

Title: Nowhere to go but Up: Investigating Bumble Bee population Shifts over Elevational Gradients

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Abstract

Bumble bees are important pollinators in both the wild and in agriculture; however, several species globally are under threat due to multiple anthropogenic factors. One of these threats is climate change, and many bumble bee species have adapted by moving up in elevation. This has only been observed in specific species, but it does stand to question that with the most recent dramatic global temperature increases, if this will become standard for all species. While this provides the benefit of keeping to a thermal environment necessary for survival and reproduction, competition facilitated by mass migration and isolation could be driving some species further towards extinction. Therefore, it is necessary to understand how species distributions have changed across elevation gradients over the past few years and to understand the mechanisms involved. Results indicate a lack of significance in the data, leading to inconclusive results for the proposed hypotheses. Further experimenting with additional years and low and high elevation sites is necessary to fully evaluate how species are moving.

Introduction:

Bumble bees (*Bombus*) are crucial pollinators, contributing to 20% of wild plants that depend solely on bee pollination (Ollerton, 2017) and are the most effective species at crop pollination (Abrol et al., 2022). However, bumble bee populations worldwide are facing significant declines, largely attributed to anthropogenic factors such as habitat loss, pesticide use, parasites, viruses, and climate change (Cameron & Sadd, 2020). Of these factors, climate change has emerged as a dominant force, disrupting bumble bee populations' survival (Pyke et al., 2016) as well as the temporal overlap between bumble bees and their floral resources (Ogilvie et al., 2017; Freimuth et al., 2022). It is critical to understand how *Bombus sp.* react to climate change, within their environment and between species in order to inform restoration and protection efforts.

One response to increasing temperatures has been for populations to shift upwards across elevational gradients, i.e. moving to a higher elevation, as well as across latitudes, to follow optimal temperature for organismal survival, growth and reproduction (Laiolo et al., 2017). Multiple fauna and flora have been recorded to do so. For example, one study in the Rocky Mountains saw 26 different small mammals species moving up an average of 131m (McCain et al., 2021). Elevation changes have also been observed in certain *Bombus sp.*, like *B. occidentalis* and *B. frigidus* (two vulnerable Rocky Mountain species (Bumble Bee Conservation, 2024)) to

maintain the required temperature conditions (Pyke et al., 2016). While population shifts can benefit species in keeping them in their optimal thermal conditions, shifts can also pose a variety of ecological issues for populations existing in that elevational area, especially given that not all species are expected to shift at the same rate or to the same degree. For example, shifts can increase competition for resources between species (Cameron & Sadd, 2020). Shifts could also create an isolated landscape, since species don't shift down in mountainous regions and can become trapped on an elevational island (Cameron & Sadd, 2020). Moreover, when species have nowhere else to go but up, where do they go when there is no more 'up?' The combination of stressors impacts all species in the environment in different ways, hindering some while creating the perfect conditions for others to succeed. In this project, I ask the following questions: (1) what, if any, bumble bee species have moved up in elevation? (2) Have the relative abundances of bumble bee species at low, intermediate, and high elevations changed over the last 15 years, and (3) what climate variables are associated with species changes?

A study at the Rocky Mountain Biological Lab compared plant and bumble bee species density and distribution at various elevations between 1974 and 2007. Overall, the study found that climate change has led to reduced bumble bee populations and an upward shift in species distributions (Pyke et al., 2016). However, the study noted a lack of elevational shifts among certain bumble bee species and most plant species. Further, the documented changes in elevation did not align with the anticipated elevation changes required to maintain historic temperature regimes for the species, often falling short of predictions. Although plant phenology advanced earlier in the season due to climate shifts, bumble bees did not adjust their timing, resulting in decreased synchrony between flowering plants and bees. This asynchrony may have contributed to a decline in bumble bee abundance (Pyke et al., 2016). However, global average temperatures have increased dramatically since 2007, almost doubling from 0.66°C to the current 1.18°C of 2023 (*Climate Change*, 2024), inviting a revisitation to *Bombus sp.* populations in the Rockies to investigate how they have further changed. In addition, Pyke et al. (2016) focused on sites at and above the elevation of Crested Butte, Colorado and did not consider how lower-elevation bumble bee species, such as *Bombus huntii*, may be changing in distribution.

