

Does snowmelt timing affect bumble bee colony abundance?

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Abstract:

Average temperatures are increasing globally and causing shifts in the timing of weather events such as spring snowmelt, which may have profound consequences on the phenology of many organisms. Working at the Rocky Mountain Biological Lab in central Colorado, we examined the relationship between spring snowmelt timing and patterns of bumble bee abundance throughout the foraging season. To do this, we conducted net sampling at each site every two weeks throughout the summer for 7 consecutive years (2009-2015) and recorded each bumble bee caught on a flower. We looked at the effects of year, date, snowmelt timing, annual precipitation, and temperature on bumble bee abundance using generalized linear mixed models in R. We found that the abundance of *Bombus bifarius* was significantly affected by the date of sampling, the date of first snowmelt, and temperature, while the abundance of *Bombus appositus* and *Bombus flavifrons* were significantly affected by date and precipitation. We conclude that earlier snowmelt dates may positively affect bumble bee populations by extending foraging seasons and thus allowing greater colony buildup.

Introduction:

Average global temperatures have increased by 0.6°C over the past 100 years (Cleland 2007). Such temperature changes have been linked to changes in annual precipitation, unpredictable weather patterns, and extreme weather events, such as frost and changes in snowmelt timing. Montane regions are often the first places to show signs of these climatic changes (Latarnser and Schneebeli 2003). For example, a study conducted in the Swiss Alps between 1931 and 1999 found that the yearly snowpack is progressively melting out earlier (Latarnser and Schneebeli 2003). Similarly, a 30-year study on snowmelt in the Rocky

Mountains found that snowmelt timing is advancing by about 4.14 days per decade (Lambert et al. 2010). These widespread climatic changes have the potential to affect organisms around the world.

One of the main ways climate change can affect organisms is by altering their phenology, which is the timing of seasonal life history events of plants and animals, such as timing of flowering (Edwards 2004). All organisms rely upon a system of abiotic factors, such as temperature, precipitation, and snowmelt timing in order to perform synchronously with their environment (Forrest and Thomson 2011).). Because climate change is altering these factors, an organism's interaction with their environment is constantly changing, thus ultimately impacting survival and reproduction.

One important system that is affected by climatic conditions is plants and their pollinators. Over 87% of flowering plants are reliant on animals for pollination, meaning that a decrease in pollinators could significantly impact plant communities (Ollerton et al. 2011). Snowmelt timing and spring temperatures are important factors for the timing of bee and plant emergence and other life history events (Hoye and Forchhammer 2008). Bumblebees are key pollinators worldwide due to their ability to carry high loads of pollen and their high abundance due to colony growth throughout the season (Bergman et al. 1996, Bingham 1998). Each fall, queen bumblebees enter hibernation in order to survive the winter. When the snow melts, the queens emerge and immediately begin searching for the best nesting sites and flowers to use as food sources (Kudo 2014). In normal conditions, flower and bumblebee abundance would peak at the same time in the summer: the first being when the queen emerges and the second when the workers emerge (Kudo 2014). However, changes in snowmelt timing and spring temperatures can alter the peak abundance period of plants and/or bumble bees (Inouye 2011, Forrest 2015).

For example, a study conducted on montane wildflowers found that climate change is causing flowers to peak sooner in the growing season, thus causing a lower abundance of flowers by the middle of the summer (Inouye 2011). Changes in floral peak abundance in the summer season can create a mismatch between plants and bumble bees if bumble bees do not reach peak abundance at the same, yet studies on bumble bee phenology are lacking. Because plants and pollinators rely on each other for growth and reproduction, phenological mismatch between them can cause the mutualistic relationship to decline.

There are several ways in which bumble bees can be impacted by a mismatch with plants. Queen bumble bees have the potential to starve if they emerge from hibernation before the flowers have begun to bloom, thus resulting in a high mortality rate and lower reproduction success during the summer season (Kudo 2014). If the queen produces a low amount of larvae, it will reduce colony development for that season (Kudo 2014). This causes a shift in the phenological relationship between the plants and the bumblebees. With earlier snowmelt (which we define as the first date of bare ground) and changing climatic conditions, we can expect to see changes in the queen emergence time.

