SURVEY OF *BOMBUS* SPECIES (HYMENOPTERA: APIDAE) NEAR AGRICULTURAL LANDS IN INTERIOR ALASKA

A

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ABSTRACT

Major world pollinators include bees, beetles, flies, butterflies, birds and bats, all of which help pollinate over 75% of Earth's flowering plant species and nearly 75% of the crops. In arctic and subarctic regions, bumble bees are considered important pollinators; however, immediate concerns involving climate change, colony collapse disorders in honey bees, and lack of faunistic insect studies in Alaska emphasize the need to study bumble bees in interior Alaska. I identified seventeen species of bumble bees from three localities: Delta Junction, Fairbanks, and Palmer, Alaska. Not all species were recovered from all localities and species richness and relative abundance varied by years. Delta Junction displayed the highest relative bumble bee abundance representing approximately 50% of the overall total of bumble bees collected during the two year study. Overall, the most common bumble bees near agricultural lands were *B. centralis, B. frigidus, B. jonellus, B. melanopygus, B. mixtus,* and *B. occidentalis.* Their populations and local diversity were highly variable from year to year. A species believed to be in decline in the Pacific North West states, *B. occidentalis*, was collected in relative abundance up to 13.5%; this species was collected from the three sites studied. Preliminary data indicates that bumble bees were found to be affected by the presence of *Nosema* and nematodes with infection rates up to 12.5 and 16.7% for *Nosema* and nematodes respectively. Of the eight species affected by parasites, *B. occidentalis* displayed the highest *Nosema* infection, while *B. centralis* was the species most affected by nematodes.

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CHAPTER 1. INTRODUCTION

The United States Department of Agriculture (USDA) and United States Forest Service (USFS) estimate that more than 150 food crops in the US, including almost all fruit and some grain crops, depend on insect pollinators (USFS and USDA 2010). The estimated worth of these pollinators is more than $10 billion per year (USFS and USDA 2009). Of the major food crops grown in the United States, common honey bees (*Apis mellifera* L.) are typically given sole credit for pollination, but native bees, butterflies, moths, and flies play roles in crop pollination that are often as or more significant than those managed by honey bees (Roubik 1995; Buchmann and Nabhan 1996). Native bees, such as bumble bees may be responsible for almost $3.07 billion of fruits and vegetables produced in the US (Losey and Vaughan 2006). No published estimates on the value of bumble bee pollination for crops in Alaska are available.

According to Morse and Calderone (2000), the most common domesticated pollinator species used in North America, *A. mellifera*, was reported to provide services to crops worth an estimated $14.8 billion annually. Imports of pollinators are becoming problematic with high transportation and packaging costs, disease, and concerns about non native species affecting native beneficial insects and habitat. Also, honey bees are undergoing extensive die-offs which do not appear to have a single underlying cause (USDA-ARS 2009). This phenomenon has been termed Colony Collapse Disorder (CCD) (Bromenshenk et al. 2010). Recently, however, it has been reported that the co-infection by invertebrate iridescent viruses with a microsporidian of the genus *Nosema* could be the probable cause of honey bee colony decline (Bromenshenk et al. 2010). Some scientists predict that native bees will buffer potential declines in agricultural production due to CCD (Kremen 2005; Kremen and Ostfeld 2005; Winfree et al. 2007), but in many cases, as in Alaska, the native bee fauna is little known.

Bumble bees (genus *Bombus*) and parasitic bumble bees (subgenus *Psithyrus*) can sometimes prove to be more efficient than honey bees (Stubbs and Drummond 2001) in crop pollination, especially when adequate habitat is available near agricultural fields (USDA 2006). Only in areas of extensive and intensive agriculture where natural habitat is limited, bumble bee communities may be insufficient to replace the pollination services currently provided by honey bees (Goulson et al. 2008). In Alaska, only 25,719 acres of the total 365 million acres is cultivated in crops (Benz et al. 2009). Two hundred ninety-six acres of those crops are vegetables that might benefit from insect pollination. Crops that require insect pollination that might benefit from bumble bee pollination includes canola, sunflower, tomatoes, peppers, strawberries, cucumbers, squash, gourds, pumpkins, mustard, and some annual forage legumes (Free 1993). Countless stands of wild berries such as blueberries, lingonberries, and cloudberries, occur throughout Alaska that benefit from bumble bee pollination (Davis 2002; NRCS 2006).