This study analyzes data collected by the Irwin lab at RMBL between 2009 and 2021. I predicted that low elevation *Bombus sp.*, like *Bombus huntii*, has moved up to intermediate-elevation sites. I also predict that due to the movement of *Bombus sp.* from lower to higher elevations, higher-elevation *Bombus sp.* will exist in smaller populations compared to their new, lower-elevation shifting neighbors. Finally, I anticipate that climate variables, such as mean maximum temperature, will be associated with species shifts, if they exist.

Methods:

Study Site Information

I used data collected from 16 sites prior to and during this season. Sites were pre-determined and are part of the Irwin Lab's long-term "Phenology of subalpine bee and plant communities in the Rocky Mountains of central Colorado" project. Site locations were a mix of RMBL, private, state, and federal-owned property, and were divided into 3 different elevational categories: low

elevation, mid elevation, and high elevation. These distributions include the following site names below:

Low elevation sites: Almont, Almont Curve, CDOT, Lypps

Mid elevation sites: Block A: David's, Tuttle, Willey

Block B: Sean's, Beaver, Gothic

Block D: Hill, Little, Copper; Rustlers

High elevation sites: Mexican Cut, N. Elko (originally Elko; was relocated from a wet depression in 2018. Data from both of these sites was combined to create "Combined Elko")

Each site had a similar layout: two 42m transects running approximately as perpendicular as possible to each other. The full span of each site was netted for bee collection.

Specimen Collection

Bumble bees were sampled between 2009 to 2024 annually during the summer (June, July, and August.) Bees were netted in each site for 1hr in the morning and 1hr in the afternoon, stopping the timer each time a bee is caught, then starting the clock once the bumble bee had been marked, cataloged and released. Collected bumble bees were (1) identified (if possible), (2) recorded, (3) marked with a spot on their thorax, (4) then released.

Any individuals that were collected within the field and needed to be taken in for sampling were stored in a vial, in a refrigerated area, in 70% ethanol until pinning. They were then (1) removed from ethanol, (2) pinned using standard/pre-established bee-pinning protocol, (3) identified, (4) and cataloged using standard procedure. These specimens were then stored with all the other individuals, mainly solitary bees, that make up the Irwin Lab's long-term phenomenology project.

These methods did not cause any short or long-term environmental impacts. Bumble bees were captured, cataloged, and marked utilizing a non-lethal method. They were immediately released back onto the site after the data-collection for the individual was complete. This method caused no damage to the bees nor to the environment. Only those which cannot be identified were kill-captured to be identified in the lab. This long-used method was rarely used for bumble bees and has demonstrated a lack of long-term environmental impact (Gezon et al., 2015).

For each bumble bee collected, the following was catalogued:

1. Location Captured (site)
2. Demographic information
 - a. Species
 - b. Caste (Queen, Worker, Drone)
3. Plant species visiting (or "air if flying and "ground" if on the ground)
4. Caught in morning (AM) or afternoon (PM)

Time netting started and ended was also noted, as well as how long each tech contributed to netting to make up the full hour. Sky quality and weather information were also noted.

Data Collection Method

Initial data collection was done on paper provided, then transferred after the collection time in the field on an official data sheet. These sheets were then scanned, hard copies stored, and their data transferred to a comprehensible digital format (Google sheets) in a format that has been pre-dictated by the phenology project.

Statistical Analysis

For assessing presence of *B. huntii* for my first hypothesis, I looked simply at the number of individuals yearly at each site. To answer my other questions, I calculated and compared relative abundance of *Bombus* sp. at low, mid, and high elevation sites. I focused on three common mid-elevation species (*B. appositus*, *B. birafrius*, and *B. flavifrons*) and three common high elevation species (*B. frigidus*, *B. balteatus*, *B. sylvicola*) for comparison. I used a two-way ANOVA, with year and elevation band (low, mid, and high) as a fixed effect and response variable is relative abundance (with a separate analysis for each species.) Regardless of if relative abundances had shifted with elevation, I used Gothic climate data collected by billy barr to assess whether there is an association between shifts and temperature. I used a two-way ANOVA test, using species and temperature as predictors, to compare relative abundance to average yearly maximum temperature over the past 12 years.

