The major recommendations are:

Minimize exposure to pesticides.

- Avoid spraying while a crop is in bloom.
- When spraying is necessary, do so under conditions that promote rapid breakdown of toxins and avoid drift.
- Provide habitat for nesting and overwintering sites.
- Leave unplowed, undisturbed areas with logs and clumps of grass where bumble bees can find nesting and overwintering sites.
- When nesting sites are limited, consider providing artificial nest boxes.
- Assure continuity of nectar and pollen resources when bumble bees are active from spring to late summer.
- Increase abundance and diversity of wild flowers, suitable garden flowers, crops, and even weeds to improve bee density and diversity.
- Mow when bumble bees are dormant, if possible.
- When summer mowing is necessary, stagger fields to ensure that some flowers are always available.
- Time prescribed burns as recommended for mowing.
- Ensure that nesting habitat is in close proximity (500-800 m; 0.3-0.5 mi) to foraging habitat.
- Encourage agricultural authorities to place tight restrictions on the use of bumble bees for crop pollination to prevent the spread of diseases.

After reviewing the literature on bumble bee conservation and management, a number of gaps in our knowledge about bumble bee biology become apparent. These gaps, listed here to stimulate research in different regions of North America, include:

- How are bumble bee populations changing over time?
- How important are forested habitats for bumble bee diversity?
- What habitats do bumble bees use for overwintering?
- How do habitats, including human-altered ones, vary in quality for bumble bees?
- Do areas where severely declining species remain share common habitat or climatic features?
- What are the foraging needs and diet breadth of bumble bee species?
- How are bumble bees affected by fire and fire management?
- How do toxins affect bumble bees differently from honey bees?
- How broad is the threat of diseases from non-native bees spilling over to native bumble bees?

Introduction

Bumble bees are a familiar component of our terrestrial fauna. In the past, sighting a bumble bee may have elicited no more than a mental note to avoid getting stung or at most wonderment at how they can be active on high mountains or in cold climates. Today we pay them much more attention. Precipitous population declines have affected several species, creating cause for conservation concern. In addition, the loss of introduced honey bees (*Apis mellifera*) in both managed and feral colonies has increased the need for native pollinator species. Bumble bees are generalist pollinators, performing a key function in their ecosystems. They also form a significant portion of the native insect community that pollinates crops worth $3 billion each year in the United States (Losey and Vaughan 2006). For both of these reasons, land managers are increasingly interested in bumble bee conservation and management (Goulson et al. 2010).

This document summarizes recent information about bumble bee declines and their management in North America. By "bumble bee", we refer to species of the genus *Bombus* (Hymenoptera, Apidae), including the cuckoo bumble bees in the subgenus *Psithyrus*. We start with a brief overview of bumble bee diversity and natural history to provide context for the subsequent discussions. We then review the conservation status of bumble bees and the potential causes for their decline. Finally, we discuss considerations for managing for bumble bee diversity and abundance. Many of the resulting recommendations apply to other native pollinators besides bumble bees, especially ground-nesting bees. Much research on bumble bee conservation occurs in Europe, so we draw on this information where appropriate. The bibliographic references provide an entry point into the growing literature on bumble bees. Because scientific papers on bumble bees are being published with increasing frequency (Goulson et al. 2010), we recognize that this document provides a snapshot of the state of our current knowledge and that subsequent research will fill in some of the knowledge gaps we identify here.

Diversity

Of the 250 species of bumble bees recognized by taxonomists, approximately 46 occur in the U.S. and Canada (See Appendix for notes on species classification used here). All North American species are native to the continent. Most species have fairly broad ranges either east or west of the Rockies or across northern Canada, although a few such as *Bombus franklini* in northern California and southern Oregon have restricted ranges. Six species, including three of the four North American species in the subgenus *Alpinobombus* extend their ranges to Asia and Europe. As in the rest of the world, bumble bee diversity in North America is lowest in the southern lowlands and highest in cooler northern and mountain regions (Figure 1). For example, most bumble bees in Arizona occur only in the mountains. This pattern is opposite of most plant and vertebrate groups, which generally decrease in diversity with latitude.

In North America, the genus *Bombus* comprises eight subgenera. These are:

Alpinobombus (4 species)—Bumble bees of the arctic and high alpine areas.

Bombias (2 species)—A small group of bumble bees that occur primarily in open grasslands.

Bombus (5 species)—"Typical" bumble bees that occur in a variety of temperate and boreal habitats.

Cullumanobombus (5 species)—Mostly bumble bees of high alpine grasslands and semi-desert.

Psithyrus (6 species)—"Cuckoo" bees that parasitize nests of other bumble bees.

