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# For everything there was a season: phenological shifts in the Tetons ecosystem

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**Abstract** Phenology — the timing of ecological events — is shifting as the climate warms. Grand Teton National Park biologists have identified this topic ("effect of earlier plant flowering on pollinators and wildlife") as one of their priority research needs. To address this, we assembled phenological observations of first flowering dates for 48 species collected by Frank Craighead, Jr. in the 1970s and 1980s. We hypothesized many species would be flowering earlier now. In 2016 we began standardized observations in the same locations targeting the same species as well as an additional 62 species (110 total). We compared four years of contemporary observations with historical to reveal striking shifts in phenology, and used local weather data to identify the key climatic drivers. The largest effect was observed in early spring flowers, which are blooming ∼17 days earlier. Mid-summer flowers bloom ∼12 days earlier, and berries bloom ∼7 days earlier. Not all species are emerging earlier: phenology of late-summer flowering plants has not changed. Also individual species within functional groups differ in their responses. The greatest drivers of early spring and mid-summer flowering are average spring temperature (March, April, May) and snowmelt timing. Late summer flowers respond more to the accumulation of growing degree days.

## Introduction

Climate change is a significant threat to biodiversity (Monahan and Fisichelli, 2014; Parmesan and Yohe, 2003). In the Rocky Mountains, climatic changes such as the earlier arrival of spring snowmelt (Hall et al., 2015) and advancing spring onset (Ault et al., 2015; Monahan et al., 2016; Monahan and Fisichelli, 2014) are leading to changes in plant and animal interactions (Armstrong et al., 2016; Dillon, 2011; Kearns et al., 1998; Middleton et al., 2013), plant reproductive success (Inouye, 2008), and disturbances such as more wildfire (Bloom et al., 2018*b*; O'Leary et al., 2016). Around the world, many species' phenologies are shifting as global and local climates warm (Inouye, 2008; Parmesan and Yohe, 2003). Examples of phenology include when plants leaf out, first flower, or reach peak flowering, when insects emerge, metamorphose, pollinate, and reproduce, or when migrating birds arrive in breeding grounds. Although some species' phenologies are closely linked to temperature and climatic events such as snowmelt (O'Leary et al., 2018; Sherwood et al., 2017; Willis et al., 2008), other species' phenologies can be driven by day-length cues (Coppack et al., 2003; Dawson et al., 2001; Gwinner, 1990). As the climate warms, this can result in phenological mismatches or novel synchronies between species pairs (Deacy et al., 2017; Kearns et al., 1998). Observed shifts in phenology are often the first signs that climate change is impacting natural populations and may be an early warning of future population declines or local extinctions (Willis et al., 2008). Previous research demonstrates that plants whose phenology is plastic to temperature shifts fare better under a warming climate (Willis et al., 2008).

One approach to understanding the impacts of anthropogenic climate change on phenology is to compare current-day phenological events with the timing of those events in historic records that pre-date the influence of climate change. Detailed historic phenology data are rare, but in Grand Teton National Park (GTNP) we have the opportunity to capitalize on data gathered by ecologist Frank Craighead, Jr. in the 1970s. These data served as the basis of his popular book *For Everything There is a Season* (1994), which gives a week-by-week account of ecological events that are likely to be occurring in the Grand Teton-Yellowstone area. Craighead wrote this book near the end of his 60+ year ecology career and may have forseen the impending changes: "You may also enjoy using the data provided in this book or your own notes to predict when a specific event may occur and where it fits into the annual sequence of events – for everything there is a season. If the event occurs earlier or later than anticipated from the base data provided in the book, you can try to determine the influencing factors – for everything there is a reason."

Similar notes have been used to compare past and present patterns of phenology in a handful of other locations around the United States. These include Thoreau's notes from Massachusetts (Primack and Miller-Rushing, 2012), Aldo Leopold's notes from Wisconsin (Bradley et al., 1999), and the notes of the Smiley brothers in New York (Cook et al., 2008).