Results:

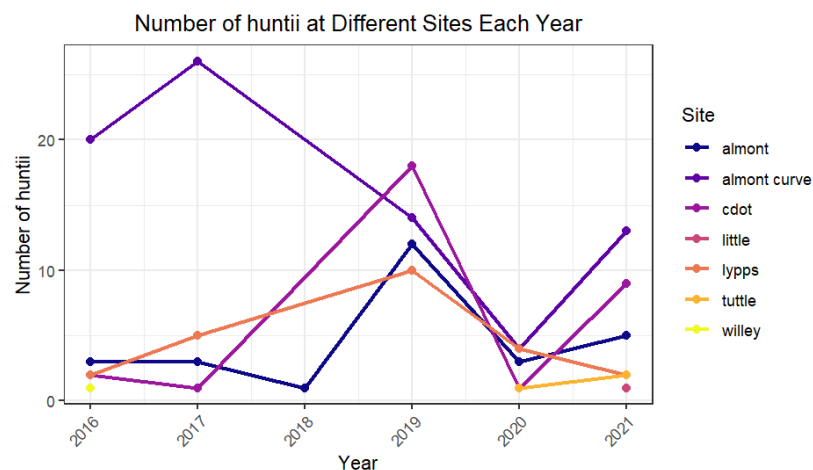


Figure 1: Number of *B. huntii* caught at different sites each year between 2009 to 2021 ($p = 0.0538$.) Plot only begins at the first capture of *B. huntii* (2016.)

There were not many individuals caught overall, with *B. huntii* only being observed at sites beginning in 2016. *B. huntii* individuals were seen to appear at mid-elevation sites with some consistency beginning in 2020, with Tuttle maintaining observable individuals into a second year (Figure 1). An individual did appear at Willey, a mid-elevation site, in 2016 but no

individuals were caught at Willey after that suggesting a deviating individual rather than sustained population. It is not possible to identify if this is the case with the individual caught at Little, as sample data ends in that year. ANOVA was performed and determined that there might be some differences in *Bombus huntii* counts across different sites, but the evidence is not strong enough ($p = 0.0538$) to conclude significant differences due to elevation.

