

**The effect of early snowmelt on pollination: A study of four Rocky Mountain subalpine
plant species**

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ABSTRACT

High elevation plant ecosystems are heavily dependent on snowmelt for maintaining spring soil moisture levels. As climate change alters traditional weather patterns and reduces snowpack, snow is melting earlier and altering flowering phenology. With this change in flowering time potentially exposing plants to increased physical stressors including drought and frost, changes in floral characteristics may consequently affect pollination. This study aimed to understand the impacts of climate change-induced early snowmelt on the pollination of four subalpine plant species at the Rocky Mountain Biological Lab of Gothic, Colorado in the summer field season of 2021. I conducted pollinator observations to assess pollination within manipulated early snowmelt plots and control plots upon four wildflower species that flower at different times throughout the summer: *Delphinium nuttallianum*, *Linum lewisii*, *Hymenoxys hoopesii*, and *Delphinium barbeyi*. I hypothesized that the early snowmelt's potential stressors upon floral characteristics will lead to lower pollinator visitation rates and a higher probability of visitation than control plants. Plants in the early snowmelt plots had significantly lower pollinator visitation rates and probability of receiving a visit on three of the four species studied. These results are concerning as snowmelt timing continues to advance in alpine and subalpine ecosystems. Decreases in viable pollination can lead to decreases in plant reproduction, potentially leading to falls in population size over time. More research into possible explanations for this decreased rate in visitation, such as how drought stress impacts floral rewards, can help us better understand potential long term consequences that earlier snowmelt will have on subalpine plant and pollinator populations.

INTRODUCTION

Climate change and its subsequent alteration of weather patterns is reshaping the hydrology of ecosystems around the globe (IPCC et al. 2014). In areas of heavy snowfall, climate change is not only leading to reduced levels of snowpack, but accelerating the rate of spring snowmelt (Clow 2010). Earlier snowmelt timing has been found to prompt earlier flowering in multiple plant species, altering their historical phenology (Dunne et al 2003, Iler 2013, Inouye 2008, Caradonna 2014). Earlier flowering can expose flowers to potential stressors such as frost damage, drought, and other effects that impact physical characteristics vital for pollinator interactions such as floral number, floral size and floral rewards (Pleasants 1981, Carroll et al. 2001, Waser and Price 2016).

Additionally, earlier flowering can disrupt the phenological synchrony between plants and pollinators, leading to pollinators visiting previously unvisited plants or having less access to historically frequented ones (Gezon et al 2016). The mutualistic relationships between plants and pollinators can also be disrupted through pollinator emergence occurring when plants are not flowering, leading to a lack of floral resources (Kudo and Cooper 2019).

My study sought to address the potential impacts of early snowmelt on the pollination on *Delphinium nuttallianum*, *Linum lewisii*, *Hymenoxys hoopesii*, and *Delphinium barbeyi* species by comparing the rate of visitation and pollen deposition between early snowmelt and control plots.. Specifically, my study addressed the following questions:

- (1) How does early snowmelt affect the rate of pollinator visitation on these four subalpine plant species?

(2) How does early snowmelt affect the probability of seeing a visitor on these four subalpine plant species?

I hypothesize that early snowmelt will result in earlier flowering and potential drought stress that will negatively impact floral resources, in turn leading to lower rates of pollinator visitation and a lower probability of seeing a visitor in areas of early snowmelt compared to controls.

METHODS

Study Species

The four species that I studied this summer were *Delphinium nuttallianum*, *Linum lewisii*, *Hymenoxys hoopesii*, and *Delphinium barbeyi*, blooming in that order throughout the season. These four perennial herbs have a range of pollinators. *D. nuttallianum* and *D. barbeyi* are primarily pollinated by *Bombus flavifrons*, *Bombus fervidus*, and other long-tongued *Bombus* species, while *L. lewisii* and *H. hoopesii* are most frequented by solitary bees and flies.