Pyrobombus (20 species) —The largest

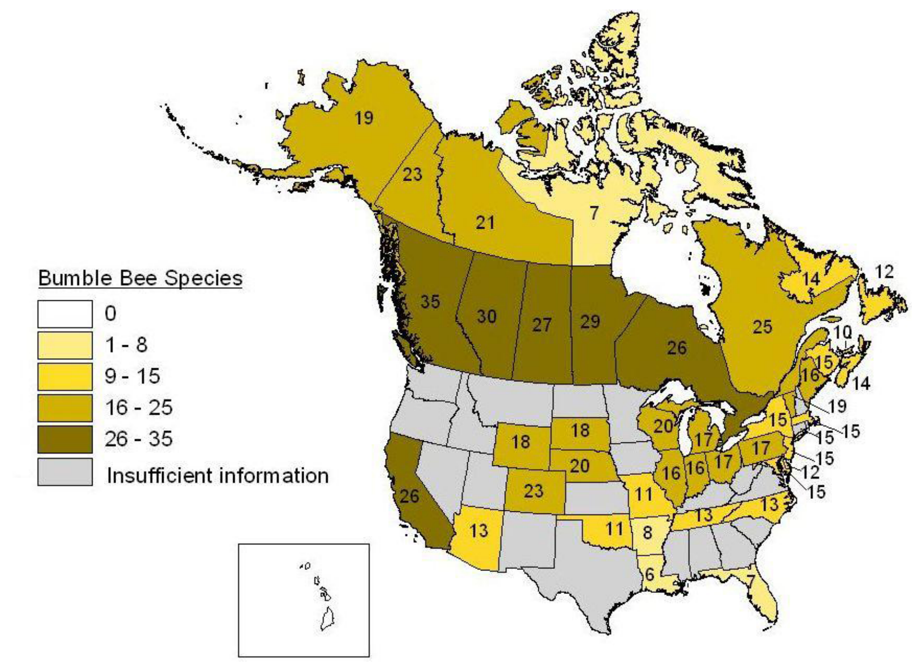

Figure 1. Documented bumble bee diversity in states or provinces for which adequate data are available. Figures for some states may still represent underestimates.

group of North American bumble bees, occurring from subtropical to boreal zones.

Subterraneobombus (2 species) — A long-tongued, underground-nesting group primarily occurring in open northern and montane areas, such as meadows.

Thoracobombus (2 species) — A widespread group occurring throughout the Northern Hemisphere as well as New World tropical mountains. In North America these species have long tongues and tend to nest above ground.

Natural History

Annual Cycle. — North American bumble bee species vary somewhat in their natural history. Bumble bees generally produce one generation per year. In the spring, queens emerge from hibernation to feed on flower nectar and search for nest sites, which may be above or below ground, or either, depending on the species (Thorp et al. 1983, Kearns and Thomson 2001, McFrederick and LeBuhn 2006). Bumble bees frequently inhabit abandoned rodent nests, probably because these structures insulate the bees from cold temperatures. Nests also tend to be constructed in areas with south facing exposures. Species nesting above ground may use long grass or hay stacks. A few species will use tree cavities or bird boxes as nest sites. In urban areas, bumble bees use spaces between cinder blocks, house foundations, abandoned furniture and decks as protection for their growing colonies.

Once they locate a suitable nesting site, a queen will modify it slightly and rear a brood (Kearns and Thomson 2001). A few weeks later, the first workers emerge. These workers tend the young, maintain the nest, and assume the food provision duties. The queen rarely, or never, leaves the nest again. Like most birds, bumble bees incubate their eggs and larvae to varying degrees with body heat to speed growth. This adaptation is probably among the reasons why bumble bees can thrive in cool conditions. As in all social bees, workers are females. Workers do not mate, but can reproduce by laying unfertilized eggs, producing males. At the end of the colony cycle, queens also lay unfertilized eggs that become males.

If nectar and pollen resources are adequate, the colony will produce males and new queens from about June to October, depending on the species, latitude and elevation. The males and queens feed and then mate. In the fall, the new queens locate a suitable site to overwinter (for example, mulch, rotting logs, or loose soil). The males, workers, and old queen all die by the onset of winter.

Foraging and nutrition. — The workers gather nectar and pollen to satisfy both their own nutritional needs and those of the nest. Adults depend on nectar for carbohydrates and gather pollen as a protein source for larvae. A queen bumble bee forages for nectar when she emerges in the spring, and for another month or more while she alone rears the first brood of workers, during which time she must also collect pollen to feed her young.

Although some bumble bees can forage up to several kilometers from their colonies in search of nectar and pollen, most species probably travel no more than 600-1,700 m (1/3 – 1 mi) to forage (Dramstad 1996, Hines and Hendrix 2005, Droege 2008, DeVore 2009). Presumably shorter foraging trips are both safer and more energy-efficient. The desert subspecies *B. pensylvanicus sonorus* can ascend as much as 1,000 vertical meters (0.6 mi) on a daily basis in search of food (Schmidt and Jacobson 2005).

North American bumble bees have been documented

Bombus insularis.
Photo James Strange

visiting hundreds of native and introduced plant genera (Robertson 1929, Mitchell 1962, Colla and Dumesh 2010). Some species are more generalized in their foraging preferences than others, but none appear to be highly specialized. In one study in Iowa prairie remnants, bumble bees foraged at 43 of 150 species of flowers available (Hines and Hendrix 2005). However, the extent of specialism at the colony or individual level is largely unknown.

Activity and cold tolerance.—Bumble bees are well known to fly when conditions are too cold for most other insects (e.g. cloudy or cool days, or early in the morning before other diurnal insects are active). They have a low surface area to volume ratio compared to other insects, are well insulated, and can generate body heat using their thoracic muscles. Bumble bees have been reported flying at slightly sub-freezing temperatures (Heinrich 1979). This ability to fly in cold weather is undoubtedly a factor in the success of bumble bees in cool to frigid climates throughout much of the world.

Bumble bees' seasonal activity differs among species. In the Mid-Atlantic states, activity starts about the end of March for the earliest species and becomes minimal in October (Droege 2008). Some early species such as *B. impatiens* are active into the fall, while others end their cycles in June or July (e.g., *B. bimaculatus*). Others, including *B. pensylvanicus*, emerge from their overwintering sites later in spring. The parasitic cuckoo species also tend to have shorter cycles. In northern New England, activity begins a month or more later and ends a few weeks earlier. A good rule of thumb in much of the eastern U.S. is that queens of the early-emerging species become numerous soon after red maple (*Acer rubrum*) blossoms drop and just before blueberry (*Vaccinium* spp.) and other early Ericaceae flower. Early emerging species also tend to be associated with woodland habitats, whereas the later emerging species tend to be associated with more open habitat (Colla and Dumesh 2010). The disappearance of bumble bees in the fall appears to be timed with the passing of native fall flowers and often precedes the first frost and leaf fall (D. Schweitzer, pers. obs.).

