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Using herbarium records to assess shifts in phenology in alpine plants and select indicator species for climate change

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Abstract

Key words

Acknowledgements

**Introduction**

Understanding variation in plant responses to climate change is important for predicting future patterns in plant biodiversity and effectively developing management plans for natural areas. Plant phenology is one of the best indicators we have to observe the biological impacts of climate change (US Global Change Research Program 2010). Owing to the importance of phenology as an indicator, phenology networks around the globe have been established in the last decade (e.g., USA National Phenology Network, Global Phenological Monitoring). Ongoing phenology measurements include ground-based phenological observations, satellite images, and repeat photography (Fitchett et al 2015). While these methods allow us to assess phenology at the ecosystem and community level or at the species level for a small subset of species, we often do not have the resources to assess a large number of species with these methods. In order to assess more species to better understand variability in phenological responses and, in many cases, tap into a longer period of observations, herbarium records have been utilized to understand long-term shifts in plant phenology (e.g., Park and Schwartz 2015, Bertin 2015, Mohandass et al 2015, Davis et al. 2015, Rawal et al 2015, Har et al. 2014, Calinger et al. 2013).

**-What we know about plant responses to climate change and variability in those responses**

**-what we know from other assessments of herbarium records: what regions, how many species, how many years**

**-why important to know more about alpine species in particular – and what we already know.** We know that climate change is affecting plant phenology at rate of 2.8 days per decade in the northern hemisphere (Parmesan 2007), specifically in alpine areas in temperate ecosystems (Inoye and Wielgolaski 2003). While plants in habitats around the globe will all face challenges and the need to adapt to changing conditions, species at the edges of suitable habitat, such as alpine species, face additional challenges. While species at lower elevations have the potential to shift ranges (e.g., moving to higher elevations to maintain suitable habitat), species in alpine areas don’t have that option. Instead, plants survival is based on their ability to adapt and one mechanism is through a shift in phenology. We might expect to see the earliest responses to climate change via changes in phenology in such environments. Results of studies of species in extreme environments do not always follow our predictions and it is therefore important to continue to study variation in responses around the globe. For example, is a warming study on Arctic tundra species, plants did not show a phenological response to temperature increases alone, but rather responded to a delay in snowmelt (Bjorkman et al 2015) and other Arctic studies have also shown the importance of both temperature and snowmelt (Legault and Cusa 2015). Ecosystem-level phenology also shows a response to timing of snowmelt in alpine systems (Filippa et al. 2015). Perhaps the most well-studied alpine system for phenology is in Colorado where Inouye has been monitoring long-term study plots since 1973. All of the species studied show a relationship to the amount of snow fall during the previous winter (Inouye and Wielgolaski 2003). For alpine species, the short window available for growth during the summer means that phenology is almost always tied to the timing of snow melt. For analyses of historical data, this information is not always available but analyses that incorporate precipitation patterns can at least start to address this relationship.

Here we look at all available herbarium records for the alpine areas in Colorado, in the Southern Rockies of the United States. We assess overall patterns in phenology over a 60 year period and the relationship between phenology and temperature and precipitation. This analysis provides information on alpine species that is relevant for understanding ongoing and future shifts in biological patterns in this habitat. Additionally, using these patterns, we provide additional support for local efforts to track phenology at the species level that contribute to larger global efforts to track biological responses to climate change.

**Methods**

**Results**

**Discussion**

-**Discussion of our shift in phenology over time relative to previous studies**. Using a combination of herbarium specimens and observations, Bertin (2015) found a 2.9 day increase in mean flowering time over the 60 year study (0.05 d/yr), with flowering advancing more in species with shorter bloom periods.

**-Discussion of our relationships with temperature and precipitation relative to previous studies.** These results indicate that plant phenology continues to be a good indicator of biological responses to climate change. For this alpine habitat, all species that showed a response to temperature shifted earlier in the year. Precipitation had a more variable response.

-**Implications of these results for our understanding of alpine communities with respect to climate change.** While previous studies have shown that alpine communities are most sensitive to timing of snow melt with respect to phenology, one might wonder if the heterogeneous topography in alpine habitats impacts the results of monitoring studies if microclimate is not taken into consideration. One study on an alpine shrub found that small scale variation mattered much less than interannual differences in the timing of snow melt (Bienau et al. 2015), indicating that the location of sampling within a habitat is less important than long-term monitoring from a representative sampling of the habitat. This might be especially important for using herbarium specimens in such analyses since we know that there are challenges

**-Using this information to select indicator species**. Of the 290 species that had sufficient herbarium records to use in these analyses, 15 are currently on the USA National Phenology Network list of observation species. If we only looked at these 15 ….discuss how overall interpretation and results would be different and what does that mean for ongoing monitoring networks and how we should select monitoring species and also incorporate historical data.

**References**

**Figure Captions**

**Figures**

**Tables**