

Title:

Effects of weather and floral density on foraging activity of cavity nesting bees (*Osmia* spp.)

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Abstract:

Thermoregulation is an important factor for bee flight which ultimately contributes to an individual's ability to forage and produce offspring. Rising temperatures could benefit insects by increasing their efficiency in reproduction and provisioning. However, warming could negatively impact floral resources, thereby indirectly affecting foraging and reproductive success in specialist bees negatively. In this study I investigated the effects of weather variation and floral density on individual foraging rate in subalpine populations of the solitary bee species *Osmia iridis* and *Osmia coloradensis* on individual foraging rate. I examined how temperature, percent cloud coverage and floral density affected the foraging rates and provisioning efficiency. Foraging rate did not increase with rising temperatures nor with increased floral densities. However, increased cloud coverage did decrease the foraging rates of bees, as expected. The results suggest that temperature, cloud coverage, and host floral density are not the only factors that affect the foraging rates of solitary bees and understanding the response to warming is critical to understanding the responses to global change in bee populations.

Introduction:

Weather patterns are changing in much of the world in association with climate change. The southwestern United States, for example, is predicted to have increased droughts (Seager and Vecchi 2010). Continued warming is expected to drive decreases in snowpack in the Rocky Mountains (Christensen et al, 2004) and it is important to understand the effects of changing weather conditions on plants and their consumers. Ectotherms are likely to be affected by rising temperatures due to the fact that their physiological functions of movement and life histories are influenced by temperature (Deutsch et al, 2008). Ectotherms such as bees are major pollinators of wildflowers and

crops and the effects of rising temperatures on bee populations is critical in understanding how global populations are likely to respond.

The Rocky Mountain Biological Laboratory (RMBL) is located in a fairly arid ecosystem and we are interested in how invertebrates, specifically cavity nesting bees, cope with natural variation in weather, including years of extreme hot and dry conditions. The ability for bees to thermoregulate quickly depends on the species' body size (Bishop and Armbruster, 1999) and the effects of climate change could be positive for smaller bees, such as solitary bees. I would like to determine how weather and floral densities influence bee foraging rates at our study sites.

This summer I investigated the effects of variation in weather conditions and floral density on the foraging activity of individual solitary bees, *Osmia iridis* and *Osmia coloradensis*. In this study I analyzed how (1) weather and (2) floral resource density affects foraging behavior of cavity nesting bees. As well as, (3) which factor is predicting bee foraging rate more strongly. To answer these questions I observed foraging trip duration and nesting progress of several individuals of *Osmia* species at multiple sites and collected data on temperature, percent cloud coverage and floral density.

Methods:

Study organisms

Solitary bees in the family Megachilidae, such as *Osmia* spp., nest in pre-established cavities in trees. In my study I observed *O. iridis* and *O. coloradensis*. *Osmia* spp. are ideal organisms for our study as they readily occupy artificial cavities, which allows us to easily monitor individuals' foraging rates and nesting progress. Females make a series of brood cells, each of which consists of a single egg laid on a lump of pollen and nectar. Each cell is separated by walls made of a layer of mud or masticated leaf material. *O. iridis* specializes on *Lathyrus lanszwertii* and *Vicia americana*, while *O.*

coloradensis specializes on Asteraceae angiosperms, in which the bee only collects pollen and nectar from their respective taxa.

Study Sites

Data collection was conducted in the summer of 2019 over an 8-week period in six previously established sites located near Gothic and Crested Butte, Colorado, USA. The sites are located at varying elevations ranging from 2877-3069m. Each site contained twelve nesting blocks attached approximately 1 meter above the base of the trunks of trees located at the edge of subalpine aspen or spruce-fir forests on hillsides near meadows or clearings (Forrest and Thomson, 2011, Forrest and Chisholm, 2017). The nesting blocks are wooden blocks with ten 14 cm deep holes of three different diameters. Each hole contains a paper straw to allow removal and examination of nesting progress (Forrest and Thomson, 2011, Forrest and Chisholm, 2017).

