

Changing distributions, Changing Climate: Using *Bombus* as an Indicator of Global Warming near Crested Butte, Colorado

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Abstract

As well-studied, annual species inhabiting an environment with a short growing season, the bumble bees (*Bombus* spp.) in the area around the Rocky Mountain Biological Laboratory (RMBL) near Crested Butte, Colorado, provide an ideal system for monitoring climate change. In 1974, Graham Pyke conducted a survey of the bumble communities around RMBL by conducting a series of five transects over varying elevational ranges. He found that bumble bee species with similar tongue lengths tend to replace each other along an elevational gradient. In 2007 we repeated Pyke's original transects to determine whether these transitions between bee species have changed in elevation. We also conducted floral surveys to determine whether any changes found in bee distributions were caused by changes in floral resources or by a direct effect of climate change. Within the groups based on tongue length, we found an overall increase in the relative abundance of low altitude species recorded and a decrease in the high altitude species. This corresponded with upward shifts in elevation in the transitions between species in all four transects investigated. For groups of bees with just one species, there was no directional shift in distribution. We did not find any major differences in floral distributions between the years, indicating that changes in *Bombus* distributions are experiencing a direct effect of climate change.

Introduction

Anthropogenic climate change, commonly referred to as global warming, is a critical and politically charged issue. Although the subject of much research, and supported by the belief of a majority of scientists, evidence for the effects of global warming remains ambiguous (Berliner 2003). The reason for the uncertainty is the tremendous variability associated with global weather and climate patterns and the relatively small changes that global warming predicts when looking at a short time scale. Thus, there is the need for a careful study of environmental indicators that are especially sensitive to changes in climate (de Groot *et al.* 1995)

In subalpine and alpine ecosystems, associated flora and fauna have adapted to very short growing seasons. Here, a slightly earlier snowmelt or a slightly later first snow cover caused by increased temperatures means a substantial percent increase in the growing season (Billick, pers com). In a series of studies done at the Rocky Mountain Biological Laboratory (RMBL, located in Gothic, Colorado), plots experimentally heated during the winter experienced snowmelt a week earlier and had a corresponding advance in fruit set in the earlier flowering species (Price & Waser 1998). The warming also may have caused changes in the vegetation, such as an increase in sagebrush (*Artemisia tridentata*) and shrubby cinquefoil (*Pentaphylloides floribunda*) (Harte & Shaw, 1995). Unfortunately these experimental data aren't comparable with natural observations. The snowmelt date at RMBL has remained relatively constant until the last several years (Inouye *et al.* 2000; Inouye, pers com). Because most plant species at RMBL are perennials (Inouye, pers com), the floral community composition may be slow to change despite the recent early snowmelt dates (Price & Waser, 2000).

Better candidates for monitoring climate change on a small time scale are bumble bees (*Bombus* spp.) Pollinators in general are very susceptible to changes in flowering phenologies.

An early snowmelt date may lead to a gap in the available floral resources for a species, which may lead to large changes in range, or even local extinction (Memmott et al., 2007). *Bombus*, unlike their cousins, the honey bees (*Apis*) are “annual” species, meaning only the present year’s queens overwinter. All males, workers, and old queens die by first snow cover (Free *et al.* 1959; Prys-Jones & Corbet 1991). Thus, *Bombus* may be prone to local extinctions and recolonizations caused by year-to-year climate differences (Bowers 1985). In addition, bumble bees with similar floral preferences tend to be in direct competition, and thus will tend to replace each other over minor changes in habitat (Inouye 1976; Pyke 1982). *Bombus* fauna can therefore be significantly different in as short a distance as 400 meters (Hanninen 1962).

The area around RMBL has records of approximately 13 regularly or semi-regularly occurring species of *Bombus* that vary in their microhabitat requirements (Inouye, pers com; Forrest, pers com). Fortunately, bumble bees and their pollination interactions have been well studied at RMBL (ex. Thomson 1980; Graham & Jones 1996; Irwin & Brody 1999). Especially relevant to a discussion of climate change is Pyke’s work in 1974 (pub. in 1982) and Inouye’s PhD. work the following summer. These studies surveyed the change of relative abundances of the *Bombus* spp. along 5 altitudinal gradients (3 of which were published; Pyke, 1982). Pyke put the bees in 4 groups based on “tongue” (glossa) length and resulting feeding behavior. Of the common species he recorded, *B. appositus* and *B. kirbyellus* are long-tongued, *B. flavifrons* is medium-tongued, *B. bifarius*, *B. frigidus*, and *B. silvicola* are short-tongued, and *B. occidentalis* is a short-tongued nectar robber. The species in the same group compete most directly for floral resources (Macior 1975; Harder 1985) and thus tend to replace each other in the order listed above moving from lower to higher elevations. Inouye repeated two of Pyke’s transects the following year (1975) and found, despite the inherent variability in *Bombus* populations, only

minor variations between the two years. Thus, drastic and consistent changes in relative abundances along the transects probably are not the result of chance or sampling error.