Bumble bees tend to have longer tongues that allow them to pollinate long, narrow corollas or flowers, and will forage during rainy, cool, and windy weather during which honey bee activity is limited (Buchmann 1983; National Biological Information Infrastructure 2009). Bumble bees have the capacity to buzz pollinate (Kevan et al. 1991; King 1993), a resonant vibration caused when the insect grabs onto the flower and moves its flight muscles rapidly, causing the anthers to vibrate thereby dislodging pollen.

Commercially-produced bumble bees have frequently been used for pollination services worldwide typically in greenhouses (Kwon 2008). The earth bumble bee, *Bombus terrestris* L., is the most common species that has been domesticated and used for commercial pollination for crops in Europe, Australia, Israel, Japan, and Korea (Kwon 2008). This species was originally distributed widely in Europe (Kwon 2008). In North America, native bumble bees such as *Bombus occidentalis* Greene and *Bombus impatiens* Cresson have been domesticated (Kwon 2008). In the past, producers in Alaska have experimented with bumble bees for greenhouse use, but it is not a commercial practice (P. Holloway, pers. com.).

Commercialized colonies tend to have greater parasitic loads than wild colonies including the bumble bee specific protozoan pathogens *Crithidia bombi* Lipa and Triggiani (Kinetoplastida: Trypanosomatidae), *Nosema bombi* Fantham and Porter (Microsporidia: Nosematidae), and the tracheal mite *Locustacarus buchneri Stammer* (Acari: Podapolipidae) (Colla et al. 2006). These pathogens and mites can have negative effects on imported and native colony survival, reproduction, and/or the foraging efficiency of individual workers (Brown et al. 2003; Whittington and Winston 2003; Gegear et al. 2005; and Otterstatter et al. 2005). Only one published report is available regarding bumble bee pathogens in Alaska. It identifies two distinct lineages of *C. bombi* occurring in Alaska (Schmid-Hempel and Tognazzo 2010).

Impoverished native bumble bee communities often are associated with the intensification of agriculture (high inputs of capital, labor, or heavy usage of technologies such as pesticides and chemical fertilizers relative to land area) and may be insufficient to replace the pollination services currently provided by honey bees (Goulson et al. 2008). Alaskan farms tend to be surrounded by native vegetation and habitat that would benefit native bee populations, but there is little information on bumble bee species composition, geographical distribution, biology, and factors affecting bumble bee species richness in this state.

The objectives of this study were:

- To provide baseline data on species composition, distribution, and seasonal biology of the genus *Bombus* at three agricultural locations within Alaska: Fairbanks, Palmer, and Delta Junction;
- To assess presence of *Nosema* that could affect native *Bombus* species; and
- To develop a pictorial key to identify common bumble bee species in interior Alaska.

CHAPTER 2. LITERATURE REVIEW

2.1 Bumble Bees

There are approximately 246 *Bombus* species worldwide; 44 are known from the US and Canada (Williams 1998). Bumble bees can be found among alpine, temperate, and arctic environments of the northern continents. In the southern hemisphere, they are native only in the East Indies and South America. (Williams 1994). They are generally recognized by their furry, brightly colored hair, the presence of meta-tibial spurs, the absence of hairs on the compound eyes, and the absence of the jugal lobe of the hind wing (Thorp et al. 1983).

Their color patterns can vary within species in a region and even more so geographically (Thorp et al. 1983). There are nearly 2,800 bumble bee names that have been published (Williams 1994) for the 246 species due to identifications based on color. Alaskan bumble bees tend to exhibit only one color pattern per species; however, males of the subgenus *Psithyrus* have shown considerable sexual dimorphism (Thorp et al. 1983).