Nest usurpation.— Species of subgenus *Psithyrus* have no worker caste of their own. Females can reproduce only by taking over a nest of another species. Workers in usurped nests tend the offspring of the replacement queen. Entomologists have not fully documented the host breadth of North American *Psithyrus*. *Bombus insularis* preys on several subgenera, whereas *B. citrinus* is apparently a specialist on subgenus *Pyrobombus*. *Bombus ashtoni* and *B. suckleyi* seem to be specialists on the subgenus *Bombus* (Williams 2008b, Laverty and Harder 1988), and *B. variabilis* appears to be a specialist on *B. pensylvanicus*. Queens of subgenera *Alpinobombus* and *Bombus* sometimes usurp nests of their own or closely related species (Richards 1973, Goulson 2010).

Aggression.—Bumble bees occasionally sting when their nest is disturbed, but rarely do so otherwise. Queens and workers can sting, but, as in all bees and wasps, males cannot. To humans, the stings are briefly painful but not dangerous, except to a few people who develop serious allergic reactions. Bumble bee hives contain far fewer individuals than those of honey bees, and workers of most species are far less aggressive than wasps and hornets. Bumble bee stingers are not barbed as in honey bees and therefore do not remain in the victim. However, this also means a bumble bee can sting more than once when provoked. Some species, such as *B. impatiens,* are remarkably non-aggressive when nesting around buildings. This species is also safely managed for crop pollination, including in greenhouses.

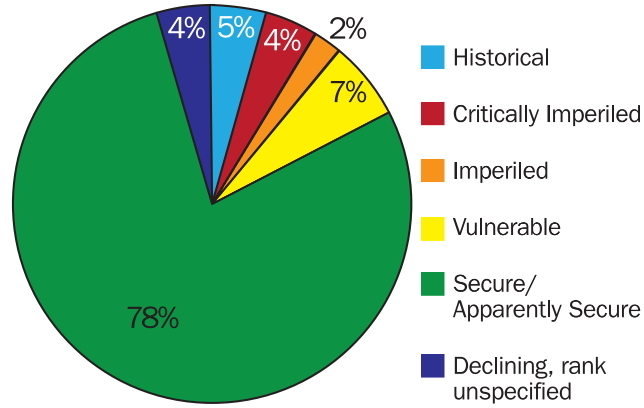

Figure 2. Proportion of North American bumble bee species at risk.

Workers of other species, such as *B. pensylvanicus*, and *B. fervidus* can be very aggressive around their nests (Thorp et al. 1983, Kearns and Thomson 2001), likely a behavioral adaptation to their above-ground nesting habits.

Pollination.—Bumble bees are important generalist pollinators of native plants and agricultural crops. The list of flowers visited by bumble bees is vast (Goulson 2010, Kearns and Thomson 2001, Thorp et al. 1983). Theoretical studies have underscored the importance of generalists in maintaining pollinator networks and communities of flowering plants (Memmott et al. 2004). One empirical study in Europe confirmed this prediction, demonstrating that the abundance of insect-pollinated plants declined in areas where bumble bees and other native bees had become extirpated (Biesmeijer et al. 2006).

Bumble bees exhibit a behavior known as "buzz pollination," in which the bee vibrates her wing muscles while holding the flower with her jaws, causing the release of large amounts of pollen. Growers of crops such as tomatoes, peppers, and cranberries prize this behavior because it leads to better fruit set than pollination by honey bees. A commercial bumble bee industry has emerged to capitalize on buzz pollination for greenhouse tomato farmers (Velthius and van Doorn 2006), a development that may have had the unintended consequence of causing the demise of several native bumble bees (see *Causes of Declines*).

Conservation Status

Declines in bumble bees and other pollinators worldwide are documented in numerous studies (Goulson et al. 2005, Kluser and Peduzzi 2007, Colla and Packer 2008, Brown and Paxton 2009, Evans et al. 2008, Williams et al. 2009, Winfree 2010, Committee on the Status of Pollinators in North America 2007, Cameron et al. 2011a). Regional studies with adequate baseline data invariably show that some bumble bees are in recent decline (Giles and Ascher 2006, Colla and Packer 2008, Grixti et al. 2009, Cameron et al. 2011b). However, the status of many species throughout their ranges is poorly known. Habitat loss in areas with intensive agriculture can cause regional extirpations of formerly common species (Grixti et al. 2009, Williams et al. 2009, Winfree 2010).

To determine the conservation status of North American bumble bees, NatureServe assessed all species according to their standard assessment factors, including rarity, threats, and population trends (Master et al. 2009). Of the North American bumble bee species, nearly four-fifths are globally secure (Figure 2, Appendix). Severe declines in North America are so far limited to eight species in three subgenera, including all four North American endemic species of subgenus *Bombus* (the species *B. moderatus* is apparently not declining, but its status is poorly documented), *B. pensylvanicus*, and three species of subgenus *Psithyrus*. In subgenus *Bombus, B. franklini* may already be extinct and *B. affinis*, a common species in the early 1990s, may be extirpated in 90% of its range (Williams and Osborne 2009; Figure 3). The latter species is now listed as Endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). The status of the cuckoo bees, subgenus *Psithyrus*, is similar to their hosts. Two species that commonly parasitize species in *Pyrobombus* appear to be doing well, while three that parasitize species of subgenera *Bombus* and *Thoracobombus* are in serious declines and may have disappeared from most if not all of their ranges.

One species in the subgenus *Pyrobombus* appears to be declining in some parts of its range (Colla and Packer 2008, Grixti et al. 2008), but not as sharply as other declining species. This species, *B. vagans*, is still regularly found across its range. Several other *Pyrobombus* have been documented as increasing. The North American species in subgenera *Alpinobombus*, *Cullumanbombus*, and *Subterraneobombus* all appear to have stable populations although rigorous range-wide monitoring data are mostly lacking.