In 2007, Dan Clarke and Ljubica Lukic and I repeated the Pyke study under the guidance of David Inouye, Graham Pyke and James Thomson. Pyke returned from Australia to reconstruct all 5 his original transects. The goal of this study was to find and quantify any changes in *Bombus* distributions that have occurred in the area around RMBL, and to determine whether these changes could potentially be attributed to global warming, either through a change in floral composition of the sites or as direct effect of climate change.

Materials and Methods

The study took place from June 16 to August 2, 2007, at sites determined to be the same as or very close to the original study sites. Combined, the sites covered a range of elevation from about 2850 meters (just south of town of Gothic) to 3750 meters (top of “Schofield Mountain”, a peak unnamed on maps that is located east of Schofield Park and north of the West Maroon Pass trail). The sites were arranged along five transects, three being the ones discussed in Pyke’s paper. The other two, Bellview and the Kettle Pond road, are sites for which Pyke collected data, but did not include in the publication. The first three transects—Schofield, Washington Gulch, and Gothic Road—contain 7, 8 and 11 sites respectively. All sites within a transect were numbered from the lowest to the highest elevation. The Schofield and Washington Gulch transects are described in the 1982 paper and this study attempted to replicate them exactly. The only exception to this was the addition of a site at the bottom of the Schofield transect (near a bridge in Schofield Park) that Pyke surveyed but did not include in his paper. The Gothic Road transect sites represent a subset of the original 19 described in the paper. The omissions were

due to conflicts with other research, questions about the precise location of the site, and time constraints. The fourth transect, Bellview, ran from Gothic Road up the face of Bellview mountain, and consisted of a site at 3140 meters, and an additional five sites spanning the elevational gradients of 3150-3250, 3250-3330, 3330-3470, 3470-3640, and 3640-3700 meters. The fifth transect was sampled by Graham Pike and consisted of 5 sites along the Kettle pond road at elevations ranging from 2850 to 2870 meters. GPS coordinates for all the sites are available on the RMBL website.

We collected data for each transect approximately once a week from June 22 to the August 2, 2007. Each site was surveyed for at least 20 minutes each day, though in many cases, the time span was longer. At each site on each day, we independently conducted a floral survey of all plants flowering at the site (excluding grasses and sedges) and rated the abundance of flowers per species on a four-point scale (Table 1). We used an additional five-point scale as a phenological index (Table 2). The floral assessments were averaged for each site across observers and compiled. For any unknown plants, we recorded a description and collected a voucher specimen to be later identified using Weber and Wittmann's *Colorado Flora: Western Slope*, Third Edition (2001) or a trained botanist.

Table 1. Description of the ranking system we propose to use for quantifying the phenology of plant species that are visited by bees.

Rank	Description
1	One to several individuals
2	Scattered occurrence
3	Moderately abundant
4	A dominant species

Table 2. Description of the ranking system we propose to use for quantifying the abundance of plant species that are in flower.

Rank	Description
1	One to a few flowers beginning to open
2	Some flowers open but mostly buds
3	Mostly open flowers
4	Some flowers open but mostly fruits
5	One to a few flowers remaining open

Identification of the *Bombus* species was done using Stephen's *Bumble Bees of Western America* (1957) as well as additional keys developed by RMBL researchers over the years. Most of the identification was done in the field either directly on the flowers or using James Thomson's invention, the "bee-squeezer". The device consists of a film canister with the bottom cut out, a mesh covering over the top and a foam plunger used to push the specimen against the mesh. We additionally collected several voucher specimens using cyanide kill-jars, for each species and each caste (queen, worker, and male) roughly distributed across the transects. This enabled us to confirm our field identifications and also to preserve a record for any future studies. Any specimens for which the field identification is questionable were also collected. For all bees (observed and collected) we recorded the caste and either the plant species it was visiting or the activity it was performing (e.g., nest searching, flying by).

The original data collected in 1974 were used for all comparisons. To keep the data consistent, all the 1974 data collected from sites other than the five transects were excluded. Also, only data collected on or before August 24 were used; this date was chosen as having a similar flowering phenology to our final survey date in 2007.

Results

Overall relative abundances. The 1974 data set contained 9,284 total bees, compared with 3153 in 2007. This large discrepancy in overall numbers was most likely due to annual climatic variation and consequent differences in bee populations, and therefore, most comparisons were done with relative percents or by standardizing the data. A comparison of the overall relative abundances between 1974 and 2007 is shown in Figure 1. The least abundant bee in 1974, *B. centralis*, was not recorded at all in 2007, but a new species, *B. melanopygus*, was found. Increases in relative abundance occurred in *B. appositus*, *B. bifarius*, and *B. mixtus*. Decreases were found in *B. flavifrons*, *B. kirbyellus*, *B. sylvicola*, *B. frigidus*, and *B. occidentalis*. The other four species either occurred in similar abundances or the sample size was too small to draw any conclusions.

