

**Investigating the relationship between *Bombus appositus* abundance
and its overlap with key floral resources**

Emilie Gitter

Mentors: Drs. Jane Ogilvie & Paul CaraDonna

Rocky Mountain Biological Laboratory Independent Research and Ecosystems Course 2021

Keywords: bumble bees, floral resources, phenology, plant-pollinator interactions, climate
change

Abstract

Many species of bumble bees (*Bombus* spp.) are experiencing population declines. In subalpine ecosystems, climate change is altering floral phenology by causing an earlier blooming period, which creates a growing season with sparser resources. Since bumble bees and their floral resources depend on phenological overlap for their mutualistic relationship to function, it is possible that changing floral phenologies could negatively impact pollinators. *Bombus appositus* is a pollinator of concern due its relatively narrow diet breadth and variable population abundance in the past seven years of study in the subalpine ecosystems near the Rocky Mountain Biological Laboratory (RMBL). In this study, we explored the relationship between *B. appositus* worker abundance and the number of weeks of phenological overlap between bees and floral resources from 2015 - 2020. We also compared *B. appositus* worker abundance with the total floral abundance of *B. appositus*' four key floral resources. We found no relationship between the number of weeks of phenological overlap and worker abundance, but we found a strong positive relationship between worker abundance and floral resource abundance. Overall, years with more floral resources gave rise to greater colony growth as measured in worker abundance. Floral abundance is strongly tied to climate conditions, which means that in the future, it will be increasingly important to understand how floral abundance varies with climate since the quantity of floral resources will ultimately impact bumble bee populations.

Introduction

Bumble bees (*Bombus* spp.) are important pollinators for plants in both agricultural and natural systems (Klein et al., 2007; Hegland and Totland, 2008; Garratt et al., 2014). Of concern is the fact that many bumble bee species are experiencing widespread population declines (Cameron et al., 2011; Cameron and Sadd, 2020) or are predicted to experience declines in the coming decades (Soroye et al., 2020). The primary hypothesized drivers of population declines for bumble bees include habitat loss, parasites, the use of pesticides in agriculture, and climate change (Goulson et al., 2015). In high elevation communities, climate change is of particular concern, as climate conditions are changing rapidly (IPCC, 2014). It is particularly important to study ecosystems at high elevations because these systems are experiencing the effects of climate change much faster compared to systems at lower elevations. Additionally, subalpine ecosystems tend to be less disturbed, which can allow us to better isolate climate change effects from other confounding factors. Studying bumble bee populations at high elevations can therefore give us insight into how pollinator communities are responding to ongoing global change.

Bumble bees and their floral resources have a mutualistic relationship in which bees rely on floral resources for nutrition and flowering plants rely on bees for pollination, which allows them to reproduce by creating a seedset (Michener, 2007; Rafferty et al., 2015). Understanding the availability of key floral resources for pollinators is important because bumble bees rely on a continual supply of resources throughout the growing season in order to survive (Goulson, 2010). In the beginning of the season, queens forage while nest searching and producing a

brood; in mid-season, workers take over foraging responsibilities from the queen; and in late season, the colony produces reproductive males and queens (Goulson, 2010). It was reported in a two year study of five bumble bee species that their abundance was greatest when floral resources were abundant across the growing season and declined when resources were low, though the abundance of one species was unresponsive to variation in resources across the season (Kudo, 2014). If bumble bees continually experience days with scarce resources, this could be of great concern to long-term population viability.

Plants and pollinators rely on phenological overlaps for their mutualistic relationship to function. Since adult bees obtain most of their sustenance from nectar and pollen produced by flowers, the timing of flower blooming is essential to the viability of pollinator populations. It has been hypothesized that climate change has the potential to disrupt plant-pollinator interactions by altering the timing of floral resource availability for pollinators (Hegland et al., 2009). Due to warming temperatures, many flowers are blooming earlier in the growing season in subalpine ecosystems (Kudo and Ida, 2013; CaraDonna et al., 2014; Cain, 2021). Additionally, it has been documented that with changing climate patterns, the growing season is extending, creating a mid-season gap in floral resources (Aldridge et al., 2011; CaraDonna et al., 2014; Ogilvie et al., 2017). When the growing season becomes longer, the same amount of floral resources are spread out over a longer period of time, meaning that at any given time, resources are more sparse compared to when the growing season was shorter (CaraDonna et al., 2014; Ogilvie et al., 2017).

There is currently little evidence of extreme phenological mismatch between plants and pollinators in which the timing of bee activity does not overlap with the blooming period of floral resources (Forrest, 2015). This finding seems to suggest that plants and their pollinators respond similarly to changing environmental cues (Forrest, 2015), that changes are not enough to completely decouple plants and pollinators in time, and/or that abundant resources are available despite changing phenologies. However, climate change has the potential to shift plant and pollinator phenologies in more subtle ways since it is unlikely that plants and pollinators will continue to respond to global change in complete synchrony (McKinney et al., 2012; Burkle et al., 2013).