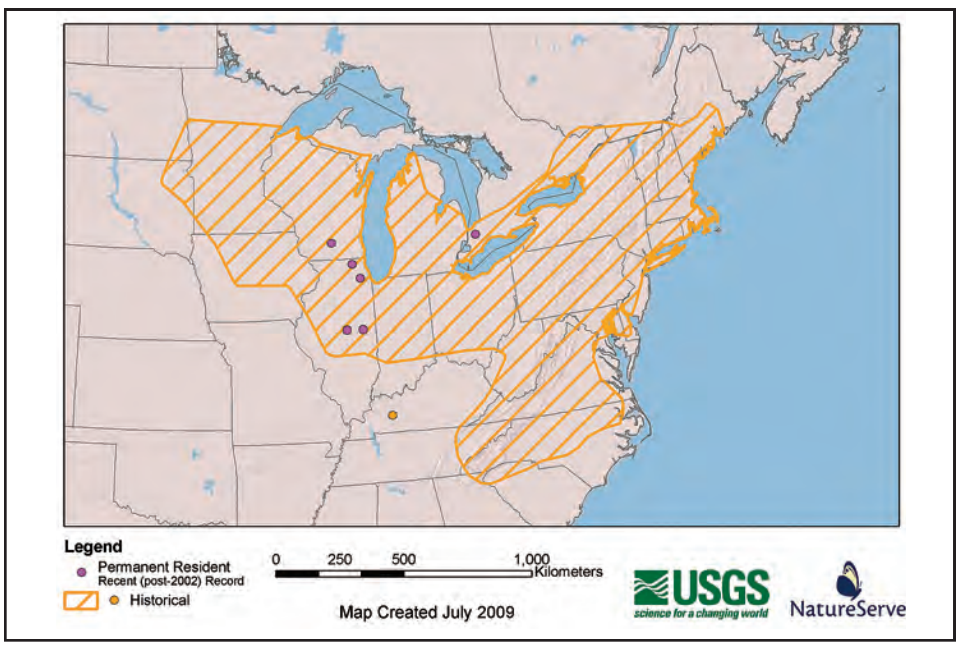

Figure 3. Distribution of the Rusty-patched Bumble Bee, *Bombus affinis*. Source: NatureServe 2009.

Causes of Declines

Hypotheses about bumble bee declines in North American can be divided into two classes. The first class, relating to the direct and indirect effects of climate change and habitat loss and degradation due to agricultural intensification, can explain gradual population declines and range restrictions in bumble bees worldwide. A second class of hypotheses addresses the swift and widespread declines restricted to endemic North American species. These hypotheses center on the "spillover" of pathogens from bumble bees imported from overseas.

A recent meta-analysis of bumble bees in North America, Europe and China has suggested that species which emerge later in the year or have narrow climatic niches are likely more vulnerable to these above threats (Williams et al. 2009). Hypotheses that failed to explain vulnerability include competition with congeners, food specialization, phenology, body size, and range extent. However, some of these factors may be more important regionally than in global analyses. For example, one European study showed that species utilizing smaller numbers of pollen sources have become rarer since the middle of the twentieth century (Kleijn and Raemakers 2008). A brief summary of the major hypotheses follows.

Habitat loss.—Because bumble bees often forage in open, disturbed habitats, the effects of habitat loss are harder to measure than for animals that depend on more natural habitats. Some agricultural habitats, such as hay meadows and pastures, are suitable to bumble bees (Carvell 2002, Goulson 2010, McFrederick and LeBuhn 2006, Rao and Stephen 2010). Some species can even prosper in urban gardens and parks (McFrederick and LeBuhn 2006, Matteson et al. 2008, Matteson and Langellotto 2009). The spread of Eurasian clovers (*Trifolium*) and vetches (*Vicia, Coronilla*) has benefited some butterflies (Schweitzer 2006) and presumably bumble bees as well. Nevertheless, intensive agriculture has caused local and regional declines in the Midwest as well as Europe (Grixti et al. 2009, Williams et al. 2009). The mismatch between the time scale of habitat loss (before the mid 20th century) and rapidly declining North American species (since the mid 1990s) suggests that habitat loss is unlikely to explain these declines (Grixti et al. 2009).

Climate change.—Although climate change has been suggested as a cause of declines and may be affecting bumble bees in some places, there is as of yet little direct evidence that climate change is responsible for global declines of widespread species. In North America, most species occur (at least formerly) in a wide array of climates, ranging through more than ten degrees of latitude and some from coast to coast. Moreover, most of the North American species that have declined precipitously had large ranges. Even *B. affinis* ranged from Maine to Georgia and the Dakotas (Figure 3). Despite this large range, members of the subgenus *Bombus* do seem to be somewhat climatically restricted as they occur mostly at high elevations in southern parts of their ranges. Range breadth, combined with high mobility and dispersal ability, and the observed rapidity of declines seem to argue against climate change as being a major factor in recent dramatic declines. However, more research is needed to further investigate this.

Species that may prove to be vulnerable to climate change are those that occupy narrow ranges near the Pacific coast, such as *B. crotchii* in oak woodland, chaparral, and deserts and *B. sitkensis* and *B. caliginosus* in cooler coastal climates. Elsewhere, isolated high alpine populations of several species may disappear due to climate change.

Phenology of queen emergence.—Some authors suggest that species in which queens become active later in the season are at a disadvantage due to competition for nest sites and vulnerability to losses of food plants that are important in mid to late colony development (Williams et al. 2009). In North America, nest competition is documented in urban areas of San Francisco where the early *B. vosnenskii* apparently excludes the later *B. caliginosus* and *B. sitkensis* from the limited supply of subterranean nest sites (McFrederick and LeBuhn 2006). However, none of these species appear to be declining globally, and there is no evidence that phenology is linked to declines of bumble bees in North America where both early- and late-emerging species are among the five non-parasitic species that are in severe decline.