Bumble bees and cuckoo bumble bees (parasitic bumble bees) belong to the tribe Bombini of the family Apidae (Kearns and Thomson 2001; Michener 2007). Bumble bees have been placed in several different taxonomic groups based on behavioral and ecological attributes. Recent classifications are based on male genitalia and place all species in a single genus, *Bombus* (meaning 'booming') and parasitic bumble bees are placed in the subgenus *Psithyrus* (Goulson 2003). A list of the bumble bees reported from Alaska, their distribution, and taxonomy from published sources is shown in Table 1.

The development, behavior, and biology of bumble bees and cuckoo bumble bees have been reviewed by Kearns and Thomson (2001). Bumble bees construct wax nests and are eusocial in that they have overlapping adult generations, cooperative brood care, and presence of sterile workers (Kearns and Thomson 2001). Fertilized queens emerge from hibernation each spring and individually start a new colony. The colony develops and grows as workers (females) are produced and start to forage. Unfertilized eggs (males) are laid and subsequent worker larvae develop into new queens. Each fall, males and the new queens mate, the colony disintegrates, and the old queen, workers and males die as the new queens hibernate. Cuckoo females enter the bumble bee nest later in the summer, kill the resident queen and begin laying eggs. The workers will then feed and nurture the cuckoo eggs. The parasite larvae emerge as male and female reproductive forms, never as worker bees.

2.2 Diel patterns

Bumble bees are diurnal (Fisher and Tuckerman 1986). During free flight, bumble bees can maintain a body temperature of more than 20°C above ambient temperature by activating thoracic muscles (Heinrich 1972, 1974) which enables them to forage during rainy, cool and windy weather (Free 1993; National Biological Information Infrastructure 2009). According to Heinrich (1979), bumble bees can be seen foraging in temperatures as cold as -3.6°C. They have even been observed foraging during snowfall and under a full moon (Kearns and Thomson 2001). Two studies conducted near arctic latitudes (North Sweden at 68° 22' N, 18° 47' E and Lake Hazen, Canada at 81° 50' N, 70° 25'W), areas above tree line, observed activity throughout the 24 hour period with lowered activity during the middle of the night (Richards 1973; Lundberg 1980). Influences on flight activity can include light, temperature, wind, and rain (Lundberg 1980; Corbet et al. 1993). Preliminary data from Alaska (Davis 2002) suggests that some species are active between 06:00 and 18:00 hours. However, that study only included twelve *Bombus* specimens in a single site in the Fairbanks area.

2.3 Bumble bee decline

The conservation status of native bumble bees across North America is lacking due to the limited long-term monitoring and baseline data available (Berenbaum et al. 2007) as is the case in Alaska. The health status of native Alaskan bumble bee populations is entirely unknown. There have been studies on pollination biology, particularly on lingonberries and arctic flowers which provide a list of pollinators, but these studies include little population or health status data on selected groups (Armbruster and Guinn 1989; Kevan 1972; Davis et al. 2003).

Nevertheless, there is evidence for bumble bee decline particularly in developed regions such as North America and Western Europe (Allen-Wardell et al. 1998; Thorp and Shepherd 2005; Kosior et al. 2007; FAO 2008; Goulson et al. 2008; Grixti et al. 2009). Potential causes of bumble bee decline outside of Alaska (and potentially in Alaska) include reductions in floral resources, loss of nest sites, invasive species (both plant and insect species), habitat fragmentation, parasitic spillover (from domesticated bees), competition, and use of pesticides (Kevan 1999; Berenbaum et al. 2007; Kremen et al. 2007; FAO 2008; Goulson et al. 2008).

Causes can vary by location, but the above all have negative impacts on pollinator populations. Reductions in floral resources and loss of nest sites can be the result of the expansion of intensive agriculture as well as increasing urbanization resulting in cleared land for highways, houses, and industrial development (Goulson et al. 2008). Pesticides can be highly toxic and there are three possible routes of exposure: direct contact with sprays, contact with contaminated foliage, and uptake of chemicals in nectar (Goulson et al. 2008).

