

Using the Randall Morgan Insect Collection to explore bumblebee phenology, plant  
associations, and their implications for conservation

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## **Introduction**

There is little information available about bumblebee populations and distributions, especially outside of Europe. Despite scarce baseline information, there is evidence of declines in many types of pollinators, including bumblebees, all over the world (Kearns and Thomson, 2001) (Goulson, 2003). There are many reasons to undertake efforts to conserve bumblebee populations.

Declines in bumblebees and other pollinators have a huge potential to disrupt both human systems and natural ecosystems. Wild bumblebees increase crop yields (Greenleaf and Kremen 2006) (Alford, 1975), and they are relatively tolerant of cold and wet conditions, allowing them to pollinate when other bees cannot (Alford, 1975). Wild pollinators such as bumblebees are particularly important in the face of declining populations of honeybees, caused by colony collapse disorder and other factors.

Bumblebees also support a large amount of biodiversity. Their decline has the ability to drastically alter plant communities, and decrease floral abundance and diversity (Kearns and Thomson, 2001). As well as pollinating many rare or specialized flowers that other pollinators cannot, bumblebees and their nests have also been found to support over 100 species of other insects and mites (Alford, 1975). Some have suggested that bumblebee decline may cause an alarming positive feedback loop (Goulson, 2003). Declining bumblebee populations might reduce pollination of their preferred flowers. The plants would then set less seed, and may be less abundant the next year, putting even more stress on bumblebee populations. This cycle could possibly reduce both bumblebee and floral diversity and abundance.

Agriculture contributes to the decline of bumblebees in many ways. The largest threat to bumblebees is habitat loss (Goulson, 2003). Both agricultural and urban development has contributed greatly to losses in bumblebee habitat. Agricultural use of pesticides, herbicides, and fertilizers also negatively affects bumblebee populations (Goulson, 2003) (Kearns and Thomson, 2001). Pesticides can affect bees directly if they come into contact with the spray, but it can also affect them indirectly, such as through contact with foliage that has been sprayed. It has even been shown that certain chemicals in pesticides can be up taken by bees through the nectar of plants that have been treated (Mach et al. 2018). Herbicides are often used in and around fields to control non-crop plants. These can directly reduce floral abundance and thus reduce pollen and nectar resources available for bees (Kearns and Thomson, 2001). Fertilizers tend to reduce plant diversity by favoring a few fast growing species rather than a full range of native flora. In addition, artificial fertilizers have largely replaced organic farming practices that may have been beneficial to bees, such as leguminous crop rotations. Legumes provide a major source of nutrition to many species of bees, and artificial fertilizers have largely replaced their use in crop rotations (Goulson, 2003).

Other agricultural practices that affect bumblebees include livestock grazing and use of farm machinery. Livestock grazing can alter plant species composition, and reduce floral resources available to bees (Kearns and Thomson, 2001). Livestock can also trample nests and cause soil compaction, which can make soil unsuitable for nesting. Farm machinery is quite disruptive and can destroy above ground bumblebee nests.

Crop plants do not usually support bumblebee populations very well because they tend to have brief flowering periods, and flower later in the season than the critical nest

establishment and development phase (Kearns and Thomson, 2001). Due to the lifecycle of a bumblebee colony, it is important for bumblebees to have access to plentiful floral resources from April through July. Thus, a continuous succession of different flowers is often required to meet resource needs. Large fields of crops that all briefly flower at the same time do not provide adequate resources throughout the season for bumblebee colonies (Kearns and Thomson, 2001).

Agricultural use of bees can also negatively impact wild bumblebee populations (Goulson, 2003). European honeybees are the main species used for crop pollination. Studies have shown that the presence of honeybees in proximity to bumblebee colonies reduces the bumblebees' forage rates and reproductive success (Thomson 2004). In one study, bumblebees and honeybees were shown to have a strong overlap in foraging preferences, which peaked late in the season when floral resources were scarce (Thomson 2006). This indicates that wild bumblebees likely have to compete with honeybees for pollen and nectar where honeybees are present. Thomson (2016) found that increases in honeybees were strongly correlated with declines in bumblebees, providing further evidence for their competition. Honeybees also have the potential to introduce and spread parasites and pathogens to wild native bees (Reynaldi et al. 2014), (Maxfield-Taylor et al. 2015).

The agricultural use of both native and nonnative bumblebees also threatens native wild bee populations. Domesticated bumblebee colonies are used to pollinate certain crops such as greenhouse tomatoes (Kearns and Thomson, 2001). One species, *Bombus terrestris*, has been spread around the world for this purpose. These domesticated bumblebees can affect wild bees in a number of ways, including through

competition and hybridization (Goulson, 2003). Nonnative bee species can introduce parasites and pathogens to native bees. Even if native bees are used, reared colonies often have higher rates of disease, and this can spread to wild bees. The agricultural use of bumblebees is thought to be a significant factor in the decline of several native bumblebee species, including *B. terricola*, *B. affinis*, *B. franklini*, and *B. occidentalis* (Goulson, 2003).

### **Research Questions**

In order to engage in more effective conservation efforts, it is important to understand bumblebee natural history and ecology. Phenology and floral use are two particularly useful aspects of bumblebee ecology in informing conservation. Using the Randall Morgan Insect Collection (RMIC), located at the Kenneth S. Norris Center for Natural History at UC Santa Cruz, I explored questions relating to bumblebee phenology and bumblebee-plant associations. Phenological investigations included comparison of male and female bumblebee phenology, emergence times across years, and identifying and comparing times of year that queen, worker, and male bumblebees were found. Research in bee-plant associations included identifying what plant families bumblebees were most often associated with in the RMIC.