It is largely unknown whether nuanced phenological asynchronies between plants and pollinators have an effect on population dynamics (Iler et al., 2021). It is worth investigating the extent to which phenological asynchronies influence important measures of bumble bee populations in subalpine plant-pollinator communities and if they may contribute to pollinator declines. *Bombus appositus* is a subalpine pollinator of concern due to its variable population abundance over the past seven years at the Rocky Mountain Biological Laboratory (RMBL) (Ogilvie and CaraDonna, unpublished data). Additionally, *B. appositus* exhibits a relatively narrow diet breadth in which it primarily forages from four select floral resources: *Delphinium nuttallianum*, *Lathyrus leucanthus*, *Vicia americana*, and *Delphinium barbeyi*. These flower species bloom at different times during the growing season, ranging from late spring to late summer, but cumulatively are available for most of the growing season. Because *B. appositus*

primarily relies on only four flower species for food resources, this could make this species more vulnerable to potential phenological changes that may be developing due to climate change.

In order to better understand the relationship between *B. appositus* abundance and its key floral resources, we investigated overlapping phenologies of *B. appositus* and its key floral resources over six years (2015 - 2020) in subalpine ecosystems in Colorado. We specifically explored the potential relationships between (1) *B. appositus* worker abundance and its overlap with key resources and (2) *B. appositus* worker abundance and floral abundance of key resources. We hypothesized that the number of weeks of phenological overlap would predict worker abundance. Alternatively, we hypothesized that phenological overlap would have no effect on worker abundance, and that flower abundance would instead predict worker abundance.

Methods

Long-term Monitoring of Bumble Bee and Floral Resource Abundance

Drs. Jane E. Ogilvie and Paul J. CaraDonna have been monitoring the abundance of bumble bees and their floral resources in subalpine ecosystems near RMBL in Gothic, Colorado for the past six years (2015 - 2020). Monitoring occurs during the growing season, which begins when the winter snowpack melts and extends until temperatures are frequently cold in the fall (September - October). Six study sites are distributed within the East River Valley near the RMBL; each study site includes three major habitat types: wet meadow, dry meadow, and aspen forest (Figure 1). Dr. Jane Ogilvie (J.E.O) has been monitoring the abundance and activity of 15 bumble bee species. Each week, J.E.O spends one hour at each site (20 minutes in each habitat type) observing bumble bees by walking along established transects. With every bumble bee observation, she notes the behavior (in flight, nest searching, foraging) and caste (queen, worker, male); if the bumble bee is foraging, she notes which flower species the bee is foraging from, whether the bee is collecting nectar and/or pollen, and if the bee has a visible corbicula pollen load. Bumble bees are identified to species and are only netted if J.E.O is unable to distinguish the identity of the bee.

At the same six sites, we have been quantifying the species richness and abundance of floral resources used by bumble bees over the past six years (2015 - 2020). Each week, the field team counts bumble bee pollinated flowers within permanent transects using multi-unit tally counters. Transects are 0.5 x 100 m in length in each habitat type and are divided into five 0.5 x 20 m segments. Spreading out transects within each site helps capture the floral variability across the area of each site. Open flowers in the transects that appear to be active nectar and pollen resources for bumble bees are counted. Only bee-pollinated flowers are counted.

Study species

In this study, we focused on *B. appositus* and its key floral resources. *Bombus appositus* is a long-tongued subalpine bumble bee with a relatively narrow diet breadth, meaning that it relies on select floral resources for food. *Bombus appositus* primarily forages from four key floral resources at our study sites: *Delphinium nuttallianum*, *Lathyrus leucanthus*, *Vicia*

americana, and *Delphinium barbeyi*. These four plant species represent 87% of visits made by *B. appositus* queens and workers over 2015 - 2020.

Comparing Overlap between B. appositus and Key Floral Resources

Using the long-term bumble bee observation data in combination with flower count data, we compared phenological overlap (i.e. potential synchrony) between *B. appositus* and its key floral resources. We added up the number of weeks that key floral resources (*Delphinium nuttallianum*, *Lathyrus leucanthus*, *Vicia americana*, and *Delphinium barbeyi*) were available when *B. appositus* was active for each of the six sites in each of the six years that bumble bee and floral resource data have been collected (2015 - 2020). We determined a threshold for floral abundance and counted how many weeks within a growing season that *Delphinium nuttallianum*, *Lathyrus leucanthus*, *Vicia americana*, and *Delphinium barbeyi* were available resources in sufficient quantities (following Ogilvie et al., 2017). We also determined the number of weeks that key floral resources overlap with *B. appositus*.