Within the Greater Yellowstone Ecosystem (GYE) and GTNP, there is currently little understanding of how climate change is affecting plant and animal phenology or potential asynchronies between these guilds. One study used remotely-sensed data to conclude that more rapid spring green-up is negatively impacting migratory elk populations in the GYE (Middleton et al., 2013). Others are showing that warming temperatures in GTNP may impact plant nectar production and pollinator resources (Sprayberry et al., 2016; Monahan et al., 2016; Debinski et al., 2014; Dillon, 2011). While these studies are indicative of changes that are occurring, a more detailed understanding of how plant phenology is changing at the species level — and what it means for the myriad species that depend on these plants in the GYE — is needed in order for managers to anticipate and mitigate impacts of these changes (University of Wyoming, 2017).

Our primary research question is: 1) How has plant phenology, on a species level, shifted now relative to the 1970s in the Tetons? Additional research questions include: What climate variables (e.g. spring temperature, growing degree days (GDD), timing of snowmelt) are most closely related with plant flowering? Can we work towards predictive phenology models based on these variables? And ultimately, what are the cascading effects of changes in plant phenology for key pollinators (e.g. bumblebees, hummingbirds) and wildlife (e.g. sage-grouse, bears)? We aim to better understand ecological relationships and assist in the mitigation of climate change impacts on the plants and wildlife of the GYE. We also seek to increase public involvement and understanding of climate change and science-based decision making through engagement in our citizen science project, Wildflower Watch.

## Methods

### Historical collections

We retrieved hand-written notes, entered these into digital form, and quality-controlled nearly 800 observations that Frank Craighead Jr. made of plant flowering and fruiting dates in 1974-1979 and 1988. During each of these year's spring or summer seasons, Craighead made near-daily observations of phenological events. His notes include 258 species of flowering plants, although not every species was observed every year. We categorized plant observations representing first presence of leaves, first presence of buds, first flower, peak flower, and occurrence

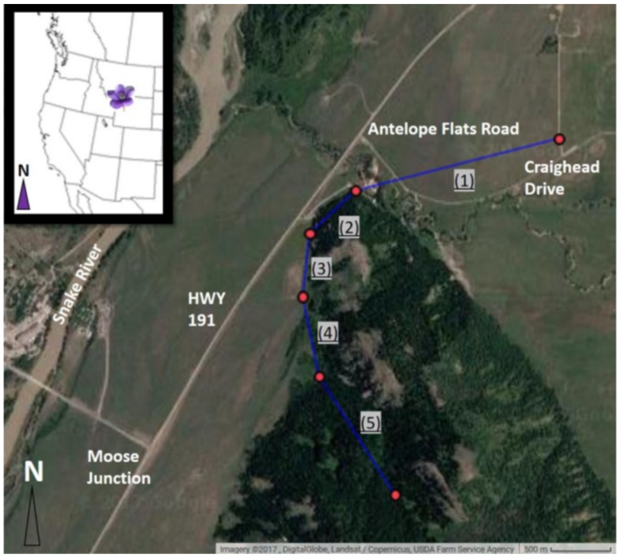


**Figure 1.** Primary sites for observation of phenology of >100 species of flowering plants and pollinators within Grand Teton National Park. Site 6, Gros Ventre Junction is located to the south of Blacktail Butte off the map. Pollinators and phenophases for each plant species were collected in at least one of the six sites encompassing a diversity of ecosystems.

| Name | Habitat | Location |
|---|---|---|
| 1) Craighead Cabin | Sagebrush steppe | 43.6645, -110.6857 |
| 2) Lower Blacktail Forest | Mixed conifer | 43.6606, -110.6969 |
| 3) Lower Blacktail Sage | Sagebrush steppe | 43.6587, -110.6991 |
| 4) Blacktail Butte Aspen | Aspen grove | 43.6564, -110.6974 |
| 5) Upper Blacktail Butte | Montane forest | 43.6518, -110.6929 |
| 6) Gros Ventre junction | Sagebrush steppe | 43.5819, -110.7185 |

**Table 1.** Six primary sites for observation of phenology of >100 species of flowering plants and pollinators within Grand Teton National Park, mapped in Figure 1.

of fruits or seeds. The vast majority of the observations were of first flowering date, and we have therefore focused our analyses on this phenological event. All data were sorted by species, year, and ecological event. We identified 48 species that had at least three observations from the 1970s. We are working to expand the historic dataset to include herbarium records and additional historic phenology notes. We are confident that Craighead's observations were made in Grand Teton National Park near his home in Moose, WY at the foot of Blacktail Butte. We focus analyses on data from this location and exclude any of the other locations. Craighead specifically noted in his book "Phenological observations of the greatest interest and comparative values are those recorded from the same local area year after year and throughout the year. This local area is referred to as the base area. The information presented here is the database. . . The nucleus of the base area is the vicinity of Moose, Wyoming, including the Grand Teton National Park Headquarters."