### **The Randall Morgan Insect Collection**

The Randall Morgan Insect Collection (RMIC) is an extensive collection of preserved insect specimens collected throughout Santa Cruz County by renowned local naturalist Randy Morgan. From 1989 to 1999, Morgan collected insects from over 39

sites. Each year, he would survey 4-6 sites, visiting each site once every 3-4 weeks throughout the whole year. At each site, he walked a consistent transect, catching as many insects as possible in a sweep net, and taking detailed field notes on where insects were found and what plants were flowering. All insects were carefully pinned, identified, and numbered. The collection contains over 70,000 insect specimens, and is an important resource for research, education, and conservation. It contains about 30,000 pollinator specimens, as well as data on associated flora, making it a particularly valuable resource for studying pollination networks.

This incredible collection was donated to UCSC in 2002. Since then, it has been used for many different purposes including graduate-level dissertation research, student internships and projects, undergraduate ecology classes, and K-12 education. Information from the collection has also been shared with land management agencies and property owners to document biodiversity and inform conservation efforts of important pollinators and other insects all around Santa Cruz County. Currently, records from the collection are being digitized and uploaded to a database, making the information easily searchable and available to scientists and researchers all over the world.

### **The Natural History of Bumblebees**

I found gaining a basic understanding of the natural history and ecology of bumblebees to be important in understanding and interpreting trends shown in the RMIC. Bumblebees are social insects, forming colonies that cooperate together to gather resources and raise young. A colony can consist of anywhere from a couple dozen to several hundred bees (Free, 1982). There are three main roles, or castes, that a

bumblebee may fall. A bumblebee is either a worker, a male, or a queen. Queens, workers, and males all perform different tasks and have a different role in the maintenance and reproduction of colonies (Goulson, 2003).

Worker bees complete a variety of tasks. Workers aid in constructing wax egg cells within the nest, as well as feeding and incubating the brood. Worker bees also forage for pollen and nectar, and sometimes guard the entrance to their nest. Worker bees can vary greatly in size, and can specialize in different tasks (Goulson, 2003). Smaller workers are well suited for working inside the nest while larger workers are inclined towards foraging (Free, 1982). Many workers begin working in the nest, and switch to foraging later in their lives. Although workers may specialize, they have the ability to switch tasks to meet the needs of the colony. If the colony is lacking in food, nest workers will come out to forage (Goulson, 2003). Foragers will focus on gathering nectar or pollen if the colony is lacking one in particular. Bumblebee workers exhibit both polyethism, where different individuals specialize in different tasks, as well as alloethism, where different sized bees perform different tasks (Goulson, 2003).

Once a bumblebee queen has established a colony in the early spring, her main task is to lay eggs and raise young. When laying eggs, bumblebee queens have the special ability to determine the sex of their larvae. After mating in the spring, the queens store their mate's sperm in a special organ called the spermatheca as they hibernate for the winter and begin their own colony the following spring. When laying eggs, the queen determines the sex of the larvae by either releasing sperm and fertilizing the egg, in which case the larvae will be female, or by leaving the egg unfertilized, in which case the larvae will be male (Kearns and Thomson, 2001). A female larva will either become a

worker, or a queen. Workers sometimes lay unfertilized eggs to produce males, but only queens produce female offspring.

Male bees do not work for the colony. They emerge later in the season, after a colony has stopped producing workers. They leave the nest immediately in search of a mate, and die after the short mating season.

Bumblebees have a unique genetic system shared by some other members of hymenoptera known as haplodiploidy (Alford, 1975). Humans, and most other familiar organisms, are diploid, meaning that they have two copies of each chromosome, and therefore two copies of every gene. Bumblebees however, have a more complicated system. Males, which develop from unfertilized eggs, are haploid, as they receive only their mother's chromosomes. Female bees are diploid, as they develop from fertilized eggs. Due to their unique genetics, sister bumblebees are highly related, with an average of 75% of their genes in common, while daughters and mothers only share an average of 50% of their genes (Goulson, 2003). This unique genetic system is quite likely what led to the development of sociality in insects (Goulson, 2003). Because sisters share 75% of their genes, they are predisposed to cooperate, passing down genes indirectly through their relatives. This likely led to sociality evolving multiple times independently within the order hymenoptera.

Bumblebee colonies go through an annual life cycle in which colonies are built each spring, and die later that season, often in late summer or fall (Alford, 1975). A bumblebee colony begins with a single queen in early spring. The queen emerges from hibernation as the weather warms, and begins to forage for nectar and pollen. These first few weeks are a critical time. There must be sufficient floral resources for the queen to



get adequate nutrition to properly develop (Free, 1982). When the queen has developed sufficiently, she begins to search for a site to nest and start a colony. Preferred nesting habitat varies by species, but many bumblebees nest in abandoned burrows or holes left by small mammals (Goulson, 2003).

Once a spot is chosen, nest construction begins. The queen lines the nest with fine materials, and begins to stockpile pollen. Once a sufficient amount is collected, the queen lays eggs on the stored pollen, and encloses them in a layer of wax. The larvae hatch, and begin to feed on the pollen. The queen continues to feed them as they grow. Once grown, the larvae spin a silky cocoon, and go through a pupal stage, before emerging as adult worker bees. During the colony growth phase, all larvae are female, and will become workers. Males and queens are not produced until later in the season (Alford 1975).