Snowmelt

I addressed my questions in the summer of 2021 within a subalpine meadow ecosystem at the Rocky Mountain Biological Laboratory (RMBL) in Gothic, CO. I worked within a series of 12 existing 5 m x 5 m plots arranged in six paired treatment blocks (in collaboration with my advisors, Dr. Amy Iler and Elsa Godtfredsen) (Figure 1). The pair (i.e., block) consist of one early snowmelt and one control plot. Each plot is surrounded by one meter buffers to account for edge effects of melting snow. To increase heat absorption from the sun and stimulate snow melt, the early snowmelt plots were covered with black shade cloth in April 2021. Shade cloth was set

out when there was approximately 1 m of snow in the spring, which translated to a 17 day earlier average snowmelt date; this is a biologically meaningful advancement of snowmelt timing for the system (Steltzer et al. 2009). This method is preferred to snow removal as it accelerates snowmelt while keeping the amount of moisture input into the soil constant, thereby isolating effects of snowmelt timing.

Pollinator Observations

Pollinator observations were conducted within three time periods on Monday-Friday: morning (10:00-12:00), midday (13:00-15:00), and evening (15:00-16:00). Each observation was performed on one of our four predetermined species: *D. nuttallianum*, *L. lewisii*, *H. hoopesii*, or *D. barbeyi*. Before starting each pollinator observation, I would first record the date, time, temperature, cloud cover, wind conditions, block, treatment, subplot, and species that I would be observing. I would then count and record the maximum number of flowers within that species that I could observe without missing a pollinator visit. I would then begin my observation, where for five minutes I would record each pollinator visit to the flowers I counted, sight-identifying each visitor to the lowest taxonomic identity possible.

I began each observation period within a subplot of either an early snowmelt or control plot. Once completing two five-minute observations within that subplot, when possible I moved to the opposite plot and completed two more, alternating back and forth until 6 observations were completed within each plot. This was done to account for any discrepancy in pollinator activity that may have arisen due to time of day. When species were only flowering in the early snowmelt (or later on, only in the control plots), I was unable to alternate. I completed as many

observations as I could under the circumstances of flowering duration, weather, and other factors.

Data Analysis

Statistical analyses were completed using R version 4.1.0. Visitation rate was calculated by summing the visits per session, divided by the number of flowers observed per observation session. This was then analyzed using a generalized linear mixed model with a beta binomial distribution to account for overdispersion (for *L. lewisii*, *H. hoopesii*, and *D. barbeyi*). The fixed effect was treatment, with day and plot as random intercept terms. Any visitation rate above 1 was converted to 1 for analysis, so that we could use the binomial family. This included one session for *L. lewisii* in the early treatment, 10 sessions for *H. hoopesii* in the control treatment, and 2 sessions for *D. barbeyi* in the control treatment. For *D. nuttallianum*, our snowmelt treatment had a visitation rate of zero, so a one-sided t-test was used to determine whether mean visitation rate across all dates in the control plots differed from zero.

Our probability data was quantified by calculating the presence of a visitor versus absence of a visitor during each observation session. The probability of receiving a visit was then also analyzed using a generalized linear mixed model with a binomial distribution, following the model structure outlined above for visitation rate. As above, for *D. nuttallianum*, our snowmelt treatment had a visitation rate of zero, so a one-sided t-test was used to determine whether mean probability of receiving a visitor in the control plots differed from zero.

RESULTS

Pollinator Observations

In total, 806 pollinator observations were completed over the course of the field season. I arrived midway through *D. nuttallianum*'s flowering period and therefore conducted the least amount of observations upon it. While each species catered to different visitors, the primary visitors to all species were bee and fly pollinators. *D. nuttallianum*, *H. hoopesii*, and *D. barbeyi* received the largest proportion of bumblebee visits, while *L. lewisii* received primarily fly and solitary bee visits (Figure 2).

