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Examining the variation in the collection date of herbarium specimens is a common method for studying the phenological effects of climate change on a flowering plant species. We used herbarium data to examine how warming temperatures have affected flowering time in *Silene acaulis* in the state of Colorado. *Silene acaulis*, commonly known as moss campion and cushion pink, is an alpine tundra plant. Using ordinal date of collection as a proxy for flowering date and year collected as a proxy for increasing average temperature, a linear regression test found that there was no significant relationship between increasing temperatures and flowering time. Further examination of the herbarium data revealed a pattern of summertime specimen collection for *Silene acaulis*. As a species that flowers in response to snow melt, the collection pattern indicates that herbarium data is insufficient for assessing the phenological effects of climate change on *Silene acaulis*. More intensive research on the relationship between snow melt and flowering time is needed to understand the impacts of climate change on *Silene acaulis*.

Keywords

Phenology, Abiotic, Biotic, Silene acaulis, Ecosystem, Herbarium

Examining Climate Change Effects on Flowering in Moss Campion

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Abstract

Examining the variation in the collection date of herbarium specimens is a common method for studying the phenological effects of climate change on a flowering plant species. We used herbarium data to examine how warming temperatures have affected flowering time in *Silene acaulis* in the state of Colorado. *Silene acaulis*, commonly known as moss campion and cushion pink, is an alpine tundra plant. Using ordinal date of collection as a proxy for flowering date and year collected as a proxy for increasing average temperature, a linear regression test found that there was no significant relationship between increasing temperatures and flowering time. Further examination of the herbarium data revealed a pattern of summertime specimen collection for *Silene acaulis*. As a species that flowers in response to snow melt, the collection pattern indicates that herbarium data is insufficient for assessing the phenological effects of climate change on *Silene acaulis*. More intensive research on the relationship between snow melt and flowering time is needed to understand the impacts of climate change on *Silene acaulis*.

Keywords:
Phenology – the study of the timing of recurring biological events
Abiotic – non-living aspects and components of an ecosystem
Biotic – living components of an ecosystem
Silene acaulis – an alpine tundra plant commonly known as moss campion and cushion pink
Ecosystem – a system of abiotic and biotic community interactions
Herbarium – a collection of plant specimens and their associated data

1 INTRODUCTION

The study of conservation biology aims to understand and mitigate factors that threaten biodiversity. As rising global temperatures impose dramatic changes throughout the world, studying the impacts of climate change on individual species and ecosystems is vital for designing and implementing conservation strategies. One method for studying climate change and its impacts on flowering plants and their surrounding ecosystems is by examining changes in phenology of flowering time.

Phenology refers to the timing of recurring biological events; it can be influenced by abiotic and biotic factors. The annual flowering of plants is an important phenological phenomenon that is primarily influenced by temperature and precipitation. As global temperatures rise due to climate change, precipitation and temperature patterns have changed for many ecosystems. In response to these shifts, many plants have begun to flower earlier in the year[1,2].

Silene acaulis, commonly known as moss campion and cushion pink, is a cushion plant that grows in alpine tundra ecosystems and can be found at higher elevations throughout most of the Western United States. It has been observed that the primary factor influencing phenology in *S. acaulis* is snow melt[3]. As a plant growing in mountainous areas, *S. acaulis* is expected to show a significant trend of earlier flowering time because climate change is found to have disproportional effects on high latitude and high elevation ecosystems. Some studies of *S. acaulis* have indeed documented earlier flowering and changing pollinator interactions in *S. acaulis* due to warming temperatures[3,4].

Herbarium data can be used to provide long term trends in phenology. Herbarium specimens are often collected when flowering or fruiting, making collection date a good proxy for flowering date. Because climate change records show increased temperature with time, looking at the collection date of specimens over time can indicate whether flowering time is occurring earlier

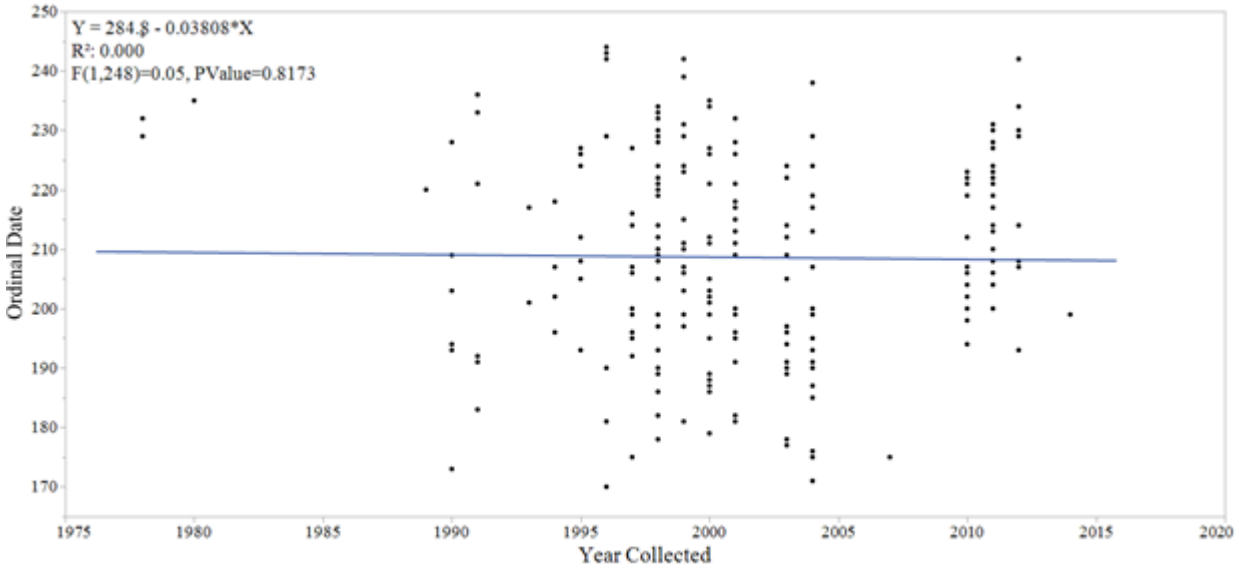

Figure 1. The graph shows the linear regression line for the relationship between the year collected and ordinal date (measurement for flowering time) of the species *Silene acaulis*. The equation of the line is $Y = 284.8 - 0.038X$, with $R^2 = 0.00$, and $p = 0.8173$.