Field Methods

Foraging trip duration and rate

Individually marked female bees were observed in existing nests for a 1-hour observation period every 3-4 days to measure the duration of as many foraging trips as possible. I recorded the time the individual departed the nesting block and the time of arrival (min), as well as whether the bee brought pollen to the nest.

To quantify nesting progress of an individual bee, I temporarily removed the nesting straw and marked the location of the outermost pollen provision on the outer surface of the straw and measured the amount of pollen added to the nest (in mm) after each foraging trip.

To calculate the foraging rate of each individual, I took the amount of pollen added to the nest and divided it by the foraging duration (mm/min). I used bee foraging trips in which I observed pollen trips only.

Weather conditions

I recorded temperature, wind speed and percent cloud cover at the beginning and end of each observation period. Cloud cover was visually estimated to the nearest 10 percent. Measurements of wind speed (MPS) were taken with a handheld analog anemometer (Sims Model # 88169). Measurements were taken at the same height as the nesting block. I also recorded wind speed approximately ten paces away from the nesting block at the beginning and end of the observation period. The average wind speed of all four measurements was used for analysis.

To measure the temperature (°C), I used an unshaded hand-held thermometer (Kestrel 3000 Part # 0830). Measurements were taken at the same height as the nesting block and ten paces away from the nesting block during the beginning and end of the observation period. The average temperature of all four measurements was used for analysis.

Floral density

The density of floral resources was estimated every 3-4 days by following the protocol described by Forrest and Chisholm (2017). Counts of open host flowers were recorded by walking in progressively larger circles from a central point until a total of 100 flowers of each species or a straight-line distance of 100 m from the center was reached, whichever was achieved first. To calculate the floral density, the distance (r) to the 100th flower was measured and the following formula was used: $100/\pi r^2$. The densities were summed across all host plant taxa at a site.

Analysis

Foraging rate

I analyzed the foraging rate as a function of average temperature, average cloud cover, and host floral density using linear mixed models with the R package “lme4”. The

response variable was foraging rate (pollen added to nest per foraging duration) achieved during each foraging trip by an individual bee; this was log-transformed to improve normality. The zeros were excluded to improve normality, and these zeros may have been meaningful, as the weather conditions may have been too cold for the bees to fly.

Floral density was included over the relevant observational day. I included day of the year, cloud coverage, floral density as covariates and included individual bee and site as random factors. I used R package “lmerTest” to estimate the degrees of freedom and evaluate the significance of the fixed factors. I used the package “MuMIn” to obtain the R-squared values from the mixed models.

Results

In all, 24 marked *Osmia* spp. bees were observed and added a total of 85 mm of pollen collectively to the nest cells at our study sites.

As average temperature increased, foraging rate decreased, although this was non-significant (df=18, $t = -0.939$, $p < 0.360$, R-squared 0.043, Fig 1). As average cloud cover increased, foraging rate decreased non-significantly (df=8, $t = -0.465$, $p < 0.655$, R-squared 0.050, Fig 2). Average temperature and cloud cover were not correlated and were treated as independent predictors. As floral density increased, foraging rate decreased non-significantly (df=5, $t = -0.312$, $p < 0.768$, R-squared 0.007, Fig 3).

Discussion

Based on my data, I cannot say that the average temperature, average cloud cover, and host floral density are significantly affecting the foraging rate of both *Osmia* spp. Temperature-dependent foraging efficiency in bees was not so evident (df=18, $p < 0.360$, R-squared 0.043, Fig 1). Days with increased cloud coverage had a negative relationship on bee foraging rate, which suggests that individual bees experience a

decrease in activity levels when increased cloud coverage occurred ($df=8$, $p < 0.655$, R-squared 0.050, Fig 2). Foraging rate decreased when floral densities were high ($df=5$, $p < 0.768$, R-squared 0.007, Fig 3).

