# Phenology Study Annotated Bibliography

1. Dunnell KL, Travers SE. 2011. Shifts in the flowering phenology of the northern great plains: Patterns over 100 years. American journal of botany. 98(6):935-945.

*Introduction*

Due to climate change and CO2 concentrations rising in the atmosphere, local temperatures and precipitation regimes are changing. Since many plants rely on atmospheric conditions, phenology or timing is also likely to change. However, plants often have intricate ecological relationships that require simultaneous existence. Shifts in flowering time or the growth period of plants could reduce reproductive success.

Objective: Analyze historical flowering data of prairie plants to find relationships with temporal trends and climate variables and to compare first flowering times.

*Methods*

Climate data including daily measurements of max and min temperature and detectable precipitation were retrieved from the NOAA and NCDC. The flowering data was transcribed from hand-written notes by O.A. Stevens and then used to determine the first flowering day between 1910 and 1961. The first flowering days and climatic data were analyzed for relationships. First flowering days were then recorded twice weekly from 2007 to 2010 for a comparison between the mean first flowering days of the two data sets.

*Results*

Annual air temperatures, spring air temperatures, and the growing season in Fargo has increased. Precipitation can be described by a concave up parabolic curve. North Dakota precipitation has been cycling. Currently, there is a wet period that is the longest on record. O. A. Stevens recorded 753 woody and herbaceous plants. The number of plants per year ranged from 17 to 309. The first flowering day was compared to independent climatic variables for 178 species. The best predictor for first flowering day really depends on the species. The variable the explained the most variation was average temperature in April. In more recent data, species flowered earlier in the warmer years.

*Discussion*

Between 24 and 41% of the species recorded in the more recent study flowered unusually late or early. Plants are flowering at least two standard deviations before or after they did earlier in the 20th century. Likely this is due to extended growing season and warmer temperatures earlier in the year. Late flowering could be explained by the success of later flowering and fruiting genotypes increasing since winter is pushed further back into the year. Plants that require a dormant, chilling period also may bloom later in the year with milder winters. Shift is flowering may be due to the combination of temperature, growing season length, and precipitation changes. The consequences of shifting flowering times needs to be studied ecologically through interactions with pollinators and with other abiotic stressors such as spring frosts.

*Impressions*

The paper precedes the bare ground phenology project and provides a background for studying the flowering species that are blooming later in the year. This paper was well written and described the implications of climate change and shifting flowering times well.

1. **Inouye DW, Morales MA, Dodge GJ. 2002. Variation in timing and abundance of flowering by delphinium barbeyi huth (ranunculaceae): The roles of snowpack, frost, and la nina, in the context of climate change. Oecologia. 130:543-550.**

*Introduction*

Flowers are not only important for sexual reproduction in plants but also, for pollinators, herbivores, and frugivores as well. Climate change is increasingly becoming a concern among researchers, calling for studies determining the biological effects that climate change has. These studies have been conducted through manipulation of growing conditions and the more powerful collection of long-term data sets that can then be correlated to environmental conditions. Shifting ranges due to climate change for montane species is even more problematic because lateral movement is not possible, limiting species to smaller and smaller ranges at higher elevations. Many of these species are also impacted by snowpack.

Objective: Examine the response of *Delphinium barbeyi* flowering to variation in snowpack.

*Methods*

Many plots were established in the Colorado Rockies in 1973 and monitored every other day from May to August. Monitoring involved counting all flowers per inflorescence of *Delphinium* flowers. *Delphinium barbeyi* was recorded in 12 plots and so, the averages across the 12 plots were used for analysis. The variables used were floral abundance per plot, inflorescence number, and mean date of first flowering day. These variables were examined in relation to snowpack depth, temperature, and date of first bare ground. Structural equation modeling was used to examine effects of variables.

*Results*

The flowering data was highly variable throughout the 22 years of data. Since snowpack also varies greatly throughout the year, flowering variables were compared to snowpack at dates throughout the spring. Snowpack on May 15 was used for the relationships between flowering variables and snowpack. Snowpack likely determines the flowering phenology by timing of snowmelt. Snowpack only had a significant effect on flower development through snow melt timing. Flower development, length of time between day of bare ground and first flowering day, had a significant negative correlation to snow melt. This could be due to temperature that leads to melting and flower development. Multiple regression analysis was used to analyze the effects of temperature and timing of snowmelt on flower development. Snowpack seems to effect flowering phenology indirectly through snow melt and floral development and then inflorescence density. Snowpack also seems to influence flowering indirectly. Snowpack may prevent frost-damage of flower buds but, researchers did not have data for frost damaged flower buds. A frost damage metric was created based on the number of days that temperature of frost-level. This was then used to explain variation in number of flowers on stem.