Bumblebee workers engage in a variety of tasks, including nest construction, raising young, defending the nest, and foraging (Goulson, 2003). The queen no longer has to forage, and can now focus on reproduction. As the colony grows, empty cocoons are used to store pollen and nectar, and wax egg cells are built on top of empty cocoons (Free, 1982). The queen begins to lay eggs more frequently, as there are more workers to feed and incubate the larvae. The colony continues to grow in this manner, until there are anywhere from fifty to several hundred workers.

At this point, often sometime in late spring to summer, the colony will stop producing workers, and will switch to producing males and queens. Some colonies will produce only males or only queens, while others will produce both (Free, 1982). Males develop from unfertilized eggs, while queens develop from fertilized eggs, like workers.

Upon maturing, males leave the nest to search for a mate, while queens remain and eat to build up a reserve of fat to survive the coming winter (Alford, 1975). The queens emerge, mate, and then find a suitable location to hibernate for the winter. As the season continues, workers begin to die off, and the colony's population gradually declines. By winter, the workers and males have died, leaving only the hibernating queens to begin new colonies and start the process again the following spring.

## **Methods**

Beginning in 2002, curators at the Norris Center have been sorting, labeling, and collaborating with taxonomic experts to identify thousands of specimens belonging to the RMIC. In 2016, data from all 30,000 records of pollinators began to be uploaded to the Symbiotic Collections of Arthropods Network (SCAN). This involves locating records of specimens in the database by their identification number, and then entering relevant data such as species name, habitat type, sex, reproductive condition, and associated flora. After records of all bumblebee (*Bombus*) specimens from the RMIC were uploaded, a dataset containing all RMIC *Bombus* occurrence records was obtained from SCAN. Microsoft Excel was used to sort and visualize data, which helped to identify potential areas of study. Bee and flower phenology as well as bumblebee-plant associations were chosen as topics of interest. Data from the RMIC was used to explore bumblebee phenology and plant associations, and results were organized and visualized using Microsoft Excel. Final versions of figures were then produced with the help of Andy Kulikowski. Results are analyzed and discussed using relevant published literature.

## Results

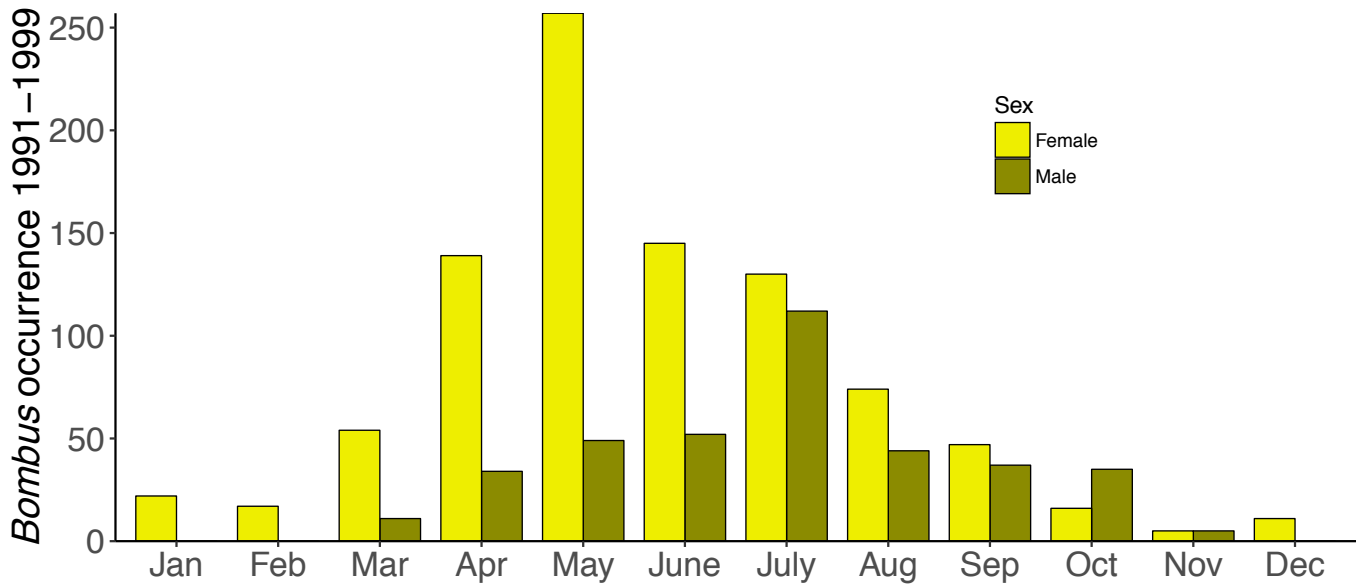


Figure 1: Occurrences of *Bombus* by month (1991-1999).