## Contemporary observations

In spring 2016, we initiated contemporary observations of the 48 species for which we had at least three years of historic data, plus an additional 62 common or ecologically important species. We focus our observations on the areas near Craighead's home in the sagebrush steppe vegetation towards the summit of Blacktail Butte, located near Moose, Wyoming in GTNP (Figure 1, Table 1). Craighead's notes and surviving relatives indicate that he walked this 2.7 km path regularly as he made his phenological observations. Blacktail Butte is an isolated outcrop of vegetated limestone with elevations ranging from 1,990-2,343 m, centered between the Beartooth-Absaroka Range to the north, the Gros Ventre Range to the east, the Snake River Range to the south, and the Teton Range to the west. The location and topographic variation of the formation means that it harbors a great diversity of microclimates, plants, and wildlife.

Along this path, we identified six key phenology sites representing a gradient of ecosystem types, from the dry, exposed sagebrush flats near Craighead's home, through an aspen woodland, and up to a montane stream waterway (Figure 1, Table 1). During our twice-weekly observations in spring 2016, 2017, 2018, and 2019 we visited each site to record the presence or absence of each species and its phenological phase (phenophase) including leaves, buds, flowers, peak flower, fruit, ripe fruit and senescence/withering. We defined peak flower as the duration of time when at least 50% of inflorescences are open in flower, as opposed to buds or fruits (Primack et al., 2004). While we do not have historic data on all of these phenological stages, it is important to begin tracking all of these parameters, as peak flowering date and seeding/fruiting date have important consequences for species of birds, mammals, and insects that feed upon plant resources such as nectar and fruits (Aldridge et al., 2011; Deacy et al., 2017; Dillon, 2011; Kearns et al., 1998) as well as management implications such as timing of seed collections for restoration efforts. We also captured coarse-scale weather observations, naturalist observations, and hundreds of photographs. In 2017-2019, over 95% of observations were made by a single researcher, Bloom, minimizing observer effects. Observations in the year 2016 were conducted by Stephanie Dykema and are only relevant for first flower dates.

| Functional Group | Description | Number of Species |
|---|---|---|
| Spring | Average first flower before June 15 | 17 |
| Mid-Summer | Average first flower between June 16-July 31 | 17 |
| Late | Average first flower after July 31 | 5 |
| Non-Native | Non-native to Teton County | 4 |
| Berries | Produces a berry that is edible to wildlife | 4 |
| Shrubs | Woody plant smaller than a tree | 1 |
| Total | All species with historic and contemporary data | 48 |

**Table 2.** Functional groups for plant species studied at Moose, WY.

## Micro-climate monitoring

Starting in spring 2018, we designed and deployed an array of climate stations across the entire study site centered around Moose, WY. As of Fall 2018, we have deployed a total of 48 Onset HOBO 8K Pendant Temperature Data Loggers across 39 independent sites. Most of these sensors are recording ambient air temperature. Each sensor is set to record temperature once every 60 or 120 minutes for approximately 200 continuous days – after which we download all data and reset the sensors to continue recording. The six key phenology sites (Figure 1, Table 1) each contain a "climate station." Each climate station contains a pair of sensors – one in the air, one in the ground. The air sensors are placed in a solar radiation shield and mounted approximately 50cm above the ground on a fence post or small tree to capture ambient air temperature. The ground sensors are buried 5cm under the ground and tethered to the air sensor post with a 1-meter cord. Ground sensors can accurately detect snowmelt timing due to the insulating properties of the snow until the time of melt. The furthest south climate station is located near Gros Ventre Junction on the far southern edge of the Blacktail Butte feature. The furthest north station is located in the sagebrush field just outside Craighead's historic cabin. The majority of the sensors, 36, are located in an array up the full elevation gradient of Blacktail Butte (Figure 2). We aim to characterize microclimate at high spatial resolution (<10m) – including multiple topographic aspects, cold air drainages, ride tops, and the summit across a diverse range of ecosystems.