Since 1998, *B. occidentalis* has disappeared from parts of its range which extends from Alaska to central California and east to northern Nevada, Arizona, and New Mexico and is thought to be near extinction (Thorp and Shepherd 2005). This species has been placed on the Xerces Society for Invertebrate Conservation Red List of pollinator insects as a result of its decline (Thorp and Shepherd 2005). Williams and Osborne (2009) suggest *B. occidentalis* to begin the International Union for Conservation of Nature Red-List process under the category, endangered. Not seen since 1997 in the Willamette Valley, Rao and Stephen (2007) collected three *B. occidentalis* workers while studying native bee diversity and abundance in 2006. The Xerces Society is documenting the former and current ranges of this species. Appendix C provides some best management practices for land owners regarding bumble bee conservation and management.

Alternatively, Roubik (2001) proposes that the evidence of decline can be misleading. His study focused on the *Euglossine* bee species in Panama over a 20 year period accompanied by three strong El Niño events and concluded that populations and local diversity can be highly variable from year to year (Roubik 2001). He observed that bee populations commonly halved or doubled in one year intervals and suggests that a minimum of four years is required to document decline (Roubik 2001). Cane and Tepedino (2001) indicate that this variability can depend on various factors including, but not limited to habitat, weather, human activities, and even the time of day one chooses to collect, suggesting the need to study bumble bee biology and seasonality in Alaska. A study on native bee (including *Bombus*) communities in Illinois showed no evidence of a decline in the species composition between late 1800s and 1972 regardless of dramatic changes in land use and agricultural practices throughout the study area (Marlin and LaBerge 2001).

2.4 Alaska Bumble Bees

There is no consensus on the total number of bumble bee species present in Alaska. Bishop and Armbruster (1999) state, but do not list, 18 bumble bee species known from Interior Alaska categorized by sites of various thermal regimes (referring to the amount of heat available for plant growth and development during the growing period). Other authors such as Washburn (1963) suggest up to 22 *Bombus* species. The University of Alaska Museum (UAM 2010) Insect Collection has 28 species of bumble bees from Alaska; however, all species have not been verified yet (D. Sikes, pers. com). Table 1 includes a compilation of species in Alaska based on literature. Please see Williams (1998) and updated web pages of Williams (1998) checklist at the Natural History Museum (London) *Bombus* database (http://www.nhm.ac.uk/research-curation/research/projects/bombus/index.html) for distribution region descriptions. Table 2 lists the 8 subgenera known from Alaska. Appendix A lists synonyms and taxonomic notes on selected species listed in Table 1.

2.5 *Nosema*

Nosema species is a common microsporidian that has been known to affect a variety of insects including economically important insects such as the silkworm moth, honey bees, and bumble bees (Otti and Schmid-Hempel 2007). Colla et al. (2006) revealed that spillover of pathogens from commercial to wild bumble bees could lead to the transmission of diseases. It has been reported that *Nosema bombi*, that typically infects domesticated bumble bees, has invaded wild native bee colonies (Berenbaum et al. 2007). The cause of recent catastrophic declines throughout North America in native bumble bee colonies such as *B. terricola* Kirby, *B. affinis* Cresson, *B. franklini* Frison, and *B. occidentalis* are likely due to the exposure of this nonnative pathogen (Whittington and Winston 2004; Thorp 2005; Thorp et al. 2005; Evans et al. 2009). It has been proposed that *N. bombi* was spread to wild populations by infected queens that were sent from European rearing facilities in the early 1990's and escaped US greenhouse captivity (Thorp et al. 2005).

Little is known of the biology and transmission of the pathogen between host individuals in native bumble bee colonies, and reports are conflicting on the effects of the pathogen on the host (Schmid-Hempel and Loosli 1998). However, *N. bombi* is an obligate intracellular parasite that infects differently in different bumble bee species (Otti and Schmid-Hempel 2007). The microsporidian can infect the Malpighian tubules, thorax muscles, fat body tissue, nerve tissue, midgut, and the muscle tissue surrounding the gut epithelium (Fries et al. 2001). Under standardized laboratory conditions in early-infected colonies, Otti and Schmid-Hempel (2007) showed that infected males had lower survival and almost no sperm when compared to those uninfected. Infected gynes (future queens) had crippled wings or swollen abdomens and infected colonies appeared dirty possibly due to diarrhea and inefficient cleaning behavior of the infected workers (Otti and Schmid-Hempel 2007). They also found that a higher proportion of workers from infected colonies died compared to the control colonies.