We conducted a field experiment in montane meadows to answer the following question: does snowmelt timing affect bumble bee colony buildup and abundance? If rates of colony buildup changes with queen emergence time and varying climatic conditions, it could lead to phenological mismatch between plants and their pollinators and/or decrease the survival rate of the colony. This could lead to fewer queen bees hibernating for the next summer, or even fewer worker bees produced due to a lack of resources.

Methods:

Study Site:

We conducted this study at the Rocky Mountain Biological Laboratory (RMBL) in Gothic, Colorado (elevation 2,886m). RMBL has been an established research center since 1928, so the land has been well preserved. Long term weather and plant data have been collected by fellow researchers for over 40 years, meaning that high quality data is readily available for studying climate change and other long-term phenomena. RMBL is also home to eleven species of native bumble bees and is located in a mountainous region that is already showing the effects of changing climatic conditions. The plants and bumblebees (typically) emerge around April or May and peter off in September (Gezon 2015).

For this study, we used 3 blocks each with 3 sites. In each block, there were 3 habitat types studied: willow, veratrum, and dry meadow. **Figure 1** shows the sites for Rebecca Irwin's long term phenology project, but for the sake of this research, we focused solely on nine sites around Gothic. Each of the plots was in close proximity to a weather station, giving us highly accurate weather data. Sites within the blocks were not independent due to close proximity (under 0.5 km), but most of the sites between the three blocks were independent of each other (over 1 km). Due to lack of independence, sites within blocks were lumped for the analysis.

Data Collection:

We collected data over seven consecutive years between 2009 and 2015. Bumble bee phenological data was collected every two weeks throughout the growing season of each year, generally between early May and late August using the methods in Gezon 2015. The netting was done for a full hour in the morning and in the afternoon at each site, not including the time it took to process and record each netted bumblebee (Gezon 2015). Each netted bumblebee was

identified to species in the field and marked on the thorax with a paint pen so that it was not recounted. This collection method gave us information on bumblebee phenology and abundance throughout the summer. Only foraging bumble bees were netted.

Data Analysis:

We used generalized linear mixed models with negative binomial distributions to look at the environmental factors that affected abundance of each of our three focal bumble bee species, analyzed separately (Kudo 2014). The response variable was abundance, and the predictor variables were year, date, 1st date of bare ground, total precipitation, and days above freezing. Date was included as a quadratic function in the model to account for the unimodal distribution of bumble bee abundance throughout the summer (Kudo 2014). The 1st date of bare ground and measures of annual precipitation were taken from billy barr's long term weather records. Total precipitation was measured for the snow year (from September to September), and the number of days with minimum temperatures above freezing were taken from the NOAA weather dataset for Crested Butte, CO. All analyses used in this study were conducted in the statistical program R, version 3.1.2 (R Core Team 2014). All models were created using the package glmmADMB (Skaug et al. 2015).

Results:

We collected 3,179 bumble bees between 2009 and 2015. For this study, we focused on three of the most abundant bumble bee species in our study system: *appositus* (558 collected), *bifarius* (997 collected), and *flavifrons* (856 collected). In addition to their high abundance, these three species are distinctive and can be reliably identified in the field, meaning that we were confident in the records. 2015 was excluded from our statistics because we do not have all of our data for this year, and 2012 was excluded from our statistics due to the drought that hit that year,

causing a low catch rate. The overall abundances of each species are lumped by year in **Figure 2**. **Figure 3, 4, and 5** show the abundance of the three focal species. **Figure 3** shows the abundances of the *Bombus bifarius* over 7 years. **Figure 4** shows the abundances of the *Bombus appositus* over 7 years. **Figure 5** shows the abundances of the *Bombus flavifrons*.

Patterns of Abundance

We analyzed each of our three primary species separately in R. The years 2009, 2010, 2013, and 2015 all have early snowmelt dates; whereas 2011 and 2014 have later snowmelt dates. *Bombus bifarius* has very distinct peaks in the years with early snowmelt, with earlier peaks in abundance compared to the years with later snowmelt. The years with early snowmelt date each have greater abundance rates compared to the years with later snowmelt. Overall abundance was also greater in years with earlier snowmelt. In the GLMM, abundances of *Bombus bifarius* were affected by date, first date of bare ground, and days above freezing. *Bombus appositus* and *Bombus flavifrons* had similar patterns in regards to snowmelt date, but only annual precipitation and date had a significant impact on abundances in the GLMMs. **Table 1** shows the results of the significance of the predictors.