Although the average temperature was not a significant predictor of foraging rate in my short term study, longer-term studies with one of the same bee species found that bee nesting rates increased with higher temperatures (Forrest and Chisholm, 2017). Differences between bee species, such as body size, could also affect the foraging rate. For example, larger bees such as bumble-bees, have the ability to efficiently thermoregulate compared to smaller sized bees, such as solitary bees (Bishop and Armbruster, 1999). Perhaps floral densities is not an important factor for foraging rate, whereas a more relevant resource measurement is pollen and nectar production.

Conclusion

Pollinator responses to climate change is critical in understanding the outcomes for populations. While the results of our study indicated that *Osmia* spp. foraging rates are not strongly dependent on weather conditions and floral densities, there may be a number of other factors that are of importance for foraging rate. Future warming is continuously altering many factors in ecosystems and the roles they have on pollinator populations may prove to be important.

Figures

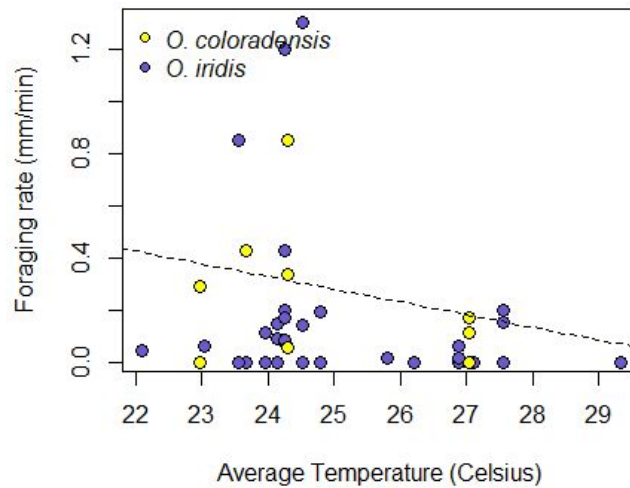


Figure 1 Relationship between foraging rate of bees and average temperature

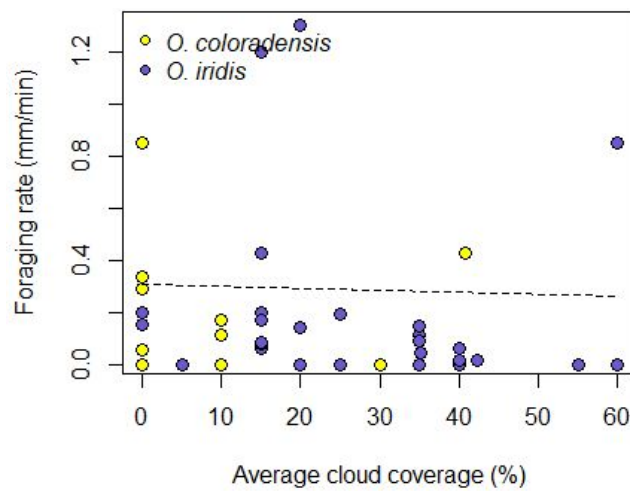


Figure 2 Relationship between foraging rate of bees and average cloud coverage

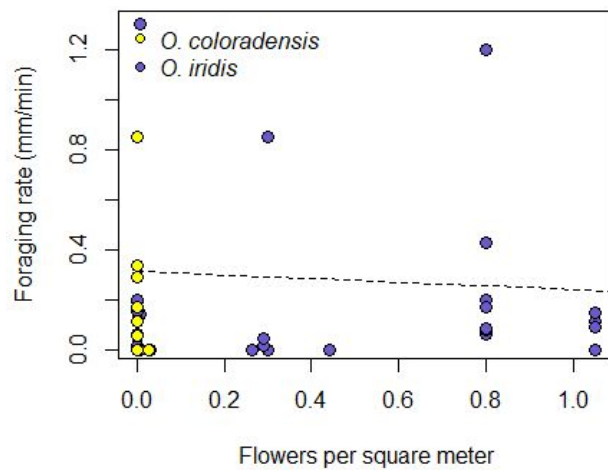


Figure 3 Relationship between foraging rate of bees and floral density

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Climate-associated phenological advances in bee pollinators and bee-pollinated plants

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