Statistical Analysis

All statistical analyses were performed using R 1.4.1717 (RStudio Team, 2021). To address whether the number of weeks of overlap affects *B. appositus* worker abundance, we used a generalized linear mixed effects model with seasonal worker abundance as the response variable and number of weeks of overlap as the predictor. We included site as a random effect and used a negative binomial distribution to account for the overdispersed bumble bee count data.

In our analysis, we established a floral abundance threshold: we only included floral abundances greater than 0.5 flowers/meter at a site as a week of overlap. A similar floral abundance threshold approach was related to bumble bee abundance within the same study ecosystem (Ogilvie et al. 2017). Floral abundance values less than 0.5 flowers/meter were excluded since such a small number of flowers would not be sufficient to support a *B. appositus* population's resource requirements. We calculated overlapping phenologies of *B. appositus* and its key floral resources by determining the number of weeks during the growing season in which *B. appositus* workers are active and > 0.5 flowers/meter (*Delphinium nuttallianum*, *Lathyrus leucanthus*, *Vicia americana*, and *Delphinium barbeyi*) were blooming. We scaled weekly floral abundance as flowers per meter per site to account for a smaller area sampled in 2015 (due to fewer transects) compared to 2016 - 2020. Similarly, we scaled weekly bumble bee abundance to 60 minutes of sampling to account for some sample sessions that were longer than 60 minutes (in 2015), and other years that occasionally had sampling sessions shorter than 60 minutes.

To address whether the seasonal floral abundance of *Delphinium nuttallianum*, *Lathyrus leucanthus*, *Vicia americana*, and *Delphinium barbeyi* affects *B. appositus* worker abundance, we used a generalized linear mixed effects model with seasonal worker abundance as the response variable and seasonal flower abundance as the predictor. Similar to the first model, we included

site as a random effect and used a negative binomial distribution to account for the overdispersed bumble bee count data.

Results

We observed moderate variation in the number of weeks of overlap across years and sites: the number of weeks of overlap ranged from seven to twelve weeks across our six sites over six years (Figure 2). Nine weeks of overlap was most frequent over the course of the growing season, while seven and twelve weeks of overlap was least frequent (Figure 2). There was no relationship between number of weeks of overlap and *B. appositus* worker abundance from 2015 - 2020 ($z = 1.185$, $P = 0.236$; Figure 2). We observed substantial variation in seasonal floral abundance (total flowers/meter) for *Delphinium nuttallianum*, *Lathyrus leucanthus*, *Vicia americana*, and *Delphinium barbeyi* across six years (Figure 3). 2015 had the greatest seasonal floral abundance of 4,909.6 flowers/meter, while 2018 had the lowest seasonal floral abundance of 1,513.2 flowers/meter (Figure 3). We also observed great variation in the timing of peak floral abundance across years; peaks ranged from week 4 to week 12 of the growing season (Figure 3).

Similar to floral abundance, *B. appositus* worker abundance varied across years (Figure 3). 2017 had the greatest seasonal worker abundance of 228 bees while 2018 had the lowest worker abundance at 63 bees (Figure 3) at a site. *B. appositus* workers were active for the majority of the weeks that key resources were available (Figure 3). The timing of peak worker abundance was less variable compared to the timing of peak floral abundance (Figure 3). For most years, peak worker abundance occurred around week 10 to week 12 of the growing season, with the exception of 2020 when peak worker abundance was in week 5 (Figure 3). Peak worker abundance usually occurred after peak floral abundance (Figure 3).

Seasonal flower abundance for *Delphinium nuttallianum*, *Lathyrus leucanthus*, *Vicia americana*, and *Delphinium barbeyi* measured in total flowers/meter was a significant predictor for *B. appositus* seasonal worker abundance at our six study sites from 2015 - 2020 ($z = 2.334$, $P = 0.0196$; Figure 4). On average, as floral abundance (flowers/meter) increased, worker abundance increased (Figure 4). Standard error increased as floral abundance values exceeded 700 flowers/meter, suggesting that *B. appositus* abundance becomes more variable after reaching a certain floral abundance threshold in which flowers are available in sufficient quantities.

Discussion

The goals of this study were to determine (1) the relationship between *B. appositus* worker abundance and the number of weeks of phenological overlap between *B. appositus* workers and key floral resources and (2) the relationship between *B. appositus* worker abundance and floral abundance of four key floral resources. Our results suggest that there is no relationship between worker abundance and phenological overlap, as measured in the number of weeks of phenological overlap between *B. appositus* worker activity and the availability of key floral resources. We showed that even years with ample phenological overlap could result in low worker abundance, which disproves our first hypothesis that phenological overlap would predict

worker abundance. In contrast to phenological overlap, we found a strong positive relationship between seasonal *B. appositus* worker abundance and seasonal floral abundance of its four key floral resources. This finding is consistent with our second hypothesis that annual floral abundance would predict worker abundance. On average, years with more abundant floral resources gave rise to greater *B. appositus* colony growth as measured in worker abundance. The likely mechanism of floral abundance predicting worker abundance is that more flower units equates to more nectar and pollen availability, which is necessary for the production of more workers.