Discussion:

Using 7 years of abundance data, we found that snowmelt timing did affect bumble bee abundance. Our results reveal that an earlier snowmelt may be beneficial to the bees. Contrary to our predictions, earlier snowmelt shifted the timing of bumble bee peak abundance forward compared to years with later snowmelt. Our original expectations were that years with earlier snowmelt would still show peak abundance at similar times to that of later snowmelt years due to low resource availability or harsh environmental conditions. However, we found that peak

abundance timing was shifted forward in years with early snowmelt, meaning that bumble bees were able to find adequate resources for similar rates of colony buildup.

In addition to showing earlier peaks in bumble bee abundance with earlier snowmelt, earlier snowmelt years had higher overall abundance than later snowmelt years. This could be due to longer foraging seasons in these years, meaning that the bees were able to create larger colonies (Forrest and Thompson 2011). In 2014, Kudo had predicted that the earlier snowmelt date could kill queen bees from a lack of food resources resulting in a high mortality rate and less reproduction at the end of the summer season, but our results support the conclusion that a later snowmelt date is more harmful to the bees than an earlier one.

We found that only abundances of *Bombus bifarius* were affected by snowmelt, and that *Bombus appositus* and *Bombus flavifrons* were more affected by annual precipitation. *Bombus bifarius* are known to be one of the earliest emerging bumble bees in the area, meaning that they could be much more affected by snowmelt date. Species that emerge later, such as *Bombus flavifrons*, may show a stronger response to other factors such as floral density, which is affected by other environmental factors such as precipitation (Forrest and Thompson 2011).

While this project has seven years of data behind it, there are still some aspects missing that we would like to take into account for future studies. Higher fidelity weather data would be beneficial, especially the first date of bare ground for each of our sites. It would also be interesting to look at how patterns of floral abundance match up with that of the bumble bee. With snowmelt date occurring earlier, it would be interesting to look for a phenological mismatch occurring between plants and their bumble bee pollinators (Harte 2015). We would also like to look at the timing and abundance of bumble bee reproductive, in order to determine whether earlier peaks and higher abundances in early snowmelt years translate into a

reproductive advantage for bumble bees. So far, we only have 2 solid years of caste data on the bombus, but with more accurate data on queens, males, and workers, we can get a more in depth look at their abundance patterns.

Bumble bees are key pollinators in montane regions due to their ability to carry ample amounts of pollen and their high abundance rates throughout the summer season. This study shows us that even as the temperature is changing, bumble bees still have the ability to thrive. With an earlier snowmelt date, the queens might have extra time to forage and expand their colonies causing the higher abundances.

Table 1: Results of GLMMs for each of the three focal bumble bee species. *p* values are shown for each predictor variable, with *n.s.* indicating non significance.

Species	Date	Year	1 st Date of Bare Ground	Total Precipitation	Number of Days above Freezing
<i>appositus</i>	p<0.0001	n.s.	n.s.	p<0.0001	n.s.
<i>bifarius</i>	p<0.0001	n.s.	p<0.0001	n.s.	p=0.0062
<i>flavifrons</i>	p<0.0001	n.s.	n.s.	p=0.0268	n.s.

Fig. 1: Map of all sites used in R. Irwin's long term phonological study. For this study of bumble bee abundances, we used data from the 9 sites (in 3 independent blocks) that are located in the Gothic area.