Tongue length and foraging ecology.—Bumble bees with long tongues are generally more specialized foragers. Although some authors have suggested that specialists (and therefore longer-tongued species) should be more likely to decline, no such pattern has emerged in North America (Grixti et al. 2009, Williams et al. 2009, Winfree 2010). One complication with relating tongue length with foraging is that tongue length is individually variable with body size, whereas foraging preferences are largely learned (Kearns and Thomson 2001). Direct measures of foraging specialization, however, indicate a weak relationship with declines in Europe (Kleijn and Raemakers 2008).

Pesticides.—Direct exposure to pesticides can kill queen or worker bumble bees, and cause minor to lethal effects to larvae that feed on pesticide-contaminated food. Some pesticides, such as spinosad, cause no direct mortality but instead reduce foraging efficiency (Goulson 2010). The toxicity of specific pesticides is better known for honey bees than bumble bees, but the available data suggest that toxicity to bumble bees is generally similar to that of honey bees (Alston and Tepedino 2000). An application of pesticides to control spruce budworm in New Brunswick illustrates the potential effects of pesticides on bumble bees and other pollinators. In this case, the pesticide application caused blueberry crop losses due to reduced availability of pollinators. In addition, reduced pollination of nearby native species caused a local wild berry shortage and consequently increased the number of birds foraging on cultivated blueberries (Kevan 1974). Bumble bee colonies can absorb the loss of a few workers to pesticides in summer, but worker loss can more seriously impact colony survival in spring before colonies have built up significant numbers of workers (Goulson 2010). Additionally, sub-lethal compounds may accumulate in the colony and affect the overall reproductive fitness of the colony. Species which may be more vulnerable to pesticide use include the above ground nesting species (e.g., subgenus *Thoracobombus*) and species with long colony cycles that can accumulate toxins over the spring, summer and fall. Pesticides likely contribute to bumble bee declines in areas of intensive agriculture, but are unlikely to be responsible for rapid, widespread declines (Colla and Packer 2008, DeVore 2009).

Pathogen spillover.—Currently, the most compelling hypothesis to explain rapid declines is the spillover of pathogens from managed to wild bumble bees (Colla et al. 2006, Otterstatter and Thomson 2008, Williams et al. 2009, Goulson 2010, Meeus et al. 2011). Field documentation of pathogen spillover and related modeling show waves of parasites and pathogens spreading out from infested commercial hives at multiple locations. Moreover, the timing of decline onset in native bumble bees corresponds with the accelerated transportation of bumble bee colonies in the mid and late 1990s after the development of techniques for domestication. The actual pathogens implicated are the protozoans *Crithidia bombi* and *Nosema bombi*, although other pathogens may also play important roles (Meeus et al. 2011). Unfortunately, due to the lack of both stable populations of declining species in affected regions and information about native pathogens, researchers cannot directly test the effects of these pathogens relative to other threats.

Conservation and Management

To complete their annual cycle, all bumble bees need nesting habitat, flowers for nutrition, and a place for queens to overwinter. They must also avoid lethal and sublethal chemicals and pathogens. We know very little about overwintering needs, so the following summary of the growing literature on bumble bee conservation and management will focus on nesting and foraging needs.

General habitat needs.—Bumble bees can be atypical targets for conservation efforts. In contrast to many other rare or endangered species, bumble bees may not require forest cover or even natural habitats to maintain large and species-rich populations. Especially in eastern North America, a hayfield or powerline cut with plentiful wildflowers may be all that is necessary for populations of a number of species (Russell et al. 2005). In fact, the endangered species *Bombus affinis* was quite common in urban areas before its collapse (Colla and Dumesh 2010). Regardless of the region, management activities should be aimed at improving flower availability and providing potential nesting habitat (Blake et al. 2011). Specific actions taken to achieve this objective will vary depending upon whether management is directed at agricultural, urban, or more natural lands.

Several studies have found bumble bee management to be compatible with agricultural practices. Moderate grazing can be beneficial to bees in the western U.S. (DeBano 2006, Black et al. 2007). In the northwestern U.S., agricultural areas with blueberry (*Vaccinium* spp.) and red clover (*Trifolium pratense*) can support abundant populations of several species of bumble bees (Rao and Stephen 2010). In any region, the keys are maintaining a reliable supply of nectar throughout the breeding season, providing unplowed nesting habitats, and limiting exposure to insecticides. Organic farming practices may help promote bumble bee populations, although other factors can confound research results (Winfree 2010). Some bumble bee species can benefit from foraging in suburban and urban gardens, (Frankie et al. 2009, McFrederick and LeBuhn 2006). Manicured lawns and golf courses with heavy pesticide use and devoid of flowers are among the least useful nesting and foraging habitats.

On more natural lands, management should focus on maintaining diverse assemblages of primarily native flora, such that flowers would be constantly available throughout the nesting season. In prairie regions, restoration of native prairie species and elimination of plowing, for example along roadsides, can result in richer bumble bee faunas (Hopwood 2008).

The extent to which bumble bees use forests is a major knowledge gap for eastern North American bumble bees, although some species such as *B. vagans* seem to be associated with wooded habitats (Colla and Dumesh 2010). Similarly, the effects of standard forest management practices, such as thinning or controlled burning, on bumble bees are mostly undocumented. Opening forest canopies often allows more flowering of understory plants, which should favor bumble bees (but see *Nesting Habitat* for the danger posed by fires).