We observed great variation in *B. appositus* worker abundance across years with differing amounts of phenological overlap with floral resources. This finding is likely because we found that most years had effectively complete phenological overlap between *B. appositus* worker activity and key floral resource availability. Another explanation for why we did not observe a relationship between worker abundance and phenological overlap could be due to great variation in floral abundances across years. We did not observe any phenological asynchronies between *B. appositus* and its floral resources, which suggests that *B. appositus* and its floral resources are responding to similar environmental cues, such as temperature and snowmelt (Forrest, 2015). This pattern suggests that at least within the phenological synchrony conditions observed over the past six years (which represent a wide range of climate and flower conditions; b. barr, unpublished data), phenological asynchrony of *B. appositus* does not seem to be an issue of concern with climate change.

Similar to our findings, Forrest (2015) found that the phenologies of plants and pollinators seem to respond to similar environmental cues, although more research is needed to explore the potential for independent phenological shifts between co-occurring plants and pollinators. Kudo and Ida (2013) also found that the timing of flowering and the emergence of spring queens were strongly tied to the timing of snowmelt and spring temperatures. However, Kudo and Ida (2013) found that in years with early snowmelt, *C. ambigua* flowers bloomed before the first bumble bee detection, which resulted in a smaller seedset. Overall, more research is needed to better understand if phenological shifts will occur independently in co-occurring plants and pollinators, and if those shifts could affect bumble bee population vital rates. Since *B. appositus* exhibits a relatively narrow diet breadth compared to other *Bombus* spp., it would be expected that *Bombus* spp. with more flexible diet requirements would similarly not be experiencing phenological asynchronies despite shifting floral phenologies. However, similar analyses to this study would need to be conducted for other *Bombus* spp. with different diet breadths to test this hypothesis.

Our finding that peak worker abundance usually occurred somewhere between 1 - 4 weeks after peak flower abundance is generally consistent with the bumble bee life cycle. Bumble bee workers forage for nectar and pollen from their key floral resources to bring back to the queen, who uses those resources to produce a new brood (Goulson, 2010). Once the queen lays eggs, it takes approximately 2 - 4 weeks for those eggs to develop into adult workers (Heinrich, 2004). It is likely that at peak flower abundance, workers were able to gather enough

resources for their queen to produce a new brood, which produced peak worker abundance between 1 - 4 weeks later. In 2015 and 2016, peak worker abundance occurred before peak flower abundance, which was unexpected. Because peak worker abundance consistently occurs around week 10 to week 12 of the growing season, it is possible that environmental conditions were more favorable for *B. appositus*' key floral resources later in the season in the years 2015 and 2016, which is why we observed flowers peak after workers.

We found that seasonal floral abundance was a strong predictor for seasonal *B. appositus* worker abundance. The likely mechanism for this relationship is that years with more flowers means more resources for brood production and colony growth, which is consistent with the findings from Kudo (2014). A floral community with more nectar and pollen can support larger colony growth, which allows queens to produce more workers during the growing season. The substantial variation that we observed in floral abundance across years is likely due to variation in environmental conditions in each unique growing season, since floral abundance is strongly tied to climate (CaraDonna et al., 2014; Ogilvie et al., 2017). Specific climate variables that can influence floral abundance in subalpine plant communities include date of snowmelt (Inouye and McGuire, 1991; Inouye et al., 2002; Inouye, 2008), temperature, and cumulative precipitation during the growing season (Lambert et al., 2010; Iler et al., 2013). In general, years with an earlier date of snowmelt, warmer temperatures, and less precipitation tend to have less flowers. This evidence suggests that as the climate changes, floral abundances will become more variable, which could be concerning for pollinators.

One of the limitations of this study is that flower counts do not capture the entire story of the nutritional landscape available to pollinators (Baude et al., 2016). We used flower counts as a measure of floral resource availability (nectar and pollen) to bumble bees. However, it is unlikely that all four floral resources that we studied have equal quantities of nectar and pollen for pollinators to eat. This means that certain flowers likely provide more nectar and/or pollen than others, meaning that flower counts alone may not be a sufficient measure of floral resource availability in a plant-pollinator community (Baude et al., 2016). Future studies should aim to incorporate information about pollen mass and nectar volume and concentration with flower counts to gain a more accurate understanding of how much food is available to pollinators at any given time in the growing season.

In conclusion, the findings from this study suggest that we should shift our focus towards floral abundance as an issue of concern for pollinators rather than phenological asynchronies in the context of climate change. Since our results indicate that floral abundance is a strong predictor for *B. appositus* worker abundance, it is going to become increasingly more important for us to understand how floral abundance varies with different climate conditions. As the climate changes, it is probable that floral abundances will become more variable, which will likely have significant implications for bumble bee populations. Future studies should aim to better understand how the floral resource landscape may change over time and how this will impact important pollinator species.