## Phenology and climate analyses

Temperatures were derived from the Parameter elevation Regression on Independent Slopes Model (PRISM) dataset (PRISM Climate Group 2018) focused on the 4km grid cell centered on Blacktail Butte. We used these data to analyze the trends in minimum, mean, and maximum temperatures from 1970 to present. We also extracted mean spring temperature (March, April, May) from the PRISM dataset.

In addition to PRISM, we utilize the long-term dataset provided by the Moose Weather Station located at the Grand Teton National Park headquarters located less than 1.5km from the base of Blacktail Butte. This weather station has been continuously recording

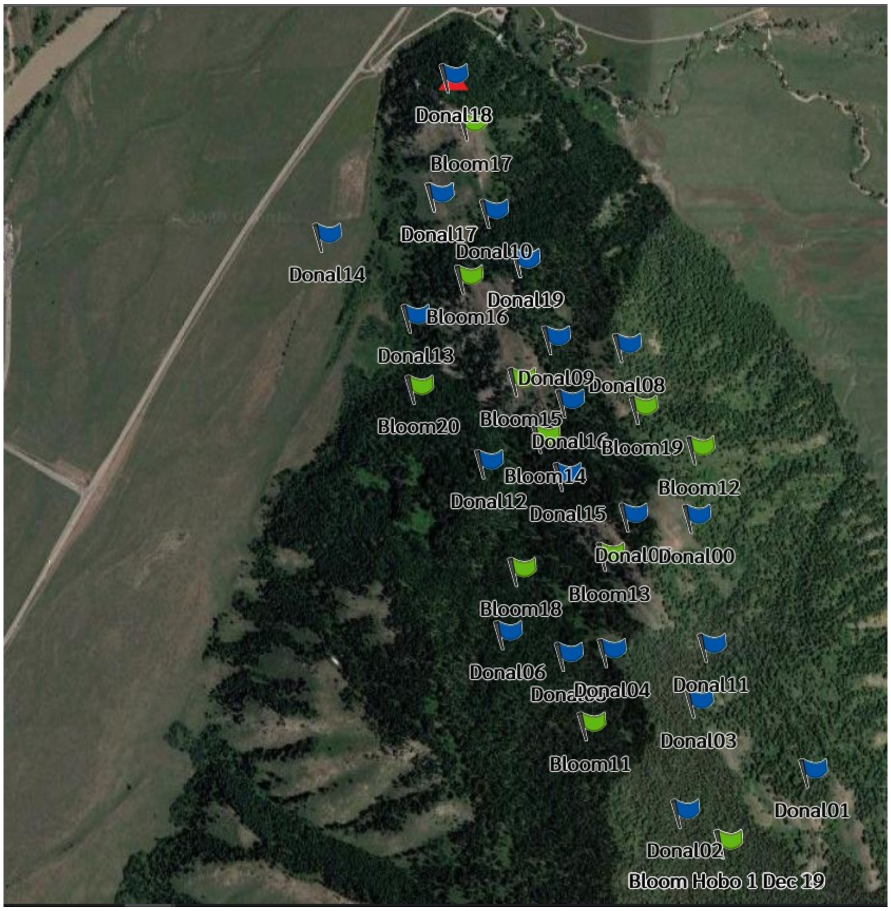


**Figure 2.** Close up view of northern Blacktail Butte where we have installed 36 climate sensors. Each station contains at least one sensor measuring ambient air temperature. Certain climate stations located at each of the six core phenology sites include a temperature sensor in the soil, pollinator collections, and game cameras for wildlife sightings and snow depth validation.

daily temperatures and daily snow depth since before our oldest historic phenology record in 1973. Using this dataset we derive spring temperature, snowmelt timing, and Growing Degree Days (GDD). For each species, we calculated the Julian day (0-365) for the first flower for each year from the combined historic and contemporary dataset. Species were also binned into one of six functional groups (Table 2).

To determine changes over time in patterns of phenology, we compared the average date of first flower for each species and functional group for the contemporary and historic datasets. To identify the drivers of phenology we used a mixed-effects linear regression model to analyze first flower date, individually and as a functional group, as a function of three predictor variables: mean spring temperature, GDD, and snowmelt timing. Based on the best $R^2$ value we determined the primary driver for each functional group. We could not analyze first flower as a function of multiple variables with our sample size and degrees of freedom. Once the primary variable was determined we performed linear regression models for each species as a function of the primary driver. All analyses were performed in R (R Core Team 2018).