*Discussion*

In montane environments the disappearance of snow pack is a cue for the beginning of the growing season which, was supported by the significant correlation between first flowering day and day of first bare ground. Increased winter precipitation is predicted for the study area in the Colorado Rockies which could influence protection from frost, meadow community patterns, developmental timing, productivity, and phenology. Pollinators could be affected by variety in flower abundance. There is evidence of climate change in the study area and the species used in this study which, could inevitable have implications for pollinators and other herbivores.

*Impressions*

This study was thoughtfully carried out by Inouye et al. It is fascinating what flowering variables they used for phenology. The bare ground phenology study uses many of the same ideas that were shared in this paper, especially in regard to the structural equation modeling and the idea of snowpack.

1. **Waters SM, Chen WLC, Lambers JHR. Experimental shifts in exotic flowering phenology produce strong indirect effects on native plant reproductive success. Journal of Ecology.12.**

*Introduction*

Climate change is causing shifts in temporal interactions between species. The interactions are both direct and indirect, or mediated through another species. Since exotic plants show more phenological flexibility, they can change more easily in response to climate change. This may have consequences or benefits for the native populations.

Objective: Observe changes in native seed-set, pollinator visitation, and composition of pollinator visitation when co-occurring exotic plants shift phonologically.

*Methods*

*Cytisus scoparius* and *Hypochaeris radicata* were selected as the exotic species and share pollinators with seven native forbs. A random block design was used for this experiment. Each block had 48 plots, with 6 from each native species. *Cytisus scoparius* was used as the exotic plant re-invading the native plants therefore, no natural occurring *Cytisus scoparius* were used. Two control blocks were used, one with no exotic plants and one with exotic plants at ‘ambient’ timing. Phenological shifts for exotic species used in this study were large but plausible. Both species were used for early flowering but, only *Hypochaeris radicata* was used for delayed treatments. Seed-set was attained for pollinator-excluded flowers and naturally pollinated flowers. Pollinator visitation was observed for each native species three times in one plot for 15 minutes on sunny days. Insects were collected once a week for three weeks. Floral patch size was identified by recording the number of conspecific floral units the pollinator visited. Floral richness and abundance were measured biweekly.

*Results*

Seed-set in all native species was dependent on pollination. The exotic species showed indirect interactions with the native species, however; the effect, facilitative or competitive, varied by species. Not all native species had a change in seed-set. Conspecific (same species) and heterospecific (different species) floral density explained the pollinator visitation rate. The phenology treatment of the exotic species was also significant in explaining pollinator visitation. The relationship between pollinator visitation and seed set varied between species.

*Discussion*

Phenological shifts have diverse effects on plants. Indirect effects of exotic phenological shifts can be beneficial or consequential for the native species. The seed set in all native species was altered by one or more of the exotic treatments. The phenological shift also affected pollinator visitation. Previous research has shown that the neighborhood (community) of plants can affect pollinator visitation. Behavior will change due to the floral density of native and non-native flowers. Phenological shifts could reduce seed set by the realized pollinator effectiveness. With a higher density of exotic flora, pollinators are likely to carry less conspecific pollen for the native forbs. The phenological shift could also influence pollinator preference depending the flowering time and pollinator emergence. Changes to seed set is likely to affect the demographics of plant populations. This could also lead to direct effects between shifting and non-shifting species in the form of competition. Not all the indirect interactions were as expected. Variable pollinator response also mediates the effects of phenological shifts.

*Conclusion*

This study was based on manipulations that could take place as a ‘proof of concept’ and not as a prediction. The native species and pollinators were not shifted which is likely to occur. Understanding the phenological shifting and indirect effects thereof will improve our understanding of the biological effects of climate change.

*Impressions*

This study examined the indirect effects of phenological shifting in exotic species on native species. Though this study doesn’t relate directly to the bare ground study, the implications of phenological shifting due to climate change are relevant.