To compare overall *Bombus* distributions between the years, a signed rank test was performed comparing the site with the mean, median, mode, and highest relative percent of each species per transect. The tests show significant upward movement of the mean ($p < .001$), median ($p = .017$) and mode ($p = .04$), but not of the highest relative percent ($p = .395$). A chi-squared test was run for the nine most common bee species (in 2007) to test whether the distributions across the sites were the same. The largely disparate sample sizes were standardized using relative percents based on the lower total count. Significant differences were found for the overall distributions of all species ($p < .001$) except for *B. occidentalis* ($p > .25$).

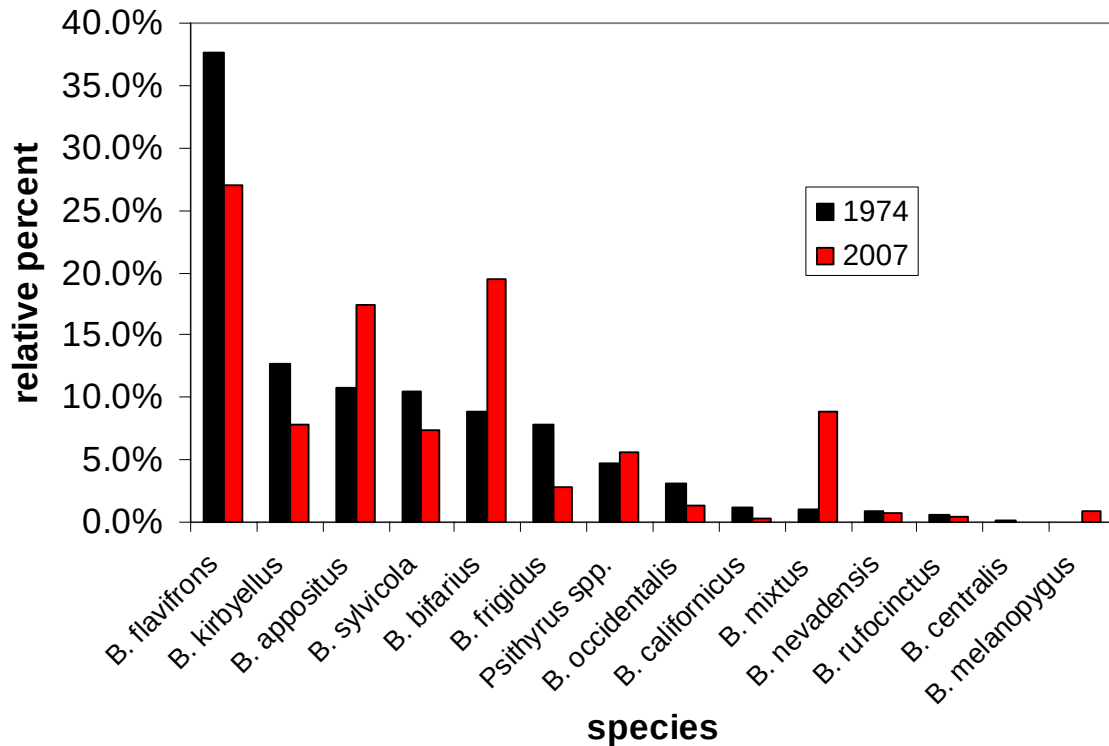


Figure 1. Comparison of the total relative percents of 14 *Bombus* species in the summers of 1974 and 2007. Species listed in order of decreasing abundance for 1974.

Site-by-site comparisons. All four transects (excluding the Kettle Pond sites which were not analyzed) showed the same relative increases and decreases as the totals (minor exceptions being *B. occidentalis* at Gothic Road and *B. frigidus* at Schofield, both of which occurred in relatively the same numbers in both years). A chi-squared test was performed on a site-by-site basis for the five most common bee species, again by using standardized numbers. Most bees at most sites showed significant differences in their distributions between the years ($p < .001$), the exceptions being *B. flavifrons* at Bellview, and *B. appositus* at Gothic Road and Washington Gulch. *B. bifarius*, *B. kirbyellus*, and *B. sylvicola* were significantly different for all four transects, with the exception of *B. bifarius* at Schofield, which had too small a sample size in 1974 to be effectively compared.