Acknowledgements

We thank Drs. Jane Ogilvie and Paul CaraDonna for their intellectual contributions to ideas, statistical analyses, and critical review of the final paper. We also thank Dr. Jane Ogilvie for contributing her bumble bee observational data. We are grateful to all of the members of the field team that have helped collect floral abundance data over the past seven years. We thank Jackie Fitzgerald for her help with making figures. This study was partially funded by the Rocky Mountain Biological Laboratory.

Literature Cited

- Aldridge, G., D.W. Inouye, J.R.K. Forrest, W.A. Barr, and A.J. Miller-Rushing. 2011. Emergence of mid-season period of low floral resources in a montane meadow ecosystem associated with climate change. *J. Ecol.* 99: 905–913.
- Baude, M., W.E. Kunin, N.D. Boatman, S. Conyers, N. Davies, M.A.K. Gillespie, R.D. Morton, S.M. Smart, and J. Memmott. 2016. Historical nectar assessment reveals the fall and rise of floral resources in Britain. *Nature* 530: 85–88.
- Burkle L.A., J.C. Marlin, and T.M. Knight. 2013. Plant-pollinator interactions over 120 years: loss of species, co-occurrence, and function. *Science*. 29;339(6127):1611-5.
- Cain, J. 2021. Global warming, advancing bloom and evidence for pollinator plasticity from long-term bee emergence monitoring. *Insects* 12: 1–11.
- Cameron, S.A., J.D. Lozier, J.P. Strange, J.B. Koch, N. Cordes, and L.F. Solter. 2011. Patterns of widespread decline in North American bumble bees. *Proc. Natl Acad. Sci. USA* 108: 662–667.
- Cameron, S. A., and B. M. Sadd. 2020. Global trends in bumble bee health. *Annual Review of Entomology* 65: 209–232.
- CaraDonna, P. J., A. M. Iler, and D. W. Inouye. 2014. Shifts in flowering phenology reshape a subalpine plant community. *Proceedings of the National Academy of Sciences, USA* 111: 4916–4921.
- Forrest, J. 2015. Plant-pollinator interactions and phenological change: what can we learn about climate impacts from experiments and observations? *Oikos* 124: 4–13.
- Garratt, M.P.D., D.J. Coston, C.L. Truslove, M.G. Lappage, C. Polce, and R. Dean. 2014. The identity of crop pollinators helps target conservation for improved ecosystem services. *Biol. Conserv.* 169: 128–135.
- Goulson, D. 2010. *Bumblebees: Behaviour, ecology, and conservation*. 2nd edn. Oxford University Press, Oxford.
- Goulson, D., E. Nicholls, C. Botías, and E.L. Rotheray. 2015. Bee declines driven by combined stress from parasites, pesticides, and lack of flowers. *Science* 347: 1255957.
- Hegland, S.J. and Ø. Totland. 2008. Is the magnitude of pollen limitation in a plant community affected by pollinator visitation and plant species specialisation levels? *Oikos* 117: 883–891.

- Hegland, S.J., A. Nielsen, A. Lázaro, A. Bjerknes, and Ø. Totland. 2009. How does climate warming affect plant-pollinator interactions? *Ecology Letters* 12: 184–195.
- Heinrich, B. 2004. *Bumblebee Economics*. Harvard University Press.
- Iler, A.M., T.T. Høye, D.W. Inouye, and N.M. Schmidt. 2013. Nonlinear flowering responses to climate: are species approaching their limits of phenological change? *Philos. Trans. R. Soc. Lond. B Biol. Sci.* 368: 20120489.
- Iler, A.M., P.J. CaraDonna, J.R.K. Forrest, and E. Post. 2021 (in press). Demographic consequences of phenological shifts in response to climate change. *Annual Review of Ecology, Evolution & Systematics*.
- Inouye, D.W. and A.D. McGuire. 1991. Effects of snowpack on timing and abundance of flowering in *Delphinium nelsonii* (Ranunculaceae): implications for climate change. *American Journal of Botany* 78(7): 997–1001.
- Inouye, D.W., M.A. Morales, and G.T. Dodge. 2002. Variation in timing and abundance of flowering by *Delphinium barbeyi* Huth (Ranunculaceae): the roles of snowpack, frost, and La Niña, in the context of climate change. *Oecologia* 130(4): 543–550.
- Inouye, D.W. 2008. Effects of climate change on phenology, frost damage, and floral abundance of montane wildflowers. *Ecology* 89(2): 353–362.
- IPCC. 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R. K. Pachauri and L. A. Meyer (eds.)]. IPCC, Geneva, Switzerland.
- Klein, A.M., B.E. Vaissiere, J.H. Cane, I. Steffan-Dewenter, S.A. Cunningham, C. Kremen, and T. Tscharntke. 2007. Importance of pollinators in changing landscapes for world crops. *Proc. R. Soc. Lond. B: Biol.* 274: 303–313.
- Kudo, G. and T.Y. Ida. 2013. Early onset of spring increases the phenological mismatch between plants and pollinators. *Ecology* 94(10): 2311–2320.
- Kudo, G. 2014. Vulnerability of phenological synchrony between plants and pollinators in an alpine ecosystem. *Ecol. Res.* 29: 571–581.
- Lambert, A.M., A.J. Miller-Rushing, and D.W. Inouye. 2010. Changes in snowmelt date and summer precipitation affect the flowering phenology of *Erythronium grandiflorum* (glacier lily; Liliaceae). *Am. J. Bot.* 97: 1431–1437.
- McKinney, A.M., P.J. CaraDonna, D.W. Inouye, B. Barr, C.D. Bertelsen, and N.M. Waser. 2012. Asynchronous changes in phenology of migrating Broad-tailed Hummingbirds and their early-season nectar resources. *Ecology* 93(9): 1987–93.
- Michener, C.D. 2007. *The Bees of the World*. The Johns Hopkins University Press.
- Ogilvie, J.E., S.R. Griffin, Z.J. Gezon, B.D. Inouye, N. Underwood, D.W. Inouye, and R.E. Irwin. 2017. Interannual bumble bee abundance is driven by indirect climate effects on floral resource phenology. *Ecology Letters* 20: 1507–1515.
- Rafferty, N.E., P.J. CaraDonna, and J.L. Bronstein. 2015. Phenological shifts and the fate of mutualisms. *Oikos* 124(1): 14–21.
- RStudio Team (2021). RStudio: Integrated Development Environment for R. RStudio, PBC,