Food supply.—Observations of nest failure due to food limitation highlight the need for a reliable nectar and pollen supply when bumble bees are active from spring to late summer (Goulson 2010). In both natural and anthropogenic habitats, multiple nectar plants with a succession of overlapping bloom periods are usually required to satisfy this requirement. In some cases foraging habitats as well as plant species will vary seasonally. In

Providing Artificial Nests for Bumble Bees

Where nesting sites are limited, artificial nests are an option to increase bumble bee populations (MacCulloch 2007, Kearns and Thomson 2001). The basic artificial nest is a box fitted with a plastic pipe as an entrance tunnel. The box can be made out of wood (such as exterior grade plywood) or Styrofoam (such as an old cooler). Dimensions vary but 8 x 8 x 6 inches (20 x 20 x 15 cm) is standard. The entrance hole should be ¼ inch (0.65 cm) in diameter. The box can be placed on the ground or 6-12 inches (15-30 cm) underground with the entrance tube connecting the box to the surface. Southern exposures, especially on a slight embankment, are best. Whatever the design or placement, the box should contain insulation in the form of upholsterer's cotton or polyester fiberfill. Reported reasons for failure include ants, excess moisture, or mammalian predators, so managers should be on the lookout for these problems.

habitats managed as natural lands, native flowering plants will be important. In other contexts, non-native crops, pasture plants, weeds, and garden flowers may all be good food sources. In some agricultural areas successive crops will provide a reliable supply of pollen and nectar throughout the season, but in other contexts supplemental sources such as native vegetation may increase bumble bee abundance and diversity (DeVore 2009). Overall flower abundance and flowering plant species richness appear to be important for bumble bee richness (Carvell 2002). Variation in tongue length among bumble bee species causes variation in preferences for flower types. Maintaining abundant, phenologically and morphologically diverse plants is therefore a prudent management approach.

Because of the diversity of habitats and bumble bee faunas across North America, we cannot make specific generalizations about particular plants that promote bumble bee diversity and abundance. Several studies list plants visited by bumble bees, including declining species, in particular regions (USFWS 1999, 2008; Evans et al. 2008; Hopwood 2008; Tuell et al. 2008; DeVore 2009, Colla and Dumesh 2010). Examples of plants favored by long-tongued species are legumes, such as red clover, and *Delphinium* (Pyke 1982).

The effect of mowing during the growing season on bumble bee colony health is debatable but in practice is probably detrimental to the pollinator community. Mowing virtually eliminates nectar for a period of days or longer and therefore can stress colonies. However, summer mowing can stimulate re-flowering that benefits the bees later in the season (Noordijk et al. 2009). In areas where mowing is essential for economic activity, staggering cutting times will help ensure a continuous food supply (Noordijk et al. 2009).

Nesting habitat.—In some places, nest sites can be a limiting resource and may affect both the abundance and diversity of bumble bees (Kearns and Thomson 2001, McFrederick and LeBuhn 2006). Managers should remember that some bumble bees nest underground whereas others nest above ground. Reducing tillage or leaving unplowed strips of vegetation will usually increase the availability of nesting habitat for ground-nesting species (Hopwood 2008, DeVore 2009). Fence rows, roadsides, powerline cuts, and fallow fields can also serve this purpose. In areas with limited nesting habitat, managers can increase bumble bee abundance by providing artificial nests.

Above-ground nesters often use abandoned rodent and ground-nesting bird nests (Kearns and Thomson 2001, McFrederick and LeBuhn 2006). Thus any management practice that promotes rodent and ground-nesting bird populations, including reducing numbers of feral and domestic cats (*Felis catus*), could have side benefits for bumble bees. When rodent and bird nests are not available, logs, stumps, snags, and clumps of grass are often suitable (DeVore 2009). Recognizing that some bumble bees nest above ground, managers should be careful not to set mower blades low enough to destroy these nests. Also, they should be aware that fires are likely to destroy above ground nests.

Landscape context.—Landscape context may be important for bumble bee management, but an impediment to assessing factors such as habitat fragmentation is defining unsuitable habitat. Bumble bees require three different habitat types (i.e. foraging, nesting and overwintering) in close proximity to each other, adding further complexity. Bumble bee species vary in whether anthropogenic habitats are favorable or unfavorable habitats (McFrederick and LeBuhn 2006, Goulson 2010). Nevertheless, studies typically find more bumble bees in landscapes with patches of uncultivated lands than in intensive agricultural areas. In most cases, the availability of floral resources within 500-800 m (0.3-0.5 mi) of survey points explained much of the variance in bumble bee communities (Hines and Hendrix 2005, McFrederick and LeBuhn 2006, Hatfield and LeBuhn 2007, Holzschuh et al. 2007, Öckinger and Smith 2007, Hopwood 2008, Goulson 2010, Winfree 2010, Carvell et al. 2011). A study near Boston, Massachusetts, found that bumble bees are reluctant to cross roads and railroads when foraging, implying that transportation corridors may be detrimental (Bhattacharya et al. 2003). The emerging consensus is that bumble bees need nesting and foraging habitat in relatively close proximity without dispersal barriers between them.

Pesticides.—Pesticide use reduces pollination by bumble bees and may even eliminate them from agricultural areas (Goulson 2010). However, because most research on toxicity and effects of pesticides are performed on honey bees (Girolami et al. 2009), the extent to which the results of these studies are applicable to bumble bees is unknown. We know, however, that insecticides are generally of greater concern than herbicides. Most herbicides probably do not harm bees directly, but their use can greatly reduce nectar supplies, which in turn limit bumble bee colony success. Absorbing insecticide toxins through the exoskeleton, drinking toxin-tainted nectar, or gathering contaminated pollen or microencapsulated insecticides can kill bumble bees directly (Vaughan and Black 2007). Bumble bees can also carry toxins on pollen and nectar to the hive where they can kill adults and kill or cause developmental delays in larvae. Sublethal doses of toxins can cause colony failure by causing impaired navigation, flight difficulty, decreased foraging efficiency or inability to tend young in the hive (Vaughan and Black 2007, Mommaerts et al 2010).