To see if these changes were random or if they represented consistent directional movements, I compared the ratios of two pairs of bees that make use of similar floral resources, one low-elevation and one high-elevation. *B. appositus*, Pyke's low-elevation, long-tongued bee, and *B. kirbyellus* the high-elevation long-tongued bee were compared, as were two short-tongued species, *B. bifarius* and *B. sylvicola* (low- and high-elevation respectively). For each transect the ratio of each of the species over the total of the two was plotted for both years. The point where the ratios cross in a year represents the elevation at which the dominant bee species shifts. For Gothic Road, sites one, two and three were combined, as were sites six and seven to obtain enough data for comparisons (all combined sites neighbored each other and had similar elevations). Along this transect long-tongued bees show an increase in elevation of the shift from *B. appositus* to *B. kirbyellus* of about two sites or 100 vertical meters (Figure 2). The short tongued species also show the shift occurring higher up, in this case a difference of about four sites, or 200 meters (Figure 3). Schofield sites one and two were combined. For Schofield, *B. kirbyellus* was the dominant long-tongued bee species at all sites in both years, but there was a lower proportion of the high-elevation bee in 2007 (Figure 4). In the 1974 data, *B. sylvicola* was the dominant short-tongued bee at all sites, but in 2007, *B. bifarius* replaced *B. sylvicola* except for the highest two sites (Figure 5). Bellview transect in 1974 only had *B. appositus* as the dominant bee for the second lowest site, and *B. sylvicola* dominated in all sites, but in 2007, *B. appositus* was dominant for the first four sites and *B. bifarius* for the first five (Figures 6 and 7). For the Washington Gulch transect, sites five and six were combined. In 1974, the crossover in dominance for both short and long-tongued bees occurred halfway up the transect at about 3250 meters. In 2007, there was no crossover for either pair, and both *B. appositus* and *B. bifarius* remained dominant over the entire transect (Figures 8 and 9). Table 2 summarizes the results of

the site-by-site comparison by estimating the upward shifts of the dominance transition for each transect.

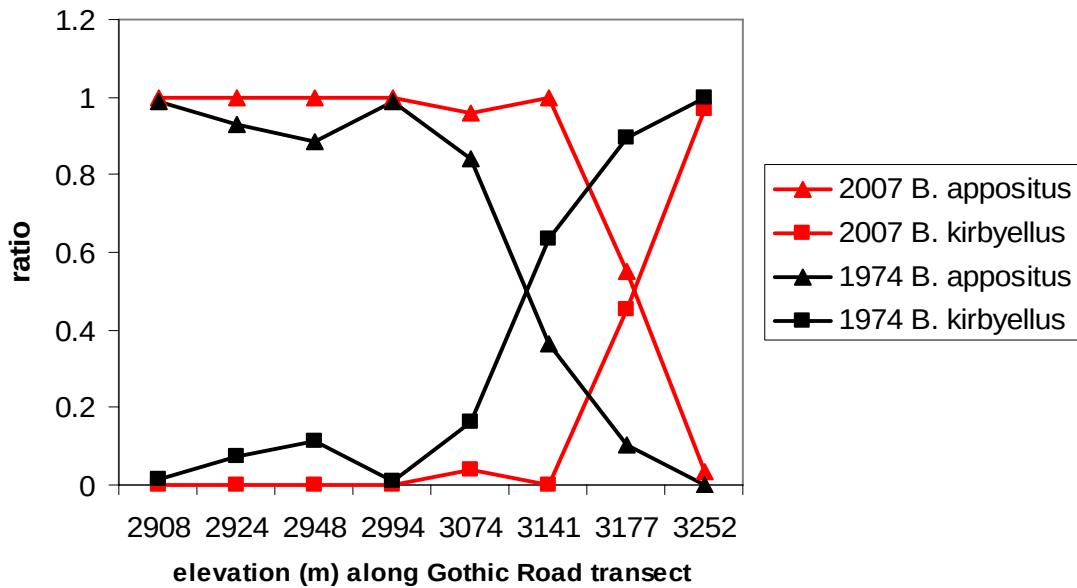


Figure 2. Ratios of long-tongued bee species along the Gothic Road transect. Sites one two and three combined, sites six and seven combined.