Hypothesis 2

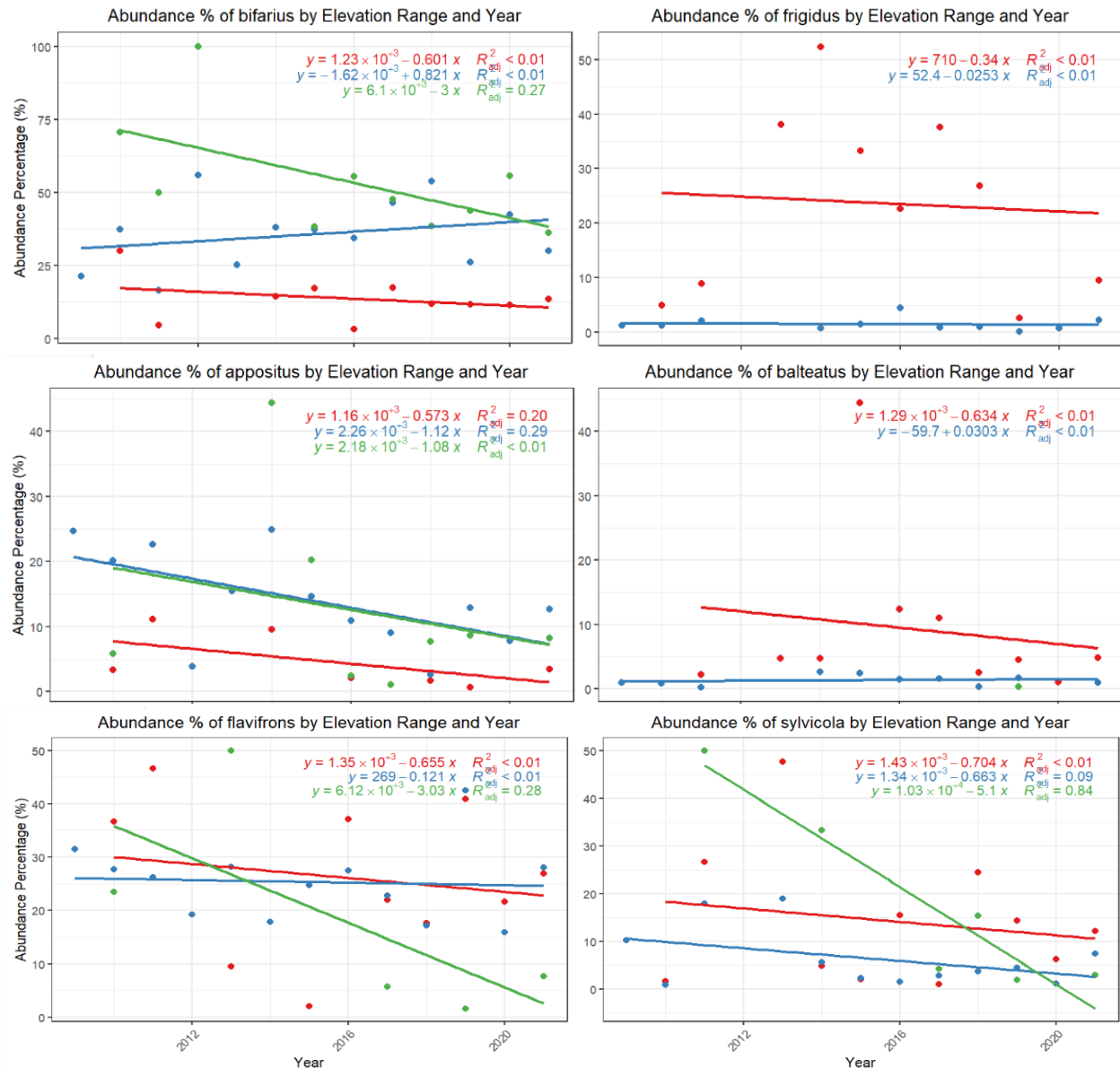


Figure 2: Side-by-side scatter-plots of species abundance percentages of a mid-elevation species (left) and a high-elevation species (right) from 2009 to 2021. Lines are lines of best fit with the green line representing low elevation sites, blue mid elevation sites, and red high elevation sites. All p -values were greater than 0.05.

Overall, all 3 high elevation *Bombus* species showed some minor level of decline at high elevation sites as demonstrated by negative slopes in their lines of best fit, but with $R^2 < 0.01$ for all high-elevation lines of best fit (Figure 2). *B. sylvicola* did have a large decline at low-elevation sites, with an R^2 value of 0.84. However, the p-value of 0.169 suggests that the elevation range does not have a statistically significant effect on the measured attribute of *B. sylvicola* at the 5% significance level. Mid-elevation species had varying results. *B. flavifrons* and *B. appostus* only saw declines in all elevation ranges. *B. bifarius*, the most common in the Rockies, showed an overall decline in both low and high elevations, but an overall increase at mid-elevation sites.