Boston, MA URL <http://www.rstudio.com/>.
 Soroye, P, T. Newbold, and J. Kerr. 2020. Climate change contributes to widespread declines among bumblebees across continents. *Science* 367(6478): 685–688.

Figure Legend

Figure 1. Vicinity map representing six study sites distributed within the East River Valley near the Rocky Mountain Biological Laboratory (RMBL), Gothic, CO. Research sites were established by Jane Ogilvie in 2015.

Figure 2. *Bombus appositus* worker abundance vs. number of weeks of overlap with four key floral resources at six study sites distributed within the East River Valley near the RMBL, Gothic, CO (n = 36). Data was collected during the growing season from 2015 - 2020. There was no significant relationship between number of weeks of overlap and worker abundance using a generalized linear mixed effects model ($P = 0.236$).

Figure 3. Seasonal floral abundance (total flowers/meter) (purple) for *Delphinium nuttallianum*, *Lathyrus leucanthus*, *Vicia americana*, and *Delphinium barbeyi* and seasonal *Bombus appositus* worker abundance (total bees) (yellow) across weeks of the growing season at six sites distributed within the East River Valley near the RMBL, Gothic, CO (n = 36). Data was collected from 2015 - 2020. The dashed purple line represents the week with peak flower abundance. The dashed yellow line represents the week with peak worker abundance.

Figure 4. The relationship between *Bombus appositus* worker abundance and the floral abundance of four key floral resources over the season. Data was collected from six study sites distributed within the East River Valley near the RMBL, Gothic, CO from 2015 - 2020 (n = 36). There is a significant positive relationship using a generalized linear mixed effects model with a negative binomial distribution and site as a random effect ($P = 0.0196$).