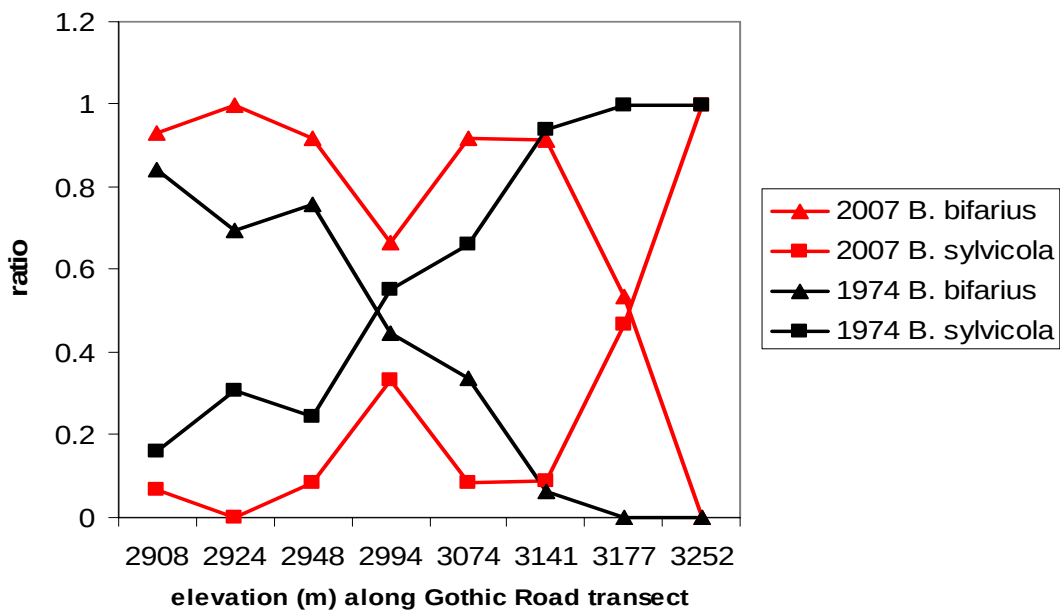


Figure 3. Ratios of short-tongued bee species along the Gothic Road transect. Sites one two and three combined, sites six and seven combined.

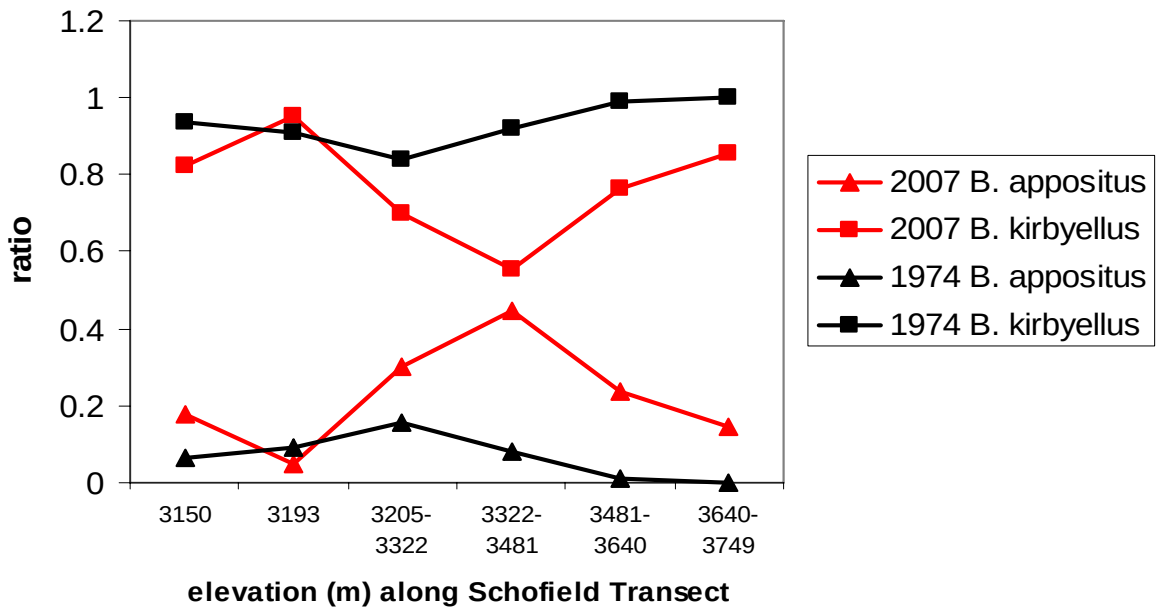


Figure 4. Ratios of long-tongued bee species along the Schofield transect. Sites one and two combined.