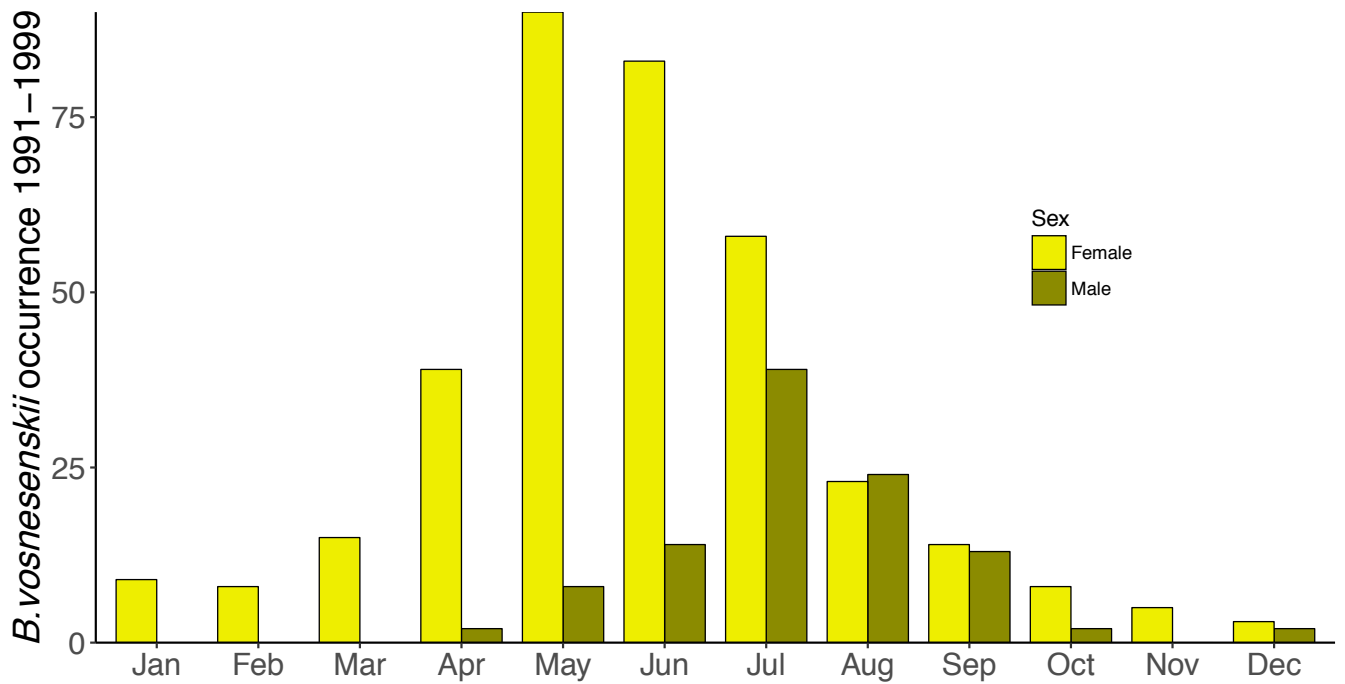


Figure 2: Occurrences of *Bombus vosnesenskii* by month (1991-1999).

Number of occurrences by month of both *B. vosnesenskii* and *Bombus* of all species by sex formed unimodal bell shaped curves. In both *B. vosnesenskii* as well as *Bombus* in general, female occurrences peaked in May, and male occurrences peaked in July, showing an approximate two month offset in their peak occurrences. While these data do not represent true abundance due to sampling at different locations, the timing of when male and female bumblebees were collected displays an interesting and noteworthy pattern.

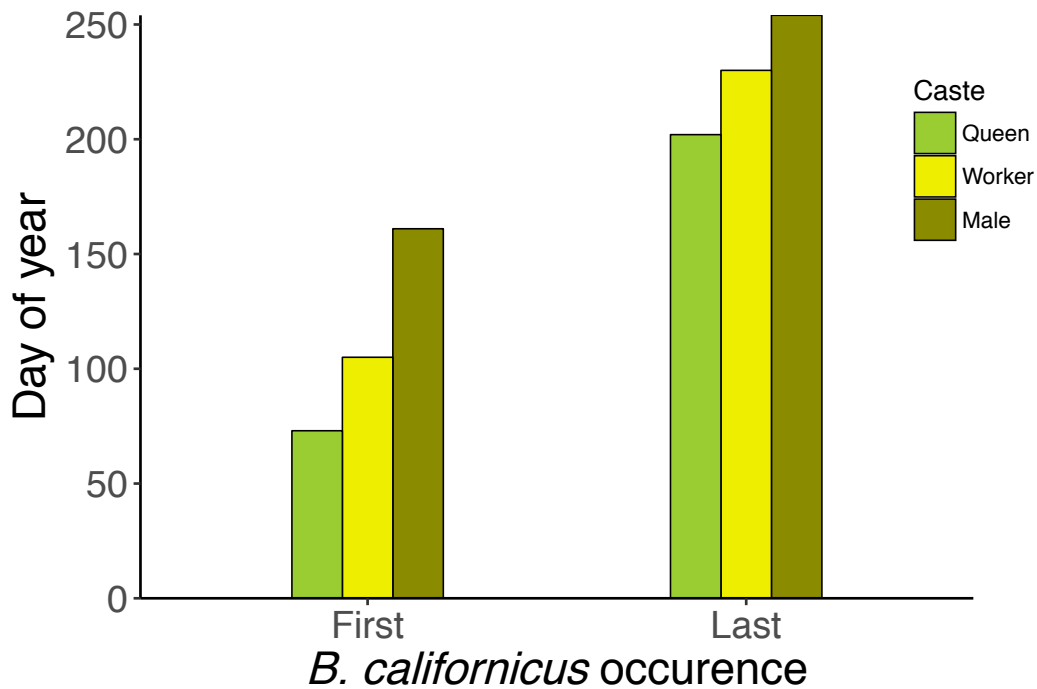


Figure 3: Date of first and last occurrence of *B. californicus* queens, workers, and males (1991-1999).