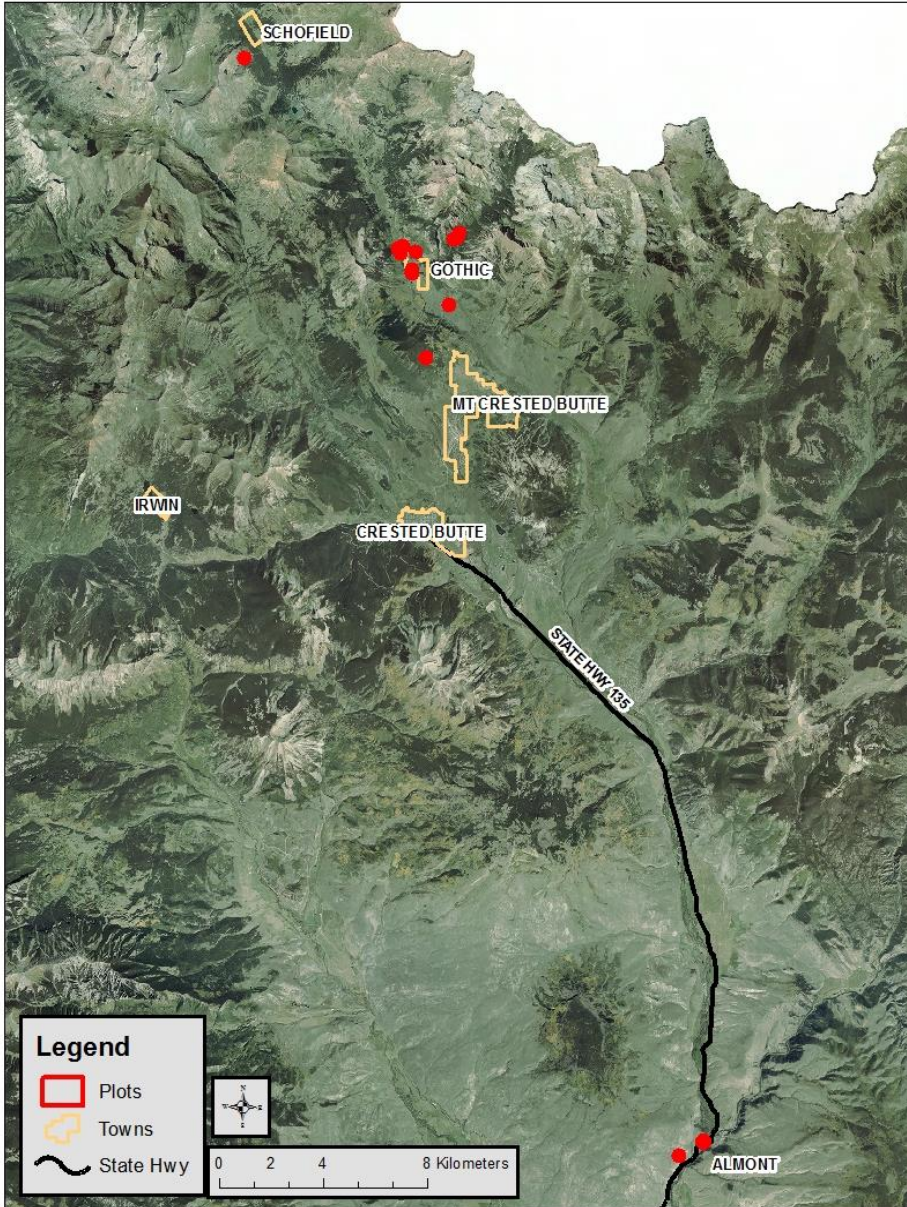


Fig. 2: The total number of bumble bees caught per year. The total number of species caught per year was divided by the total sample effort (hourly) per year to give a standardized measure of bees caught per hour, to control for sample effort.