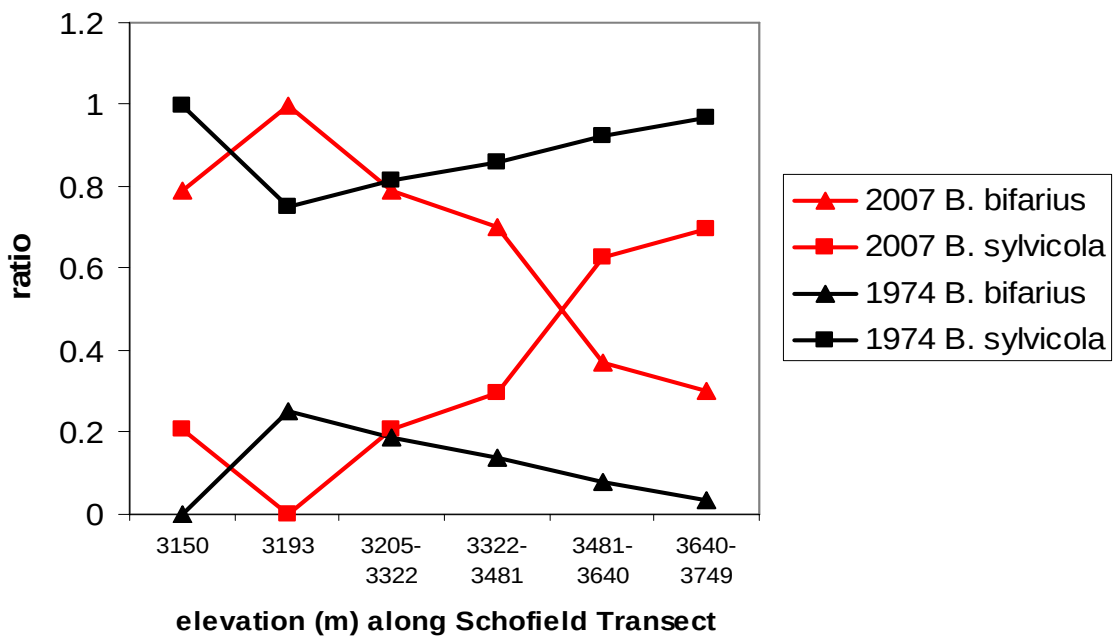


Figure 5. Ratios of short-tongued bee species along the Schofield transect. Sites one and two combined.

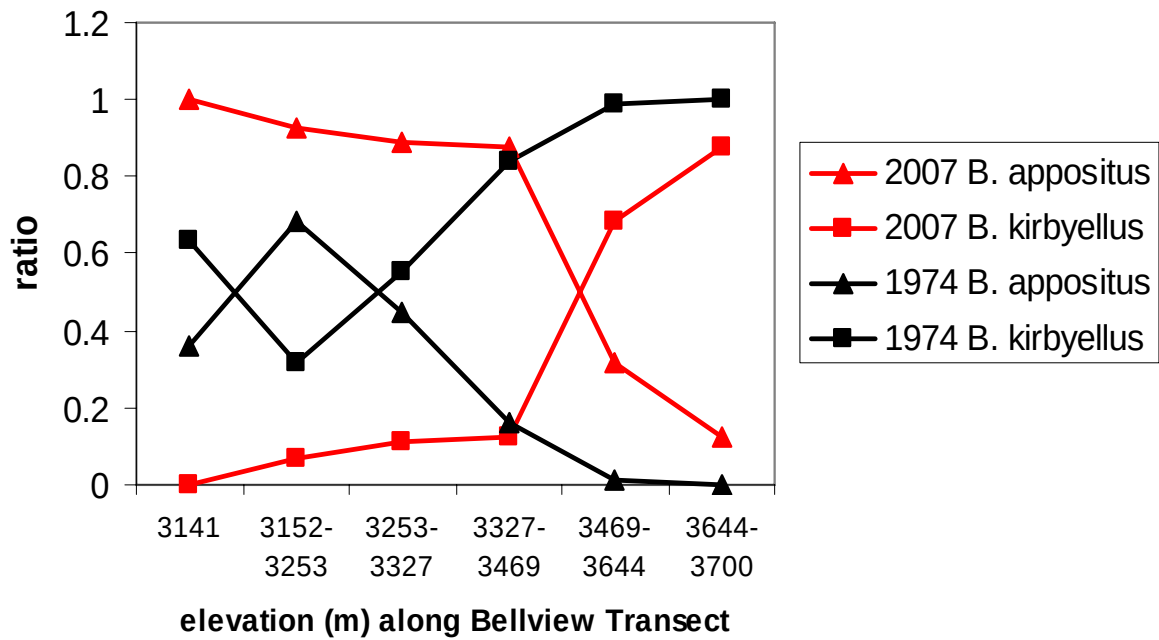


Figure 6. Ratios of long-tongued bee species along the Bellview transect.

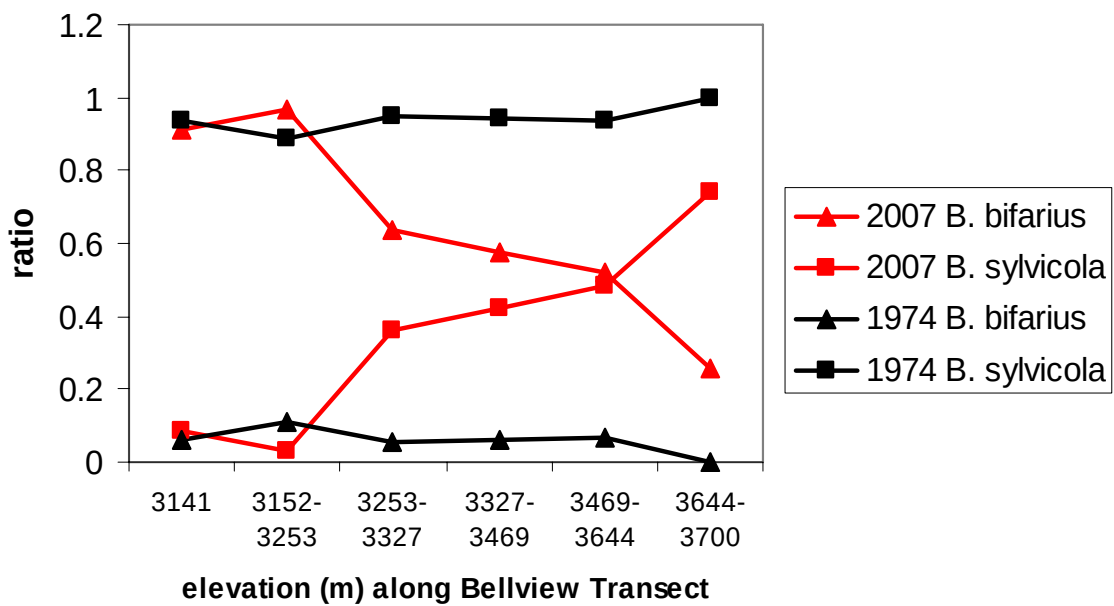


Figure 7. Ratios of short-tongued bee species along the Bellview transect.