Hypothesis 3

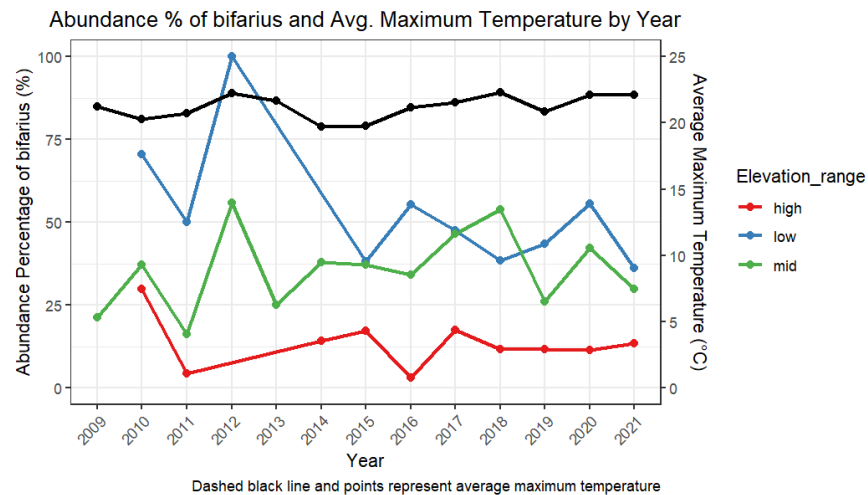


Figure 3: Species abundance percentage of *B. bifarius* and avg. max temperature by year from 2009 to 2021. P value is

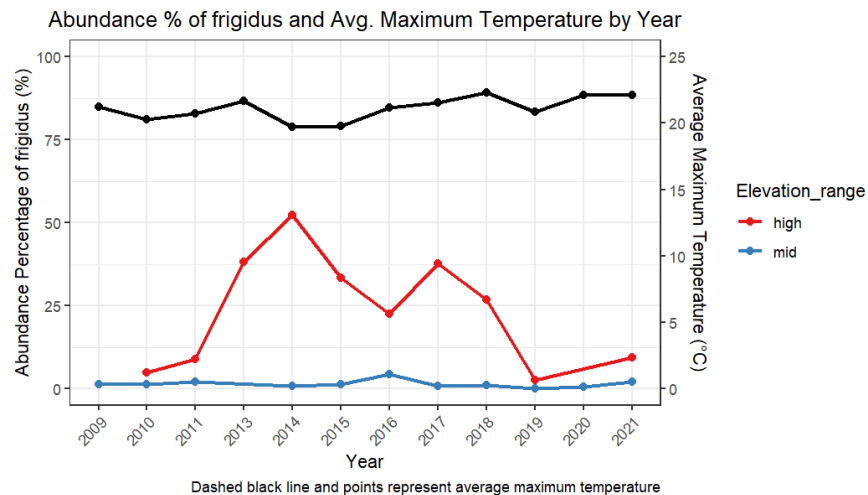


Figure 4: Species abundance percentage of *B. frigidus* and avg. max temperature by year from 2009 to 2021.

From 2009 to 2021, the maximum temperature in Gothic, the region of mid-elevation sites, experienced a minor increase from 21.2°C to 22.1°C; a ~1°C increase overall (Figure 3 & 4). While all species of focus had overall declines in populations in high elevation sites, all main *Bombus* sp. of focus demonstrated unique fluctuations in species population abundance over the 12 years of sampling, which is observable through the points in the scatter-plots (Figure 2). *B. bifarius* demonstrates the overall independence movement of mid-elevation species; specific to *B. bifarius*, high variation year to year of sp. abundance at mid and low elevation sites, with less variability in high elevation sites (Figure 3). These contrast to the average max temperatures each year, with elevation population densities not moving in tandem with predictions matching an overall temperature impact; high elevation populations did not increase exactly with increased temperature, mid-elevation populations did not decrease exactly with increased temperatures. In high-elevation species *B. frigidus*, mid elevations had almost no fluctuation, but high elevation population abundance had dramatic peaks that were independent of the observed max temperature changes each year (Figure 4).

Discussion:

Hypothesis 1

There initially appears to be evidence suggesting that *Bombus huntii* have moved upward in elevation, as indicated by their presence in mid-elevation sites such as Little and Tuttle since 2020 (Figure 1). However, there have been documented instances of this species reaching elevations as high as 4100m (Miller-Struttmann and Galen 2014). In this study, the highest elevation where *B. huntii* was recorded was 3052.67 meters, which is below that 4100m range. The figure also shows that an individual was caught at a mid-elevation site (Willey) in 2016, which supports their tendency to achieve higher elevations.