## Pollinator collections

In 2018 we collaborated with the University of Wyoming/AMK Ranch to engage undergraduate students to sample pollinators at our sites. At each of the six key phenology sites, we placed three different colored pan cups (blue, white, and yellow) and 1 blue vane trap to capture pollinators. The pan cups contained soapy water used as a surfactant. Pollinator collection traps were deployed June 3 to August 5, 2018 and June 15 to August 1, 2019. During this time period, traps were set out once a week (typically Thursdays) for 24-hour periods to capture relative abundances and emergence curves for the pollinators collected. Collaborators from the University of Wyoming are currently working to identify all insects collected over the summer field season. The most abundant pollinators are from the orders Hymenoptera, Coleoptera, and Lepidoptera. Full results are not available yet and will be reported in the future.

## Preliminary results

### Climate monitoring

Analysis of historic climate data in Teton County reveals consistent increases in spring temperature since the 1970s, especially in minimum temperatures, which have risen more than 2 °C in the past 40 years (Figure 3). We derived snowmelt timing for the entirety of our study period from the Moose Weather station. Snowmelt occurs approximately 20 days earlier now as compared to the 1970s (Figure 4).

We are currently analyzing the first full year of HOBO data to extract climate variables such as daily high and low temperatures, cumulative growing degree days (Richardson et al., 1975; Tuhkanen, 1980), and snowmelt timing (Lundquist and Lott, 2008). Snowmelt timing can be identified easily – as snow is a powerful insulator and thus the sensor records a constant temperature until the snow melts and a diurnal temperature cycle is clearly observed. This method improves upon existing remote-sensing based data (O'Leary et al., 2017) by allowing for a daily snow-presence reading that is free of cloud interference and that has a spatial precision of <1m. However, the presence of anomalous snowpack conditions (e.g. a large wind drift, or mechanical snow clearing by a herbivore in search of forage) may influence such local snowmelt timing observations.

### Phenology and climate analyses

Most wildflower species we studied are flowering weeks earlier now relative to flowering observed by Craighead in the 1970s (Figure 5 and Supplementary Figure 1). Early flowering species (n=17) including yellowbells (*Fritillaria pudica*) and arrowleaf balsamroot (*Balsamorhiza sagttata*) show the largest effect and are blooming ∼17 days earlier. The greatest shift was observed in an early spring flower, Hooded Phlox (*Phlox hoodii*), which flowers 36 days earlier. Mid-summer flowers such as sticky geranium (*Geranium viscosissimum*) are emerging ∼12 days earlier. Nonnative species such as musk thistle (*Carduus nutans*) are emerging ∼14 days earlier today. Berries, an important food sources for many animals, such as Canada buffaloberry (*Shepherdia canadensis*) and Oregon grape (*Mahonia repens*) are blooming an average of ∼7 days earlier today than observed by Craighead. Yet not all species are shifting. Late season flowers like Engelmann aster (*Eucephalus engelmannii*) do not appear to have changed their first flower timing dramatically. There is also lots of variation between the species within each functional group (Figure 5).

We found that the timing of first flower for different functional groups was correlated to different climatic cues (Figure 6). The most important variables for early spring and mid-summer flowering species were spring temperature and snowmelt timing. These variables are auto-correlated, as warmer spring temperatures typically lead to early snowmelt years. Timing for late summer flowers was more tightly correlated with accumulated growing degree days, rather than the spring climatic cues.

## Conclusions

As climate warms, the timing of seasonal ecological events is shifting causing cascading effects on entire ecosystems (Butt et al., 2015; Hughes, 2012; Middleton et al., 2013; Miller-Rushing et al., 2010). Our preliminary results demonstrate that individual plant species in the Tetons region respond differently to temperature cues. Previous research has demonstrated that plants whose phenology is more plastic