Jane Ogilvie's Research Sites

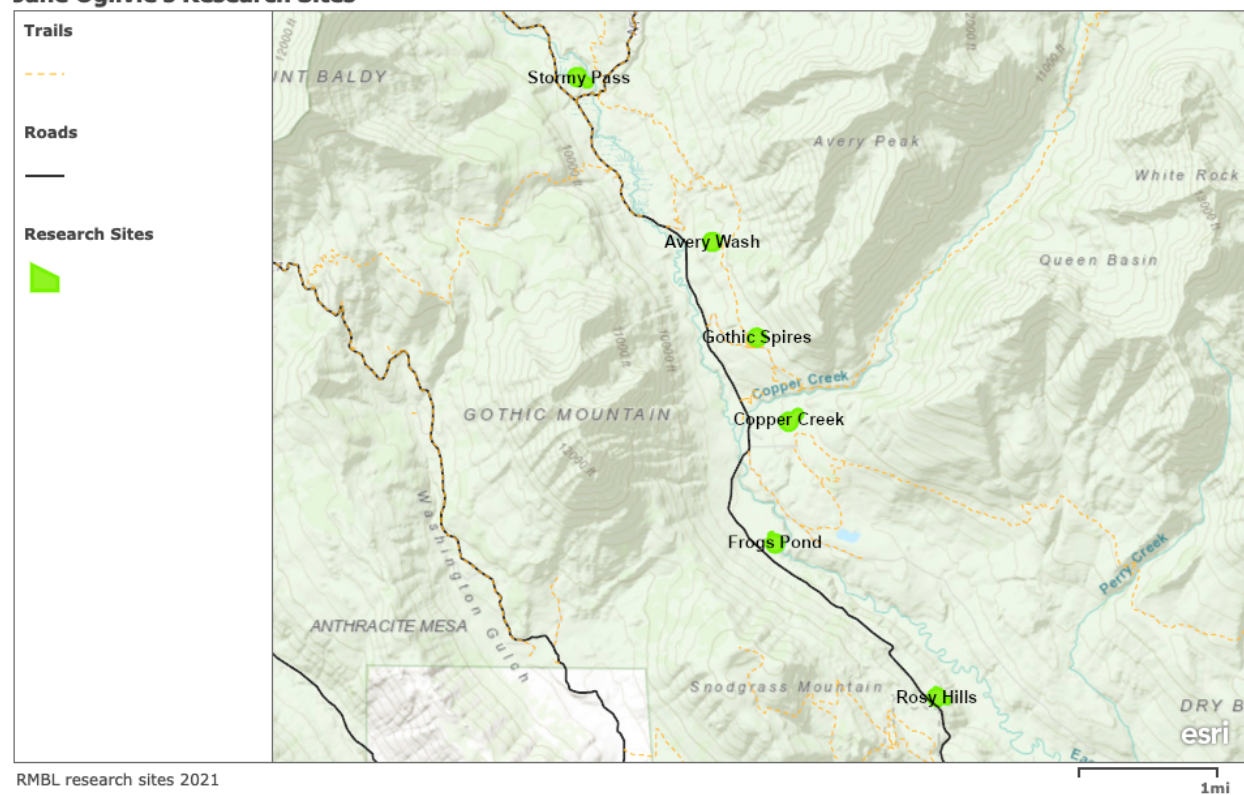


Figure 1