The best means of preventing negative impacts of pesticides on bumble bees is to avoid applying insecticides to patches of flowers that attract bumble bees (Vaughan and Black 2007, Black et al. 2007). When pesticides must be used, dosage and application method can affect toxicity to bees. Growers may apply pesticides early or late in the day to avoid contact with honey bees, but bumble bees may still be active at these times. The best alternative is to prevent drift of pesticides from target crops to foraging and nesting habitats by application from the ground, when winds are calm, and with solutions or soluble powders rather than dusts or wettable powders. Growers should avoid application to crops in bloom when bumble bees are most likely to be present. Pesticides tend to lose their toxicity quicker at warmer temperatures and on dewless nights, so application should take place during these conditions.

Bombus vagans. Photo Sheila Colla

The impact of broad scale spraying for pest control in natural habitats on bumble bees is mostly unknown. Spraying for grasshoppers in western North America, gypsy moths (*Lymantria dispar*) in the east, spruce budworm (*Choristoneura fumiferana*) in the north, and mosquitoes in the south and east are examples of these practices. The pesticide used, dosage, time of spraying, and application method may all influence toxic effects on bumble bees (Goulson 2010). Some pesticides, such as *Btk*, Gypchek, pheromone flakes, and the fungus *Entomophaga maimaiga*, used to control gypsy moths do not affect bees (Schweitzer 2004). The chitin inhibitor Dimilin® (Diflubenzuron) does not kill adults, but is toxic even at low concentrations to larvae when they molt (Mommaerts et al. 2006). Neonicotinoids have negative impacts on bees under lab conditions (Mommaerts et al. 2010), but their effects on wild bumble bee populations are unknown.

Diseases.—Unfortunately, little can be done to address what appears to be the greatest threat to the most imperiled North American bumble bees: protection from non-native pathogens and parasites, including *Nosema* and *Crithidia*. These diseases cannot be controlled even in commercial hives, leaving few options to protect wild bumble bees. The best approach is to minimize contact between wild bumble bees and commercial bees. Suggestions include using mesh to prevent the escape of managed bumble bees through venting systems and proper disposal of colonies after use. Also, agricultural authorities should place tight restrictions on the importation of bumble bees, whether of native or non-native species, that have been reared outside of North America.

Notes about Monitoring

Sound management includes monitoring to measure the success of conservation efforts. Bumble bee monitoring is possible, but requires more training and experience than for many other organisms. The USGS Patuxent Wildlife Research Center is working to develop guidelines for monitoring native bees, including bumble bees. The major challenges to monitoring bumble bees are identification difficulty and low nest visibility.

Identification.—Identification of bumble bees is challenging in many areas such that positive identification requires skill and experience. Distinguishing look-alike species (e.g., the forms of *B. bifarius* and *B. melanopygus* that occur on the Pacific coast) and bumble bee mimics often requires a trained entomologist. Male bumble bees are particularly difficult to identify to the species level. Even experienced field zoologists should collect voucher specimens and seek expert help to confirm identifications. If you are interested in learning bumble bee identification, consider taking a course such as the one offered by the USGS Patuxent Wildlife Research Center. Alternatively, you can work with a local entomologist to learn the species that may occur in your area. Websites are also available (see *Internet Resources*) but these are best used at least initially with someone familiar with your local species. In addition, the U.S. Forest Service in collaboration with the Pollinator Partnership has just released a guide, *Bumble Bees of the Eastern United States*, to facilitate the identification of eastern species (Colla et al. 2010).

Nest visibility.—Bumble bee nests are notoriously difficult to locate and consequently are overlooked. The number of bees entering and exiting is modest to the point of not calling attention to a nest's location. In addition, workers of most species do not readily give away their location by attacking when a person or other large animal is near their nest. Thus studies monitoring nest density may suffer from low detection rates.

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Internet Resources

The Bee Genera of Eastern Canada.—A useful reference for distinguishing the bee genera of eastern Canada. (http://www.biology.ualberta.ca/bsc/ejournal/pgs_03/pgs_03.html)

Bombus *Bumblebees of the World*.—Williams (2008a) checklist of the species of the world. (http://www.nhm.ac.uk/research-curation/research/projects/bombus/index.html)

Bug Guide.—A resource for bumble bee identification, images, and information. (http://bugguide.net/node/view/3077)

Bumble Bee Conservation.—Links to many useful conservation documents, created by the Xerces Society. (http://www.xerces.org/bumblebees/)

Bumblebee Pages.—General bumble bee information for beginners. (http://www.bumblebee.org/)

Guide to Bumble bees.—An online key most useful for species of the eastern U.S. (http://www.discoverlife.org/mp/20q?guide=Bumblebees)

Plants for Pollinators.—Recommendations on plants that will enhance pollinator populations. (http://plant-materials.nrcs.usda.gov/technical/pollinators.html)

Pollinator Partnership.—Information on protecting pollinators through conservation, education, and research. (http://www.pollinator.org)

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Appendix – Conservation Status of North American Bumble Bees

Taxonomy follows Williams (2008a), except that we follow other authorities in recognizing *Bombus occidentalis* as distinct from *B. terricola* (Thorp and Shepherd 2005, Rao and Stephan 2007). Most species do not have English names. Rapidly declining species are indicated with an asterisk (*). Conservation status is denoted by the NatureServe Grank scheme, where "G1" indicates the highest level of imperilment and "G5" the most secure. "GU" indicates that information on current population size and distribution are not comprehensive enough to specify a rank, although all bumble bee species with this designation are declining. "Q" denotes a species of questionable taxonomic validity. A "?" indicates lower confidence in the rank.