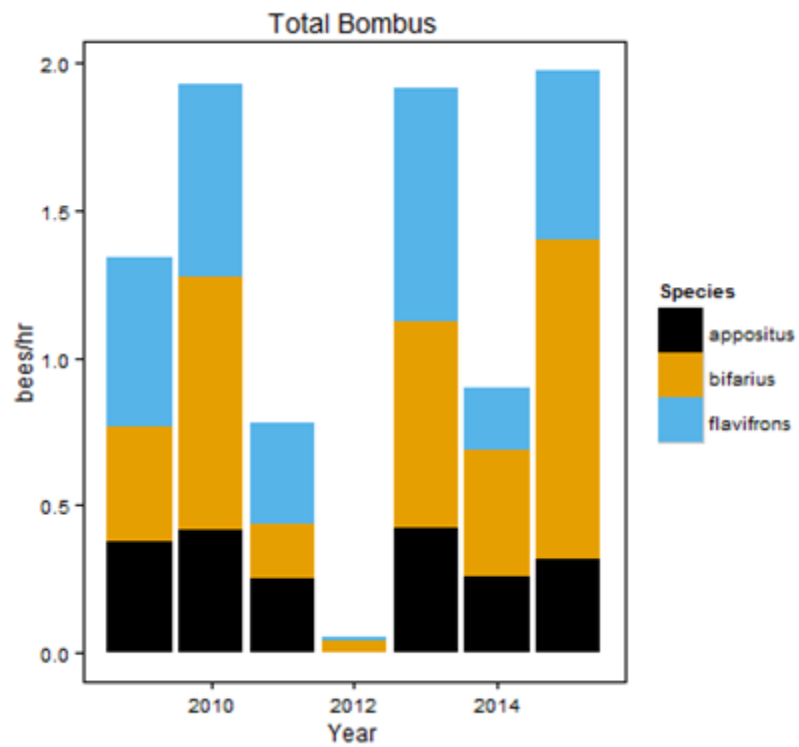


Fig. 3: This graph is a result of seven years of data. This shows the number of *bifarius* caught per hour at each sample date per block. The vertical black line represents the date of the first bare ground.