The day of year of first and last occurrences of *B. californicus* queens, workers, and males shows offset intervals of time of when Morgan was able to find different various sexes and castes. From 1991-1999, Morgan collected all *B. californicus* queens in between days 73 and 202 of the year (March 14 and July 22). Only one queen was found

on day 202, and all other queens were collected before day 121 (May 1). Workers were collected in between days 105 and 230 (April 15 and August 18). Males were collected in between days 161 and 254 (June 10 and September 12). The mean day of year for queen, worker, and male occurrences was 109, 167, and 209 (April 19, June 16, and July 28), respectively.

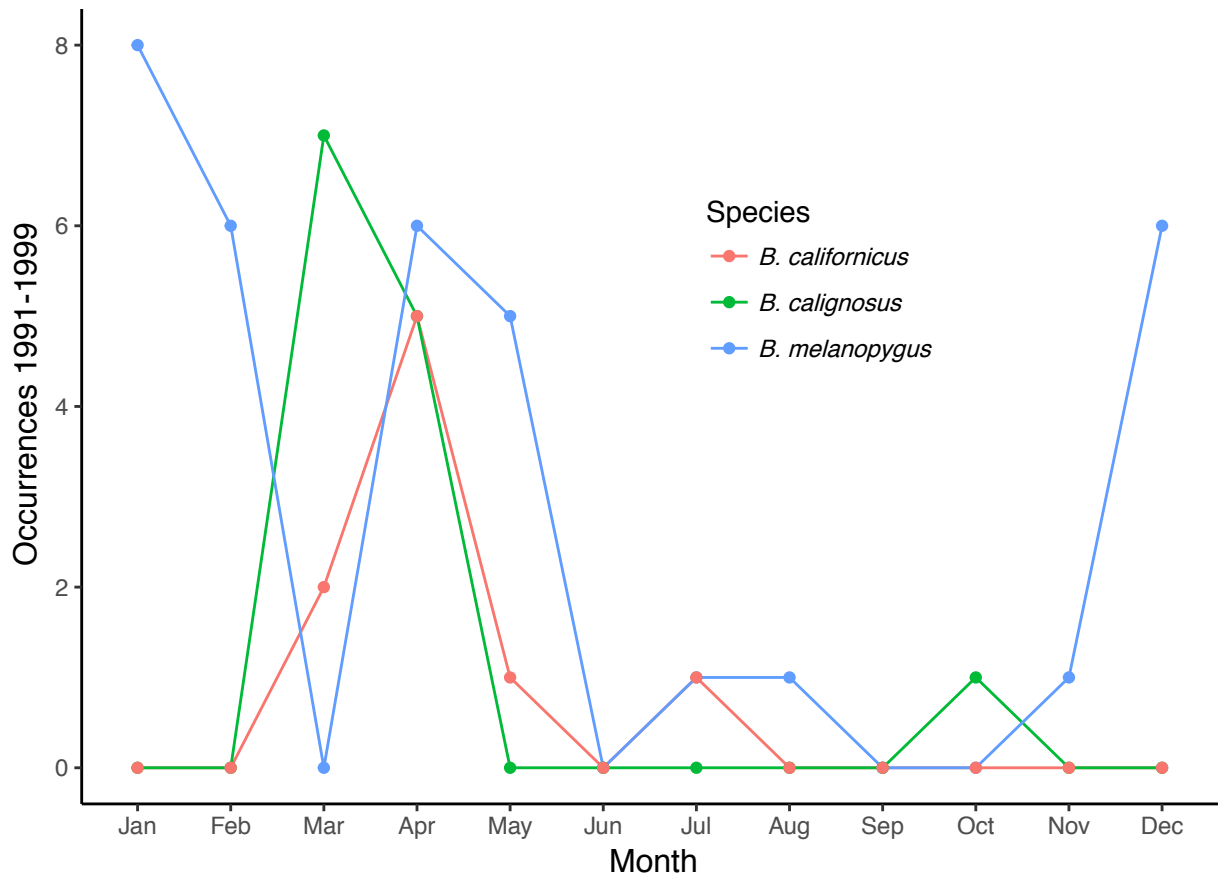


Figure 4: Occurrences of three different *Bombus spp.* queens by month

*B. californicus*, *B. calignosus*, and *B. melanopygus* all exhibited a peak in queen occurrences in March-May. In addition, *B. melanopygus* exhibited another peak in occurrences in December-January. The peak in March-May likely represents the time of year in which bumblebee queens are emerging from hibernation and establishing

colonies. The December-January peak in *B. melanopygus* might represent the period in which queens are foraging, mating, and looking for a site to hibernate. Other species may have not had an increase in occurrences at this time of year due to different mating/foraging habits, differing phenology, or for other reasons.