Visitation Rate & Probability of Visitation

D. nuttallianum, *D. barbeyi*, and *H. hoopesii*, visitation rates were significantly lower in the early snowmelt compared to control (DENU: $t = 2.74$, $P = 0.025$; DEBA: $X^2 = 15.73$, $P = < 0.001$; HYHO: $X^2 = 20.308$, $P = < 0.001$). For *L. lewisii*, there was a marginally significant difference between treatments, with lower visitation rates in the earlier plots (LILE: $X^2 = 3.47$, $P = 0.063$) (Figure 3).

The probability of a plant receiving a visitor during an observational period was significantly lower in the snowmelt plots for all species (DENU: mean probability control: 0.24, mean probability snowmelt: 0; $t = 2.82$, $P = 0.023$; LILE: control mean: 0.57, snowmelt mean: 0.46, $X^2 = 5.27$, $P = 0.022$; HYHO: control mean: 0.48, snowmelt mean: 0.33, $X^2 = 6.99$, $P = 0.0057$; DEBA: control mean: 0.74, snowmelt mean: 0.54, $X^2 = 11.54$, $P = 0.0007$).

DISCUSSION

This study showed a decreased visitation rate and a lower probability of observing a visitor in early snowmelt plots compared to controls. There are numerous potential explanations for these results, including frost damage, phenological mismatch and physiological drought stress (Pardee et al 2018; McKinley, Roulston and Williams 2013). Frost damage in wildflowers, typically manifested as damaged buds, flowers or other tissues through the formation of ice crystals, was rare in snowmelt plots (Pardee et al 2018). A lack of frost damage points towards physiological stress caused by early snowmelt or phenological mismatch with pollinator timing may be more likely explanations of these visitation differences (Descamps et al 2018, Waser and Price 2016, Kudo and Cooper 2019). In order to quantify the potential source of these differences, future studies should dive deeper into the ways that early snowmelt affects plants and their ability to attract pollinators. Since plants use floral rewards to encourage pollinator visitation, this could be done through quantifying how nectar volume, pollen mass, flower size, and other traits differ between the early snowmelt and control plots (Godtfredsen, unpublished data). If plants in early snowmelt plots produce smaller flowers and less rewards, this could help explain why they are being less frequented by pollinators. Indeed, preliminary data for one species, *L. lewisii*, suggests that plants in snowmelt plots make fewer, smaller flowers (Godtfredsen, unpublished data).

Potential artifacts of our experimental design could have arisen due to the nature of our plots. Our early snowmelt plots created small patches of early flowers, whereas the control plots were nestled within flowers of the same species and on the same phenological schedule. Ideally, plots would have been isolated from surrounding flowers, allowing for pollinators to choose only between early snowmelt or controls. This could have been done by removing surrounding

vegetation, but a study of this nature could not be conducted within the RMBL Research Meadow. We may have observed lower visitation rates and reduced probability of observing visitors in the snowmelt plots because the species being observed are not yet abundant enough within the community to attract pollinators to them. Control plots may have in-turn reached a ‘critical mass’ of flower abundance to induce pollinators to switch over to forage on that species. Alternatively, we may see intraspecific competition amongst flowering species for pollinators in the control plots that the early plots do not have to contend with, in which case the design would bias us toward finding more visits in the early melt plots. This again highlights the importance of the floral reward data, for if we see no changes in floral rewards or displays but lower visitation rates in the snowmelt plots, the previously outlined explanation may be our culprit.

Our results suggest that early snowmelt may decrease pollinator visitation on plants, which could result in decreased plant reproduction (Moody-Weiss 2001). The impact of early snowmelt on viable pollination is especially concerning in the context of climate change, where snowmelt timing is advancing in alpine and subalpine ecosystems worldwide (Clow 2010). A substantial decrease of viable pollination and therefore plant reproduction due to early snowmelt could lead to widespread population declines of subalpine plants species (Biesmeijer et al 2006). However, this depends on the extent to which declines in seed production affect plant population growth rates; long-lived species like the ones in this study may be fairly buffered from losses in seed production (Franco & Silvertown 2004). Gaining a deeper understanding of how early snowmelt might impact pollination will better illuminate potential long-term consequences to subalpine plant and pollinator communities.