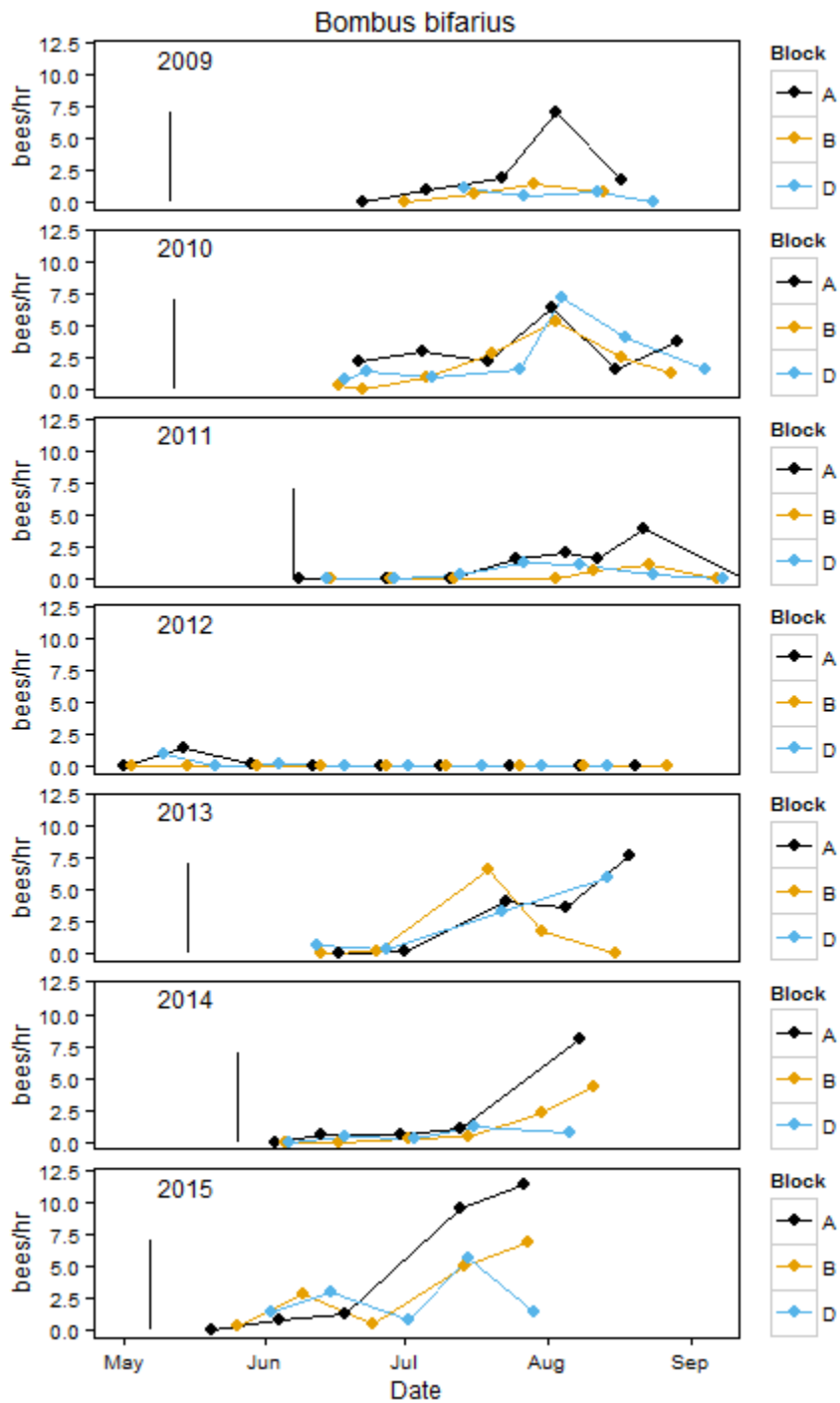


Fig. 4: This graph is a result of seven years of data. This shows the number of appositus caught per hour at each sample date per block. The vertical black line represents the date of the first bare ground.