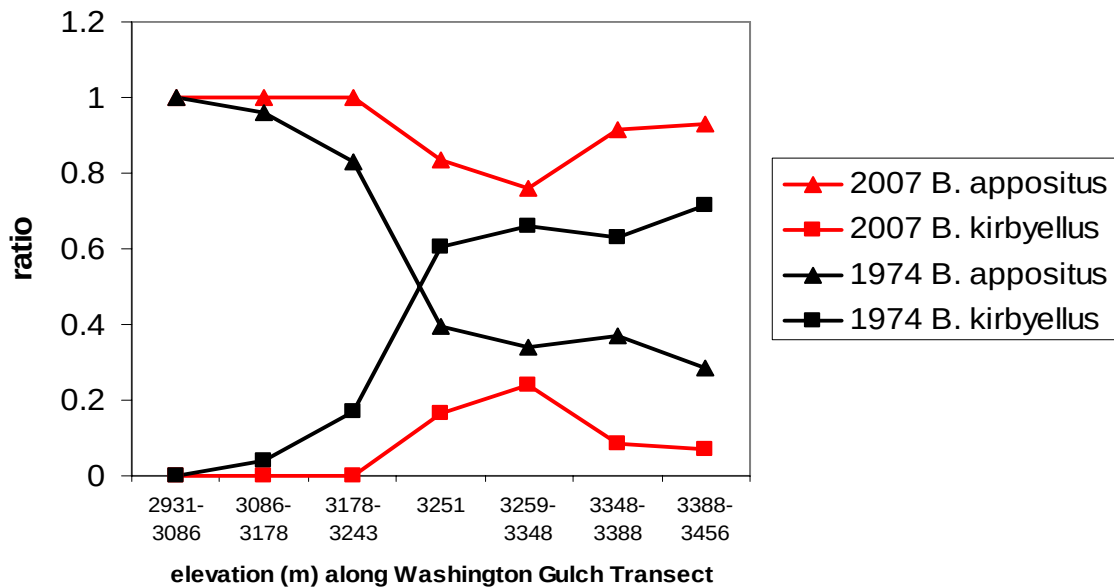


Figure 8. Ratios of long-tongued bee species along the Washington Gulch transect. Sites five and six combined

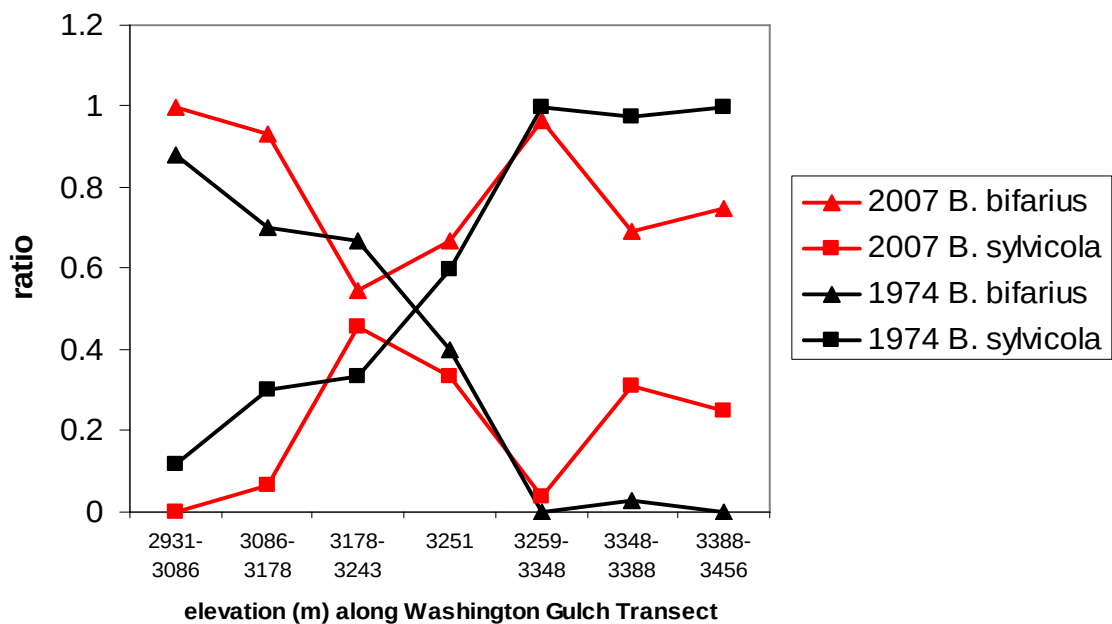


Figure 9. Ratios of short-tongued bee species along the Washington Gulch transect. Sites five and six combined.