The limited number of individuals observed at these sites suggests that *B. huntii* has not established populations at these elevations; instead, they must be exploring and foraging. Additionally, there is insufficient yearly data to establish a clear trend, making it uncertain if *B. huntii*'s appearance at Little was a unique capture like at Willey in 2016. The ANOVA analysis demonstrated a lack of certainty in the results, leaving the outcome of the hypothesis in question.

Hypothesis 2

For there to be a proven hypothesis, there would have to have been a significant overall decline in high elevation sites for high-elevation *Bombus* sp. while simultaneously an overall increase of mid-elevation *Bombus* sp. in high-elevation sites. However, while all common high-elevation species did demonstrate some level of decline, all mid-elevation species also demonstrated an overall decline in high elevation sites. Additionally, all R^2 values associated with lines of best-fit for high elevations were less than 0.01, indicating a lack of correlation between species abundance at different site elevations. The lack of significance may indicate that other factors, not captured by the elevation range, are influencing the species, or it might reflect limited data or variability within the groups.

Hypothesis 3

As there was already a lack of correlation and a disproving of hypothesis 2, temperature was guaranteed to not have been the driving factor of species movement. This was further demonstrated by the large fluctuation of species abundance for each species from year to year over the entire sampling period.

Conclusion

Most results lack significance, leaving one inconclusive answer, and two disproven hypotheses. It cannot confidently be said if low elevation species have been moving up, as *B. huntii* could have established in the past few years since 2021. Additionally, species abundance in high elevations for high-elevation species are insignificant in their decline, while abundance in mid-elevation species has demonstrated the likelihood of decline in high elevations as well. Temperature is most likely not the main driver of species movement between elevations, suggesting that independent site or species drivers have a greater effect on species abundance and movement. There is a potential that with more years of sampling and additional sites that there may be a trend, but current evidence indicate focus should say on more regional drivers of population and movement including inter-species interactions, resources, and habitat availability.

References:

- Abrol, D. P., Mondal, A., & Shankar, U. (2022). *IMPORTANCE OF BUMBLE BEES FOR CROP POLLINATION AND FOOD SECURITY*.
- Bumble Bee Conservation*. (2024, June 18). Xerces Society.
<https://www.xerces.org/bumblebees>
- Cameron, S. A., & Sadd, B. M. (2020). Global Trends in Bumble Bee Health. *Annual Review of Entomology*, 65(1), 209–232. <https://doi.org/10.1146/annurev-ento-011118-111847>
- Climate Change: Global Temperature* | NOAA Climate.gov. (2024, January 18).
<http://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature>
- Freimuth, J., Bossdorf, O., Scheepens, J. F., & Willems, F. M. (2022). Climate warming changes synchrony of plants and pollinators. *Proceedings of the Royal Society B: Biological Sciences*, 289(1971), 20212142. <https://doi.org/10.1098/rspb.2021.2142>
- Laiolo, Paola, and José Ramón Obeso. "Life-history responses to the altitudinal gradient." *High mountain conservation in a changing world* (2017): 253-283.
- Ogilvie, J. E., Griffin, S. R., Gezon, Z. J., Inouye, B. D., Underwood, N., Inouye, D. W., & Irwin, R. E. (2017). Interannual bumble bee abundance is driven by indirect climate effects on floral resource phenology. *Ecology Letters*, 20(12), 1507–1515.
<https://doi.org/10.1111/ele.12854>

Ollerton, J. (2017). Pollinator Diversity: Distribution, Ecological Function, and Conservation. *Annual Review of Ecology, Evolution, and Systematics*, 48(Volume 48, 2017), 353–376. <https://doi.org/10.1146/annurev-ecolsys-110316-022919>

Pyke, G. H., Thomson, J. D., Inouye, D. W., & Miller, T. J. (2016). Effects of climate change on phenologies and distributions of bumble bees and the plants they visit. *Ecosphere*, 7(3), e01267. <https://doi.org/10.1002/ecs2.1267>

Unusually large upward shifts in cold-adapted, montane mammals as temperature warms—McCain—2021—Ecology—Wiley Online Library. (n.d.). Retrieved June 23, 2024, from <https://esajournals.onlinelibrary.wiley.com/doi/10.1002/ecy.3300>