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I would like to extend the biggest thanks to my advisors, Dr. Amy Iler and Elsa Godtfredsen, for mentoring and supporting me through every facet of this project. I have learned so much this summer and I am forever grateful. Thank you to Dr. Paul CaraDonna and Jackie Fitzgerald for assisting me with statistics and R Studio. Thank you to Lena Heinrich, JJ Jonas, Mika Jones, and Aeven Mooney for helping me to conduct pollinator observations. Thank you to my friends Kevin Flores, Willow Lovecky, and Michael Troutman for helping me identify insects that I was unfamiliar with. Lastly, thank you to the RMBL Research Experience for Undergraduates program for allowing me to conduct this research and have such an amazing summer.

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FIGURE DESCRIPTIONS

Figure 1. Aerial map of my study sites in the Rocky Mountain Biological Lab Research Meadow.

Figure 2. Species composition of recorded visitors by species and by treatment.

Figure 3. Boxplots of the average visitation rates by day between early snowmelt and control plots for all four study species.



Figure 1

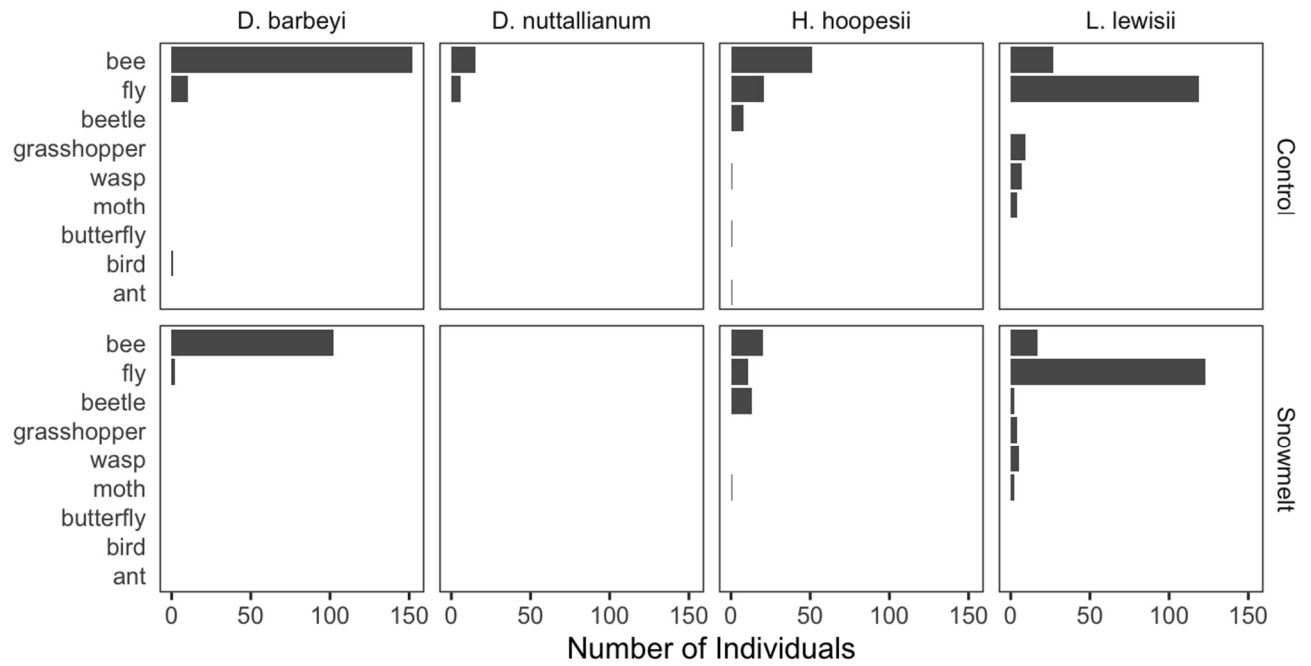
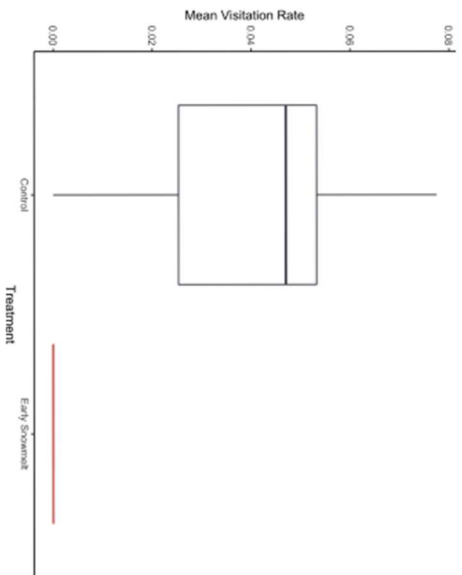
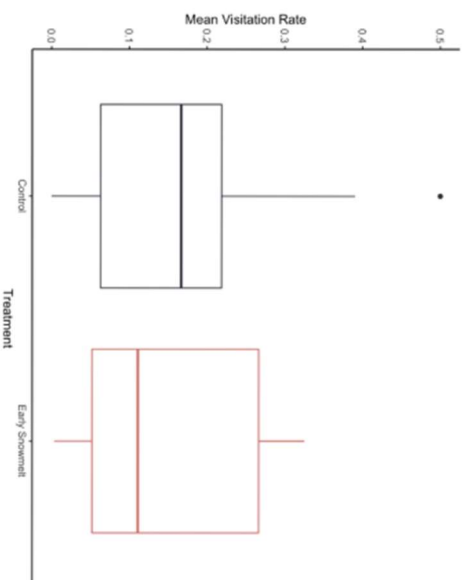