Table 2. Summary of elevation changes in the transition of dominance between low and high-elevation bees. Greater or less than symbol means no transition occurred within the transect.

	long-tongued transition elevation (m)			short-tongued transition elevation (m)		
transect	1974	2007	increase	1974	2007	increase
Gothic Road	3100	3200	100	3000	3200	200
Schofield	< 3150	< 3150	0	< 3150	3500	> 350
Bellview	3250	3400	150	< 3100	3500	> 400
Washington Gulch	3250	> 3450	> 200	3250	> 3450	> 200

Comparison of floral data. Across the transects, the nine most common bee species fed on mostly the same flowers in 2007 as they did in 1974. In total, 2/3^{rds} (38 of 57) of the flowers that made up more than 3% of a bee's visitations in 2007 also did so in 1974. This is true of 100% (5 of 5) of the long-tongued bee's preferred flowers. In both years the flower species that *B. kirbyellus*, *B. appositus*, and *B. flavifrons* most frequently visited was *Delphinium barbeyi*, and the preference of *B. sylvicola* and *B. bifarius* was *Helianthella quinquenervis*.

There were minor changes in visitation rates between the years. To see if their distributions across the transects had changed, five species of plants were analyzed that showed visitation rates that varied both between members of a group of bees and between years: *Arnica longifolia*, *Mertensia ciliata*, *Chamerion augustifolium*, *Cirsium* spp., and *Heliomeris multiflora*. None of these five species showed any large increases or decreases in the total numbers of sites at which they were found (Table 3). Small variations in distribution across the sites that were found did not show a pattern of moving either up or down the mountain in any species.

Table 3. Number of sites at which five species of flower occurred. Total of 36 sites.

flower species	1974	2007
<i>Arnica longifolia</i>	12	13
<i>Mertensia ciliata</i>	33	31
<i>Chamerion augustifolium</i>	21	18
<i>Cirsium</i> sp.	18	17
<i>Heliomeris multiflora</i>	18	16

Conclusions:

B. flavifrons, the medium-tongued bee, despite a decrease in overall relative abundance and significant variation in distribution between the years, does not seem to show any pattern of movement up or down in elevation. *Psithyrus* spp. (cuckoo bumble bees) occurred at about the same relative proportion in both years, and also didn't show any movement. *B. mixtus* and *B. frigidus* seem to have had a switch in relative abundance with the latter abundant in 1974 and the former more common in 2007. The reason for the change is unclear because in both years, both are most abundant at mid elevations. If this change is not simply an artifact of seasonal variation, then it may be due to competition between each-other and the other short-tongued bee species.

The overall changes in relative abundance in bee species between years indicate an increase in the total relative percent of low-elevation species (*B. appositus* and *B. bifarius*) and a corresponding decrease in the total of high-elevation species (*B. kirbyellus* and *B. sylvicola*) for both short and long-tongued bees. These overall changes correspond with an increase in the maximum elevation at which the low-elevation species are dominant. This holds true for both pairs of bees for all four transects investigated. The data suggest that climate change in the form of an earlier snowmelt and warmer, drier weather, is either directly or indirectly affecting the distributions of these four bumble bees.

Although not all floral data were formally analyzed, the floral surveys seem to indicate consistency of flower distribution between the years. This, combined with the bee floral preference data, suggest that a change in floral composition at the sites is not the cause of the changes in *Bombus* distributions. Instead, the bees may be responding directly to climatic changes. There are two possible ways that the response may be occurring. First, it is possible that high-elevation queens overwinter more shallowly in the ground than low-elevation queens, relying on a long and permanent snow pack to keep them from freezing. Climate change may cause a reduction in the size and the length of the snowpack, forcing the bees to take refuge at higher and higher elevations. Second, low-elevation queens may emerge earlier in the spring than high-elevation bees in anticipation of a longer growing season. If the growing season becomes lengthened at higher elevations, low-elevation bees would emerge first and out-compete the high-elevation bees for nest locations and floral resources. Further investigation is needed to determine if either or both of those hypotheses are correct.

The data from this study can be used to make many inferences about changes in *Bombus* distributions, but there is a danger of putting too much faith in data from two widely spaced years. A long term goal is to be able to repeat this study every few years so the changes we have discovered can continue to be monitored. Our results indicate that annual insects such as bumble bees may make better indicators of climate change over the short term than more long-lived organisms such as perennial plants. Because of their dynamic population fluctuations, at least certain species of *Bombus* have rapidly and dramatically responded to a change in their environment. Their relatively fast response may give an indication of longer developing changes that the area around RMBL may eventually experience.

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