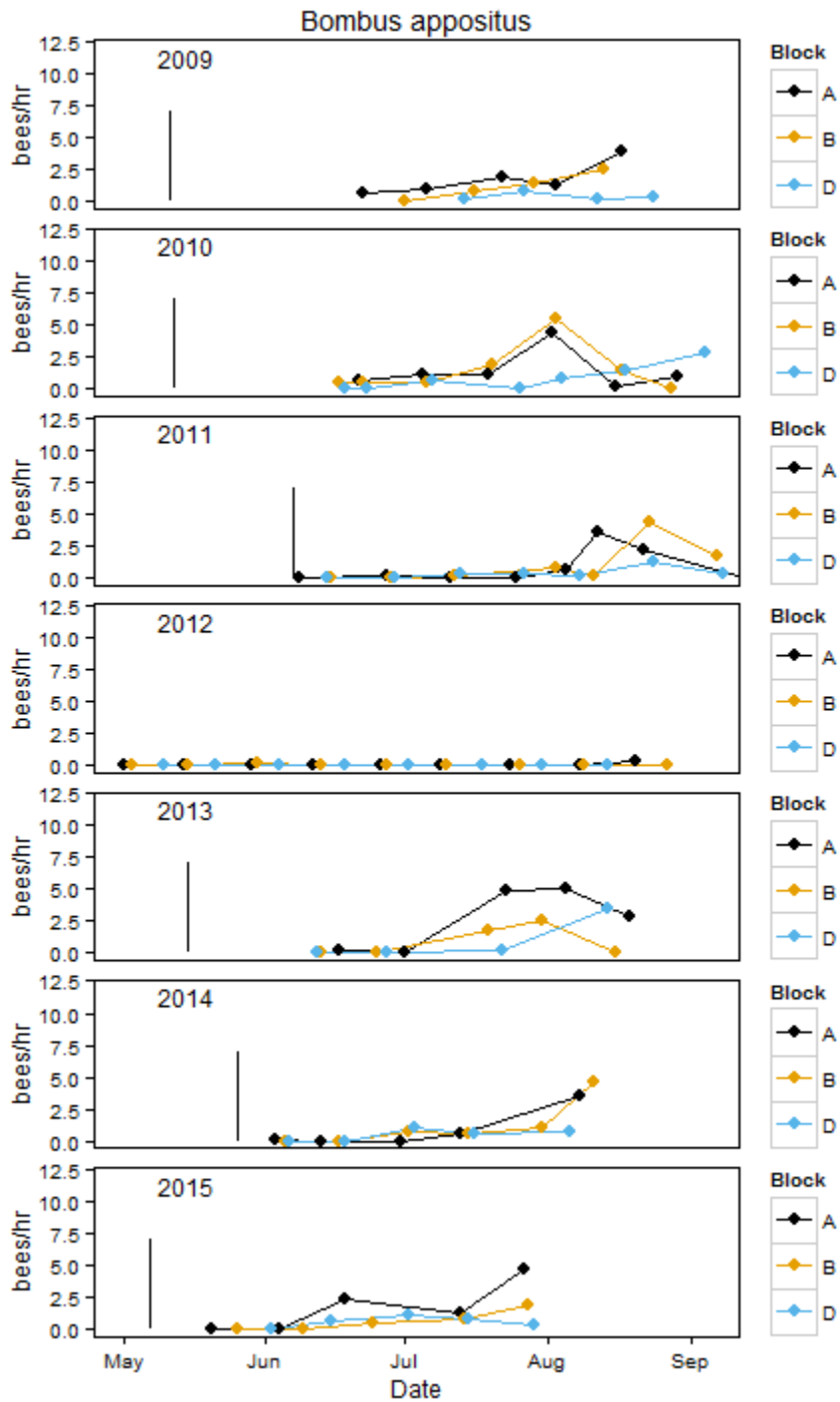
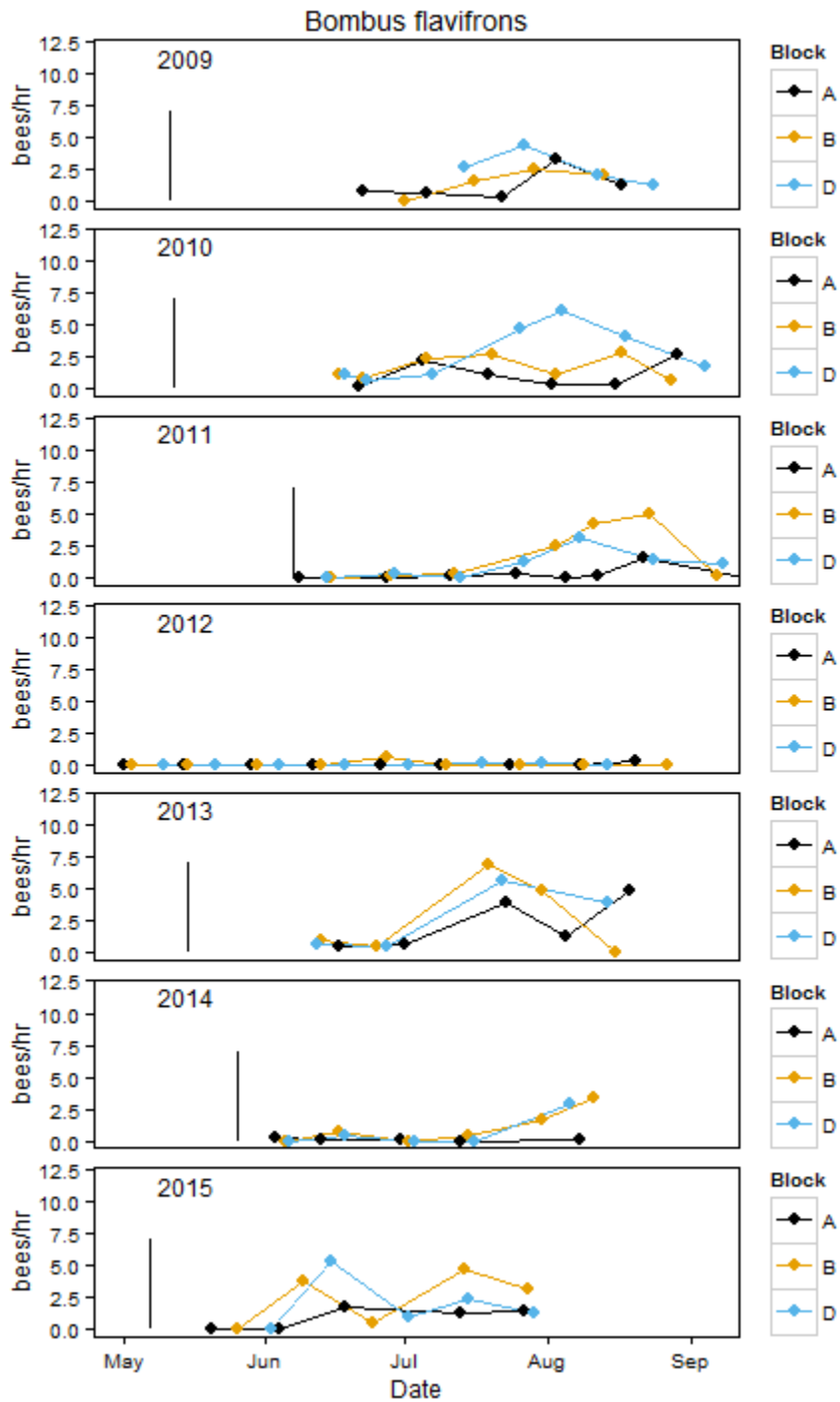


Fig. 5: This graph is a result of seven years of data. This shows the number of flavifrons caught per hour at each sample date per block. The vertical black line represents the date of the first bare ground.



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