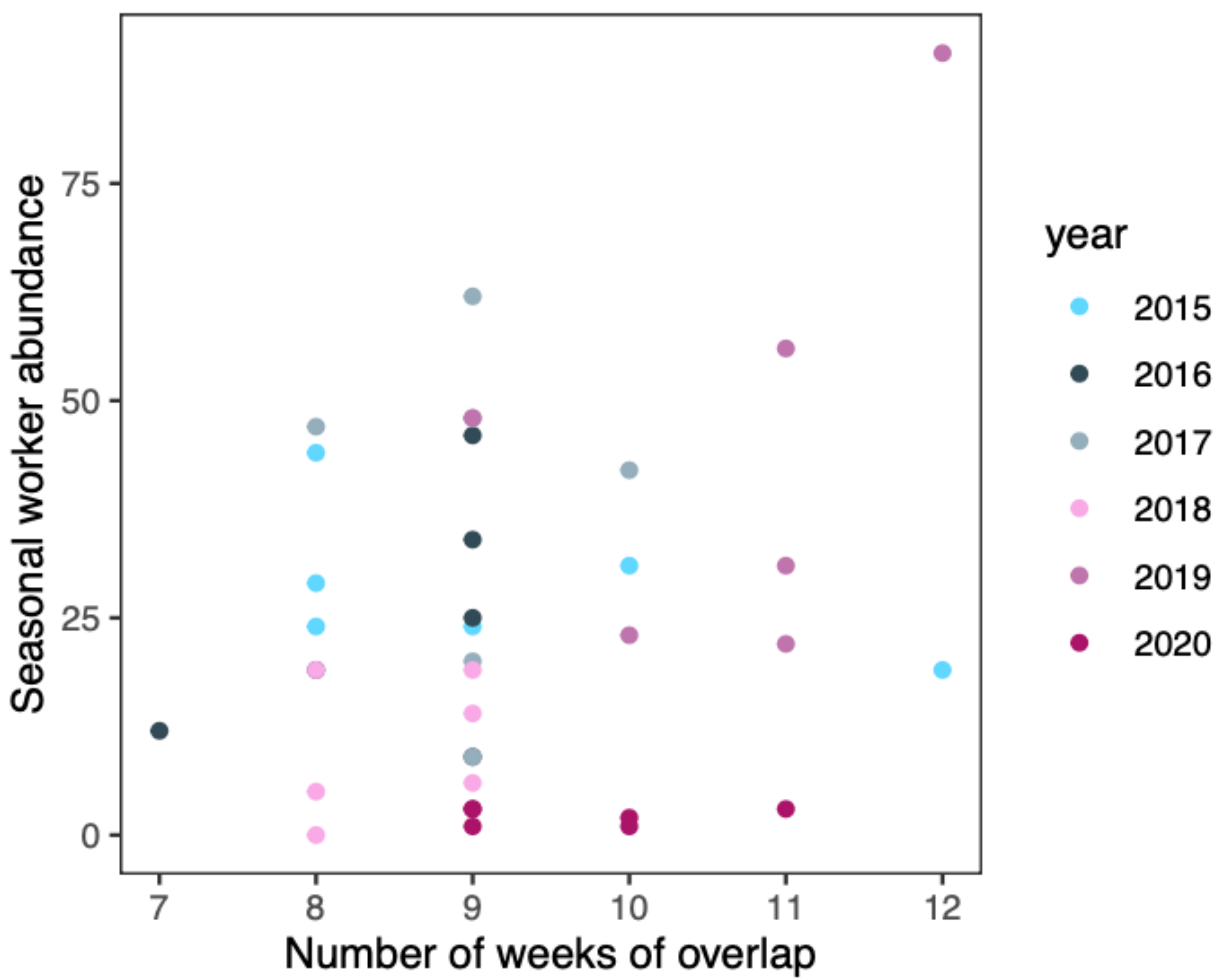


Figure 2



Figure 3

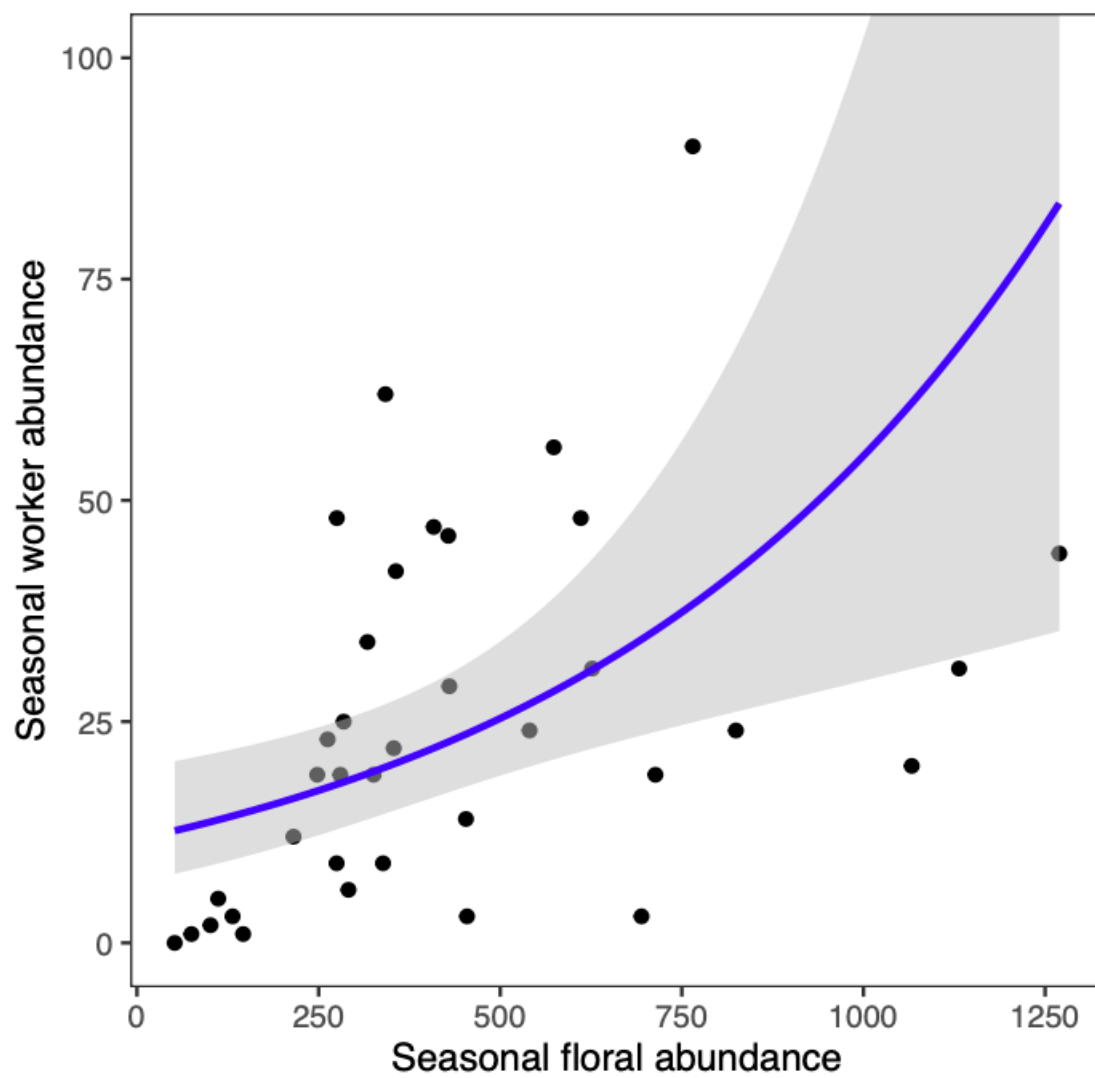


Figure 4