Figure 2

*D. nuttallianum***

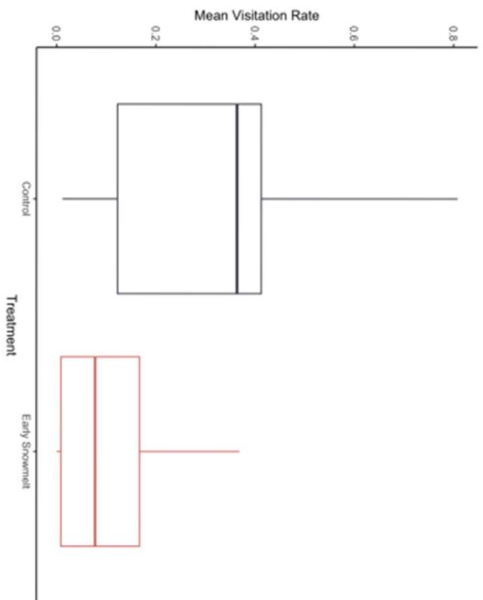


*L. lewisii**



Significance codes:
 , * ' <0.1
 , ** ' <0.05
 , *** ' <0.001

*H. hoopesii***



*D. burbeyi****

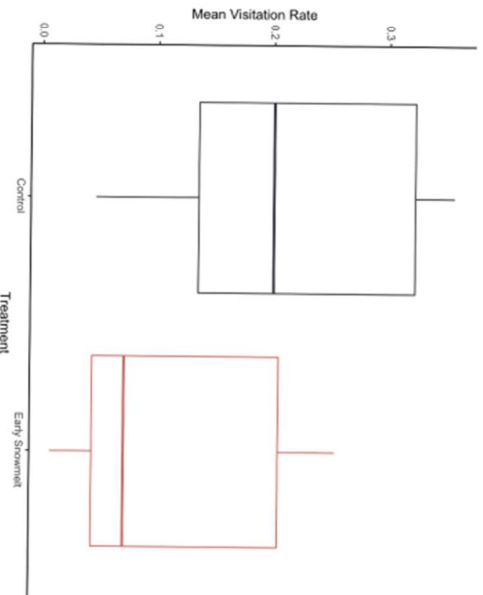


Figure 3