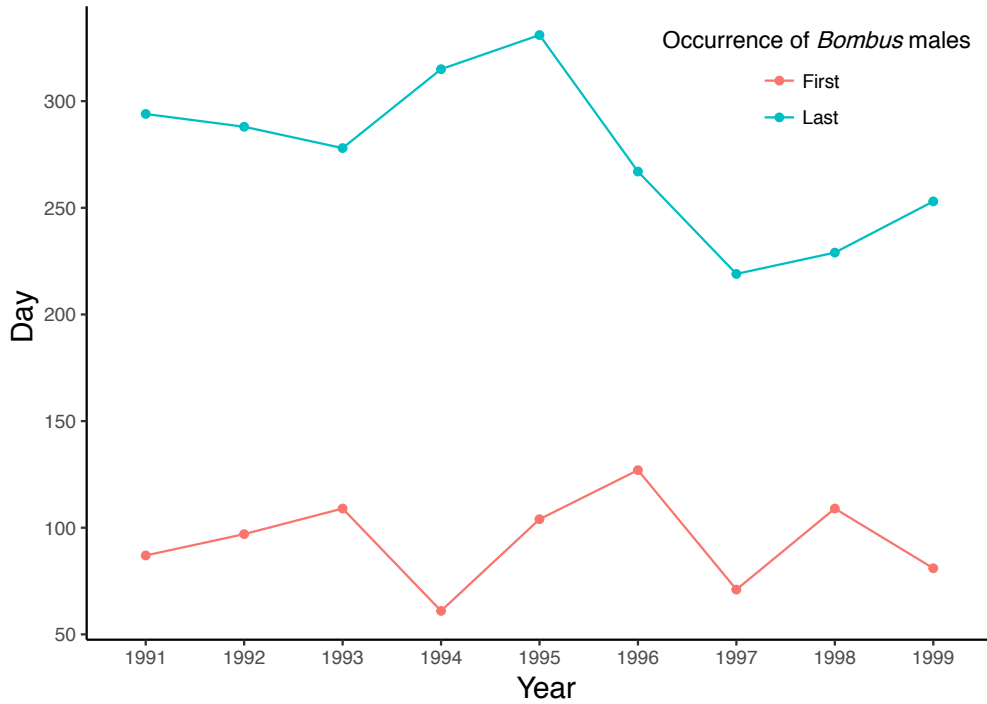


Figure 5: Date of first and last occurrence of *Bombus* by year (1991-1999).

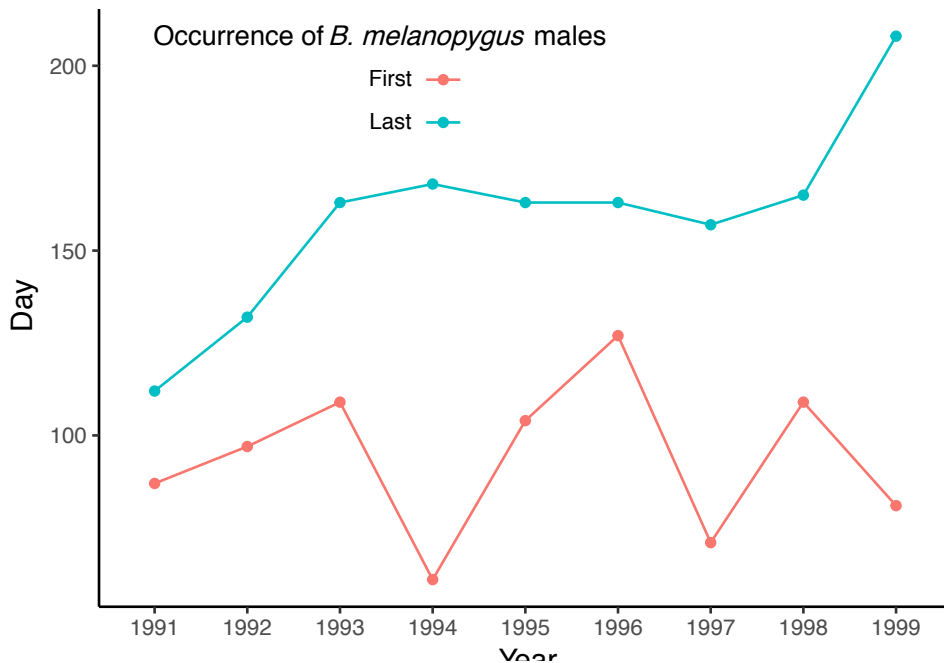


Figure 6: Date of first and last occurrence of *B. melanopygus* by year (1991-1999).

While no overall discernable trend occurred over all *Bombus* species, *B. melnopygus* males were found increasingly late in the season over the course of 1991-1999. Despite no overall trend in *Bombus*, it is possible that further study of the data by species will illuminate more patterns such as the increasingly late times of year in which *B. melanopygus* was found. This is a possible area of future study that could potentially have significant implications for the conservation of bumblebees.

Family	% Female Use	Family	% Male use	Family	% Total use
Fabaceae	28.78	Asteraceae	34.74	Fabaceae	24.31
Asteraceae	12.17	Lamiaceae	15.79	Asteraceae	17.13
Lamiaceae	8.31	Polygonaceae	12.63	Lamiaceae	9.95
Papaveraceae	7.12	Brassicaceae	9.47	Brassicaceae	7.41
Brassicaceae	6.82	Fabaceae	8.42	Polygonaceae	7.18
Polygonaceae	5.64	Boraginaceae	4.21	Papaveraceae	5.56
Boraginaceae	5.04	Crassulaceae	4.21	Boraginaceae	4.86
Rosaceae	4.45	Rosaceae	3.16	Rosaceae	4.17
Ericaceae	2.67	Rhamnaceae	2.11	Scrophulariaceae	2.31
Scrophulariaceae	2.37	Scrophulariaceae	2.11	Ericaceae	2.08

Figure 7 shows the ten plant families most often associated *Bombus* in the RMIC. Associations are shown for males and females as well as combined together.