in relation to warmer winters and springs. Herbarium data can be particularly useful for a plant species such as *S. acaulis* which lives in areas that are more difficult to access or monitor.

In this study, the long-term effect of rising temperature on *S. acaulis* flower phenology was tested using linear regression to determine how ordinal date, an approximation for flowering date, changed over time in the state of Colorado. It was expected that ordinal date would decrease as collection date increased, showing a trend of earlier flowering times in *S. acaulis* as a result of climate change.

2 METHODS

S. acaulis data for the state of Colorado was collected from the Rocky Mountain Herbarium Specimen Database website[5]. Within the database website, "Silene acaulis" was entered as the search term in the scientific name search field, "Colorado" was used as the search term in the location search field, and "Rocky Mountain Herbarium" was selected in the herbarium search field. No other search filters were used. The resulting data set was then downloaded and processed to exclude non-flowering specimens and specimens that were missing the day, month, or year from their time of collection.

The Excel equation, =ABS(TEXT(X-DATE(YEAR(X), 1,0), "000")), was used to calculate ordinal date, where X is the date (Year, Month, Day) of specimen collection. Ordinal date gives an approximation of the day of the year that each sample was flowering. To test for a relationship between *S. acaulis* phenology and rising temperatures, linear regression was used to determine whether there was a relationship between the year collected and the ordinal date. Ordinal date was the dependent variable and year collected was the independent variable.

3 RESULTS

The graph of the data shows a small negative slope in the regression line. It also shows acceptable distributions of data as well as a clearer picture of the data and how it may have changed over time. In the raw data, ordinal date for collection of samples shows that specimens were collected between the months of June and August. The slope of the regression line is -0.038 and the equation is $Y = 284.8 - 0.038X$, with $R^2 = 0.00$, and $p = 0.8173$. The slope of the regression line is not significant, and the p-value is much higher than the 0.05 accepted alpha value parameter. The graph shows a slight general trend in the data of earlier flowering over time, but this is not significant enough to show a true trend in the data.

4 DISCUSSION

The results do not support the hypothesis that *S. acaulis* has been flowering earlier over time in response to warming temperatures. The linear regression shows that there is no significant relationship between ordinal date and collection date ($R^2 = 0.00$, $p = 0.8173$); thus the null hypothesis fails to be rejected. Because the linear regression does not indicate a significant relationship,

it suggests that *S. acaulis* phenology has not changed over time in response to rising temperatures. Although the data analysis for this study does not show a relationship between ordinal date and year collected, it does not mean that climate change has no effect on flowering time. In fact, many other studies of *S. acaulis*, including specifically in Colorado, have shown that the species has experienced flowering times earlier in response to climate change[3]. Because other studies have found that *S. acaulis* has had earlier flowering patterns with increased global temperatures, and because there was a slightly negative slope, the results from this linear regression suggest that a Type II error occurred. In other words, there is evidence of a relationship between climate change and flowering time, but there is not sufficient data for this relationship to be seen in this statistical analysis.

The lack of a causal relationship between the collection date and ordinal date is likely due to specimen collection habits of *S. acaulis*. *S. acaulis* typically blooms in the summer months of June, July, and August. This is reflected in the herbarium data set, as all specimens were collected during this expected time frame. Earlier collection dates during the spring would be needed to determine if there is earlier flowering occurring as a result of climate change. Many herbarium specimens are collected with flowers, making collection date a possible estimate for flowering date. However, because there were no specimens collected during the spring, it is likely that the collection date does not accurately reflect the approximate time of initial flowering. Thus, herbarium collection date may be not the best indicator for earlier flowering time of *S. acaulis* in relation to climate change.

Because the herbarium data results are inconsistent with previous recorded trends of earlier flowering times in *S. acaulis*, specimen collection habits should be altered, and other study approaches should be utilized to research the effects of climate change on S. acaulis phenology. To provide more accurate data about changes in *S. acaulis* phenology, a more intensive approach of monitoring *S. acaulis* flowering in relationship to snowfall and snow melt should be utilized. Studies that have monitored for flowering after snow melt have been successful in determining earlier flowering[3]. Furthermore, herbarium specimen collectors should consider looking for and harvesting specimens of *S. acaulis* at an earlier date to provide more comprehensive data for when *S. acaulis* begins flowering. This may be applicable to other species as well.

The study of *S. acaulis* is important because it can provide information on climate change effects in alpine tundra ecosystems. Phenological studies are particularly important for possible conservation efforts as they can provide valuable information on the reproductive success and dispersal of *S. acaulis* as the species faces the threat of climate change. This information will also be important to understand how plants and animals that rely on *S. acaulis* as a nurse plant or food source may be impacted. However, as studies of *S. acaulis* continue, more intensive snow and flower monitoring research is needed as herbarium samples may not provide the most accurate method for examining climate change effects on flowering time.

5 EDITOR'S NOTES

This article was peer reviewed.

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