Taxonomic notes.—The western North American form *Bombus californicus*, not recognized by Williams (2008a) and not listed here, is considered by some authorities to be distinct from *B. fervidus*. Taxonomists disagree over whether *B. jonellus* and *B. lapponicus* occur in North America, but we include these two species following Williams (2008a). We include *B. moderatus* (= *B. lucorum* complex of Williams 2008a, in part) following Bertsch et al. (2010). We also omit the Eurasian *B. distinguendus*, which occurs on Attu Island, Alaska.

Scientific Name (subgenus)	English Name	Grank	Range
Bombus (Alpinobombus) balteatus		G5	Circumpolar, south to New Mexico
Bombus (Alpinobombus) hyperboreus		G5	Circumpolar in high arctic
Bombus (Alpinobombus) neoboreus		G4G5	Arctic regions of western Canada and Alaska
Bombus (Alpinobombus) polaris		G5	Circumpolar in high arctic
Bombus (Bombias) auricomus	Black and Gold Bumble Bee	G4G5	Much of North America south of the arctic
Bombus (Bombias) nevadensis		G4G5	Western North America
*Bombus (Bombus) affinis**	Rusty-patched Bumble Bee	G1G2	East central North America (see Figure 3)
*Bombus (Bombus) franklini**	Franklin's Bumble Bee	G1	Southern Oregon to northern California
Bombus (Bombus) moderatus		G5	Western Canada and Alaska
*Bombus (Bombus) occidentalis**	Western Bumble Bee	G2G3	Western North America
*Bombus (Bombus) terricola**	Yellowbanded Bumble Bee	G2G4	Southern Canada, northern U.S., and in mountains south to North Carolina
Bombus (Cullumanobombus) crotchii		G3G4	Central California to Baja California del Norte, Mexico
Bombus (Cullumanobombus) fraternus	Southern Plains Bumble Bee	G4	Central and coastal plain of eastern U.S.
Bombus (Cullumanobombus) griseocollis	Brown-belted Bumble Bee	G5	Southern Canada and most of the U.S.
Bombus (Cullumanobombus) morrisoni	Morrison's Bumble Bee	G4G5	Western North America
Bombus (Cullumanobombus) rufocinctus	Red-belted Bumble Bee	G4G5	Widespread in North American except for the southeastern U.S.
*Bombus (Psithyrus) ashtoni**	Ashton's Cuckoo Bumble Bee	GH	Across northern North America
Bombus (Psithyrus) citrinus	Lemon Cuckoo Bumble Bee	G4G5	Eastern North America
Bombus (Psithyrus) fernaldae	Fernald's Cuckoo Bumble Bee	GU	Northern North America

Scientific Name (subgenus)	English Name	Grank	Range
Bombus (Psithyrus) insularis	Indiscriminate Cuckoo Bumble Bee	G4G5	Northern and western North America
*Bombus (Psithyrus) suckleyi**	Suckley's Bumble Bee	GH	Western North America
*Bombus (Psithyrus) variabilis**	Variable Cuckoo Bumble Bee	GU	Eastern and southwestern U.S., and disjunctly from southern Mexico to Honduras
Bombus (Pyrobombus) bifarius		G4G5	Western North America
Bombus (Pyrobombus) bimaculatus	Two-spotted Bumble Bee	G5	Eastern North America south of the boreal zone
Bombus (Pyrobombus) caliginosus		G4?	Coast ranges from Washington to California
Bombus (Pyrobombus) centralis		G4G5	Western North America
Bombus (Pyrobombus) flavifrons		G5	Northern and western North America
Bombus (Pyrobombus) frigidus		G4?	Northern and western North America
Bombus (Pyrobombus) huntii		G5	Western North America
Bombus (Pyrobombus) impatiens	Common Eastern Bumble Bee	G5	Eastern North America south of the boreal zone; introduced in California and Mexico
Bombus (Pyrobombus) jonellus	Heath Bumble bee	G5	Alaska, Canada (east to Hudson Bay), and northern Eurasia
Bombus (Pyrobombus) lapponicus		G5	Eurasia and Alaska
Bombus (Pyrobombus) melanopygus		G4G5	Western North America
Bombus (Pyrobombus) mixtus		G4G5	Western North America
Bombus (Pyrobombus) perplexus	Confusing Bumble Bee	G5	Western North America
Bombus (Pyrobombus) sandersoni	Sanderson's Bumble Bee	G4G5	Northeastern North America
Bombus (Pyrobombus) sitkensis		G4G5	Western North America
Bombus (Pyrobombus) sylvicola	Red-tailed Bumble Bee	G5	Western North America
Bombus (Pyrobombus) ternarius	Tri-colored Bumble Bee	G5	Northern and eastern North America
Bombus (Pyrobombus) vagans	Half-black Bumble Bee	G4?	Southern Canada and northern U.S.
Bombus (Pyrobombus) vandykei		G4	Southern Washington to southern California
Bombus (Pyrobombus) vosnesenskii	Yellow-faced Bumble Bee	G5	Western North America
Bombus (Subterraneobombus) appositus		G4G5	Western North America
Bombus (Subterraneobombus) borealis	Northern Amber Bumble Bee	G4G5	Southern Canada and northern U.S. from Alberta and the Dakotas east
Bombus (Thoracobombus) fervidus	Yellow Bumble Bee	G4?	Southern Canada and most of U.S. except southeast.
*Bombus (Thoracobombus) pensylvanicus**	American Bumble Bee	G3G4	Eastern and southwest North America

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Front cover left, *Bombus impatiens male,* photo Sheila Colla.

Front cover right, bee aloft, photo Ron Panzer.

Back cover left, *Bombus perplexus,* photo Sheila Colla.