The vast majority of plant species associated with *Bombus* in this collection seem to belong to a few particular plant families. These families include Fabaceae, Asteraceae, Lamiaceae, Brassicaceae, Polygonaceae, and Boraginaceae. While a plant species being associated with an occurrence means only that the bee was collected from that plant, it seems likely that these associated plants are being used for pollen/nectar resources. Fabaceae was the family most often associated with *Bombus* occurrences. Nearly a quarter of all occurrences were associated with Fabaceae. Asteraceae was the next most

associated family, associated with about 17% of *Bombus* occurrences. Notably, while Fabaceae was associated with 28.78% of female occurrences, and 24.31% of all occurrences, it was only associated with 8.42% of male occurrences. Asteraceae, while associated with 12.17% of female occurrences, and 17.13% of all occurrences, was associated with 34.74% of male occurrences.

## **Discussion**

Certain patterns within the RMIC *Bombus* data clearly reflect and illustrate bumblebee phenology and the annual lifecycle of a bumblebee colony. The first noteworthy pattern is the distribution of *Bombus* occurrences throughout the year, and the offset in between male and female bumblebee phenology (Figure 1, Figure 2). This pattern is consistent with bumblebee phenology and the annual lifecycle of a bumblebee colony, as described by Alford (1975), Free (1982), Kearns and Thomson (2001), and Goulson (2003). The peak in females in May likely corresponds with the time of year in which bumblebee colonies are reaching sufficient size to switch from producing workers to reproductive males and queens. Throughout the late spring and summer months, fewer workers are found, as they begin to die off, and an increasing number of males are found, peaking in July. This illustrates the timing of the switch from worker to queen and male production in local bumblebees.

Phenological patterns illustrating the annual lifecycle of a bumblebee colony can also be seen when looking at phenology by sex and caste of *B. californicus* (figure 3). As well as females occurring earlier in the year than males, queens also occurred before workers. This early season period in which queens are found without workers likely



reflects the critical nest establishment phase that occurs after queens have emerged from hibernation, but before they have raised their first brood of workers. The times of year in which different sexes and castes were found illustrate the differing phenology between them. All queens were found between days 73 and 202. Workers were found between days 105 and 230, and males were found in between days 161 and 254. The mean day of year of queen, worker, and male occurrences was 109, 167, and 209, respectively, showing the progression of a colony from founding queens, to production of workers, to production of males. Additional research could include broadening this investigation by comparing *B. californicus* to other *Bombus* species. Although number of occurrences does not necessarily represent true abundance due to sampling methods, it is nonetheless noteworthy that these phenological trends are shown so clearly in occurrences of *Bombus* in the RMIC. Further study of the mechanism and timing of the switch from worker to queen and male production in bumblebee colonies, particularly in North America, may provide further insight into these patterns and the forces driving them.

Comparison of the phenology of queen bees of different species also displayed a noteworthy pattern (figure 4). Occurrences of *B. melanopygus*, *B. caliginosus*, and *B. californicus* queens all peaked dramatically in March-May. The March-May peak likely coincides with the critical nest establishment phase, in which a queen has emerged from hibernation, but has not yet raised a brood of workers and established a colony. Several strategies for conserving bumblebees focus on the critical nest establishment phase. Strategies include efforts to provide early-season floral resources and avoidance of pesticide use during nest establishment (Goulson, 2003).

Pesticide use during nest establishment can be critical. Baron et al. (2017) found that colony-founding queens exposed to field-relevant levels of neonicotinoid insecticides were significantly less likely to establish colonies, and this effect dramatically increased the likelihood of extinction at the population level. Wu-Smart and Spivak (2018) found neonicotinoid insecticides to have lethal and sublethal effects on colony-founding queens. In addition to causing mortality, exposure to neonicotinoids also caused delays in egg-laying and worker emergence, as well as affecting nest and queen weight. These studies highlight the danger that pesticides pose to bumblebees, particularly during the nest-establishment phase.

Understanding when *Bombus* queens are active is important for modeling bumblebee phenology and for informing bumblebee conservation. For example, these results (Figure 4) suggest that if you are attempting to time pesticide use in order to best conserve local *B. melanopygus* populations, March may be an appropriate time to apply pesticides. If your concern is *B. caliginosus* however, March may not be appropriate. Although extreme caution should be used in any direct application of these results due to sampling methods, possible phenological inconsistencies and potential differences in locality and conditions, this serves as an example of how our understanding of bumblebee phenology can inform conservation. Further research on the distribution of different bumblebee species as well as differences in their phenology and nest-establishment phase will considerably support efforts to reduce the impacts of pesticide use on bumblebees.

While *Bombus* showed no overall trend in male emergence times by year (Figure 5), *B. melanopygus* males were found increasingly later in the year from 1991-1999 (Figure 6). The annual emergence times of different *Bombus* species, sexes, and

reproductive castes is a topic that warrants further study. Emergence times of bee species can be used to study climate change, and the possible effects that it may have on a phenomenon known as pollinator-plant asynchrony. Flowering plants and their pollinators evolved together over millions of years. A shifting climate can change both when plants flower and when insects emerge, possibly causing a mismatch. This could potentially have detrimental effects on both flowering plants and pollinators, reducing pollination rates as well as pollen and nectar resource availability (Aldridge et al. 2011).

Although potential effects of climate change on pollinator/plant synchrony have been significantly researched, climate change is incredibly hard to model and predict, and there is little consensus on how much of a threat pollinator asynchrony poses to plant and pollinator communities. For example, Benadi et al. (2014) found that the species within the scope of their study did not appear to be threatened by phenological decoupling. It was however noted that specialized pollinators often rely on corolla tubes of a particular length, so their results may have been dependent on a high degree of functional redundancy in the studied plant community, and communities with less diversity may face a much greater threat.