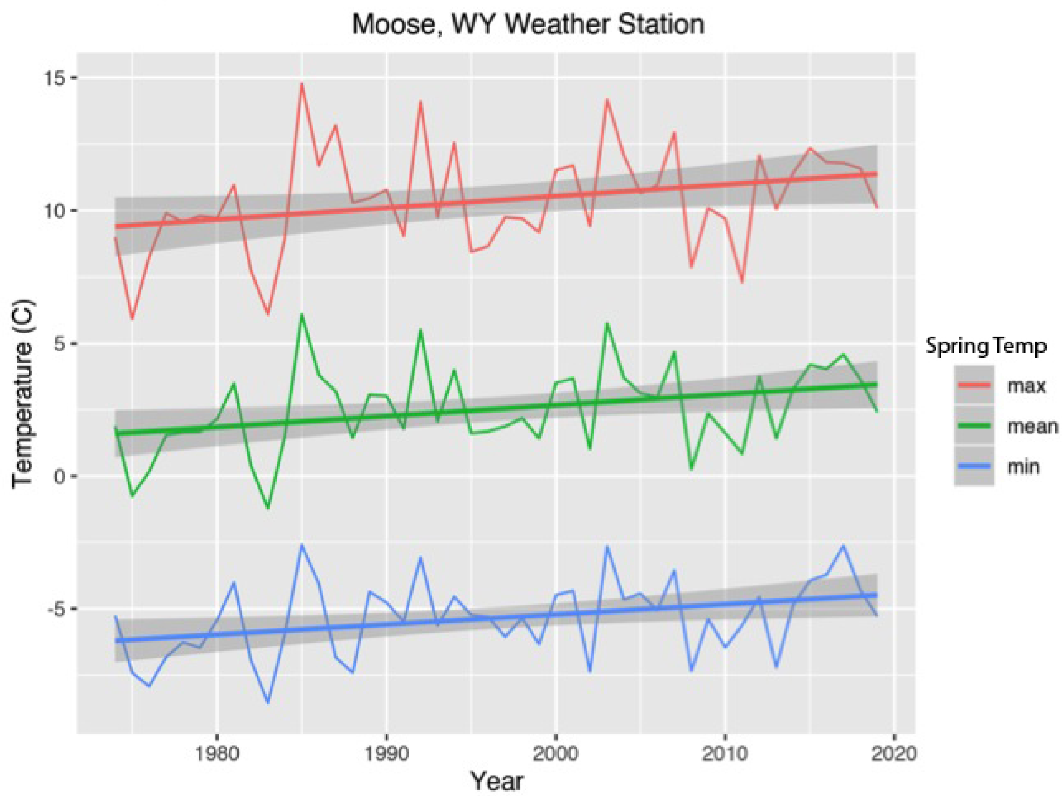


**Figure 3.** Spring temperatures (March, April, May) from 1970-2019 derived from the Moose Weather Station located at Grand Teton National Park headquarters. Moose has experienced spring warming in the past 40 years, evident in increases in maximum (top line), mean (center line), and minimum (bottom line) temperatures. Most notably, minimum temperatures have risen more than 2°C since the 1970s.

to temperature shifts fare better under a warming climate, whereas those that do not rapidly adapt may experience declines in abundance and even local extinction events (Willis et al., 2008). We have already observed that many species are flowering earlier now than they were in the 1970s. It is likely that the phenology of certain plants is no longer lining up in timing with other important ecological events such as the arrival of migratory birds and the pollination habits of insects (Mayor et al., 2017; McKinney et al., 2012; Singer and Parmesan, 2010).

For example, the first flowering date of Canada buffaloberry (*Shepherdia canadensis*) has advanced by nearly 12 days, whereas the phenology of wild rose (*Rosa woodsii*) shows little to no change. These two shrubs fill similar ecological niches and their fruits are important food sources for migratory birds and bears before hibernation. Given that wild rose is less plastic in response to variation in temperature, we expect this species to be more vulnerable to climate change than buffaloberry and that it could experience population declines over the coming decades. This could have negative consequences for species that consume berries. Species that are flowering early may also experience increased phenological mismatches with important pollinators or herbivores that respond to day-length cues.