Forrest and Thomson (2011) found that plants are more likely than insects to experience advances in their phenology due to climate change, potentially causing a mismatch. However, it also concluded that phenological decoupling alone is unlikely to threaten populations in the study area, particularly of the more generalist pollinators. It found that phenological advances of plants are more likely to cause an increase or decrease in their overlap with particular pollinators, rather than a complete decoupling. This can still represent an important shift in resource availability and use, and source of

pollen can significantly affect larval growth and survival (Forrest and Thomson 2011) or (Williams 2003).

Kudo (2014) shows evidence of phenological decoupling during years with unusually warm weather. In a typical year, bumblebee queen emergence corresponds with a peak in available flowers. An unusually warm spring caused queen bumblebees to emerge from hibernation an estimated 10 days before the first flowers. Despite the early queen emergence, worker emergence was delayed, showing that colonies grew slower and were not as successful under these conditions. The unusual warm spring also caused the flowering season to end earlier than usual, by about two weeks. While one species of bumblebee seemed to readily adjust, other species were mismatched, and were the most abundant at the end of the flowering season, rather than at the peak (Kudo 2014). These results are noteworthy, given the potential for unusually warm years to become more prevalent due to climate change.

Kudo and Ida (2013) provide further evidence for phenological decoupling. The early onset of spring led to *Corydalis ambigua* flowering before its pollinators were detected. This mismatch led to lower pollination services, resulting in lower seed production. Phenological mismatch was found to be a limiting major factor for reproduction of spring ephemerals.

Bartomeus et al. 2011 did not find evidence of increasing pollinator/plant asynchrony. It found that phenological changes in plant flowering and bee emergence had essentially kept pace with one another, at least among generalist species. However, it was found that the phenology of 10 North American bee species has advanced by a mean of 10.4 days in the past 130 years, and that most of this shift has occurred since 1970,

paralleling increases in carbon emissions and global temperatures. While flowering plants seem to have shifted similarly, and there was not evidence of decoupling, this shows that it is certainly possible that climate change is affecting bee and flower phenology.

Although there was not evidence of decoupling, different plant and pollinator communities may not always respond the same way. Further research of the mechanism of synchrony between plant and pollinator phenology will help us understand how vulnerable these communities really are.

Additional study is needed to fully understand and assess how much of a threat pollinator/plant asynchrony may pose. While the subject has received significant research, there is much conflicting information, and little consensus. It seems likely that pollinator/plant asynchrony will have variable impacts and effects on different communities. Some communities are likely to be largely unaffected while others may experience drastic impacts. Therefore, consequences of pollinator asynchrony may be extremely difficult to predict and generalize. Close, long-term monitoring for pollinator disruptions at a local scale may be necessary to understand how climate change is impacting local pollinator and plant communities.

While some studies found no evidence of decoupling, others have found phenological disruptions. Many studies, although they found no evidence of decoupling, acknowledged that studied organisms were fairly generalized, and highly specialized species are more likely to be disrupted. More research into identifying vulnerable plants and pollinators with highly specialized relationships and assessing impacts on these organisms will contribute greatly to our understanding of pollinator/plant phenology and how they may be affected by climate change.

There is a major difference in what plant taxa male and female *Bombus* species are associated with in the RMIC (Figure 7). Females were highly associated with the family Fabaceae, while males were more closely associated with Asteraceae. One possible explanation for this difference could be differing pollen/nectar requirements between males and females. While female bumblebees collect pollen to feed their young, as well as nectar, male bumblebees forage only for nectar (Bumblebee Conservation Trust). There is evidence that Fabaceae and Asteraceae provide different nectar/pollen resources for bumblebees. In the UK, Fabaceae has been shown to be the largest source of pollen for bumblebees (Goulson et al. 2005). Asteraceae, while being used very little for pollen, was found to be an important source of nectar. This could explain the difference in association with these families between male and female bumblebees in the RMIC. Another factor influencing this difference could be the differing phenology of male and female bumblebees, for example if more asters are available later in the season, when male bees are foraging.

Goulson et al. (2005) suggests that the loss of Fabaceae-rich grasslands may be an important factor in the decline of many *Bombus* species. In addition, the distribution of several UK species may be best explained by their close association with Ericaceae and their specialization to utilize those plants in moorland and heathland habitats (Goulson et al. 2005). Knowledge of what plant species and families bumblebees rely on informs our understanding of bumblebee distribution, ecology, and conservation. Further study of these associations will improve our ability to effectively protect bumblebees and the resources they need.

## **Conclusions**

Records associated with *Bombus* specimens in the RMIC illustrate clear temporal patterns that are consistent with published literature describing the natural history of bumblebees. The timing of occurrences of queen, worker, and male bees was consistent with descriptions of how a colony grows and develops. Significant differences were found in the plant taxa that male and female bumblebees in the RMIC were associated with. This could be due to differences in pollen/nectar requirements between sexes and differences and differences in pollen nutrition between plants. Detailed records such as Morgan's can improve our understanding of queen bumblebees and how they establish colonies, which can have significant implications for conservation. The extensive information Morgan included about plant associations and phenology provides a valuable resource for studying pollination networks and climate change.

Bumblebees are important native pollinators that benefit both natural and agricultural systems. Bumblebee populations face many diverse threats, and therefore there is likely no single best strategy for their conservation. A variety of issues must be addressed in order to protect bumblebees. Knowledge of bumblebee ecology is crucial in supporting conservation efforts, and further research on a wide array of topics such as *Bombus* phenology, floral use, distribution will greatly contribute to our ability to effectively protect bumblebees.

## **Acknowledgements**

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