These variations among species in plasticity to temperature changes are not surprising, since it is well-established that other factors beyond spring temperatures can affect phenology. Snowmelt timing may be a more important driver of phenology than tem-

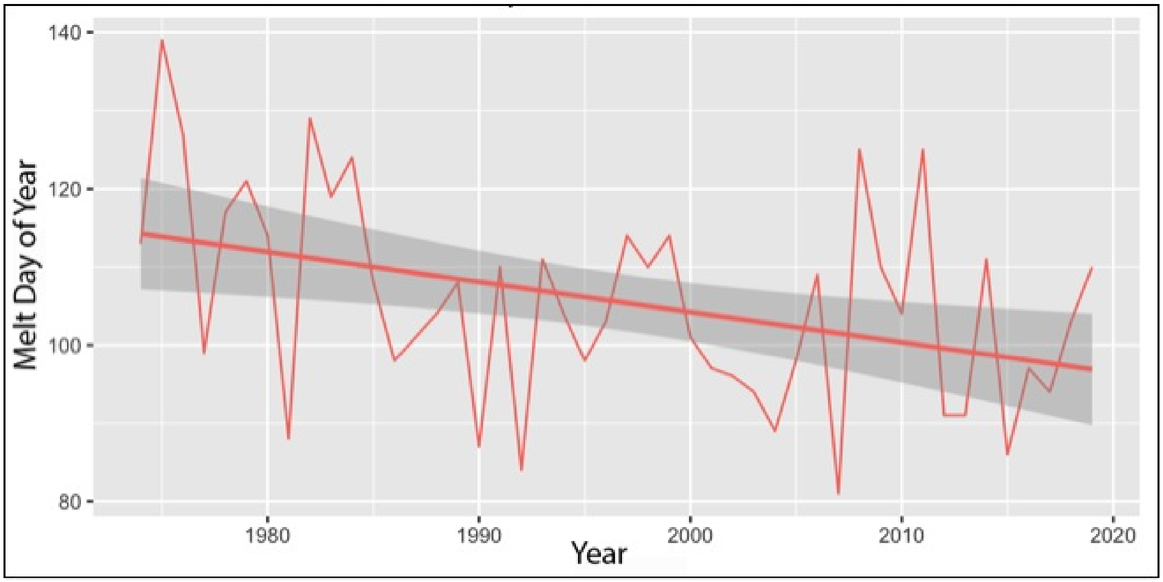


**Figure 4.** Snowmelt timing recorded at Moose Weather Station. Snowmelt has advanced by as much as 3 weeks relative to the 1970s.

perature for many species, particularly within these mountainous ecosystems where snowpack is a dominant climatic control (O'Leary et al., 2018; Sherwood et al., 2017). This may explain why we found that early spring flowers which emerge soon after the snowmelts are shifting their flowering dates much more in response to climate change than plants that bloom later in the summer. Other potential drivers of phenology include day length, precipitation as rain, growing degree days, drought, and grazing by herbivores (Wolf et al., 2017).

We are building our historic data set to include data on when certain plants began to bloom, when migratory birds arrived, and when bears exited hibernation. Changes in these patterns can signal changes in the "health" of the ecosystem. Such large shifts in flowering time as we are observing in the Tetons may result in large phenological mismatches or novel synchronizations between plants, pollinators, and foragers (Deacy et al., 2017; Debinski et al., 2014). Certain organisms, including migratory birds, respond seasonally to the length of the day, rather than the temperature (Coppack et al., 2003; Dawson et al., 2001; Gwinner, 1990). Thus they base their annual migration patterns to arrive at the same time each year to a certain region or habitat. In the Colorado Rockies, broadtail hummingbirds are arriving the same time each year, yet flowers are blooming earlier, thus they are missing peak nectar availability resulting in reduced brooding success (McKinney et al., 2012). Our early data suggest that berries that make up a large portion of bears' diets are fruiting earlier rather than later in summer/early fall, when bears need them most. With less natural food to eat, this may cause bears to seek out human food more. Also novel synchronies can occur when foragers or pollinators gain access to novel food resources during different times of the year (Deacy et al., 2017). With greater knowledge of the problem, managers can take actions to prevent some of these problems.

Teton County has experienced substantial warming over the past forty years, in line with the rest of the region and country. This trend in increasing air temperature is expected to continue for the next several decades (Pachauri et al., 2014). Given the relationship between mean spring temperature and first flowering date we have shown, we can expect many flowering species to bloom earlier in the future, possibly having cascading effects on the entire ecosystem. Assessing the plasticity of certain species to increases in temperature may help managers mitigate impacts of climate change. Our study helps to reveal

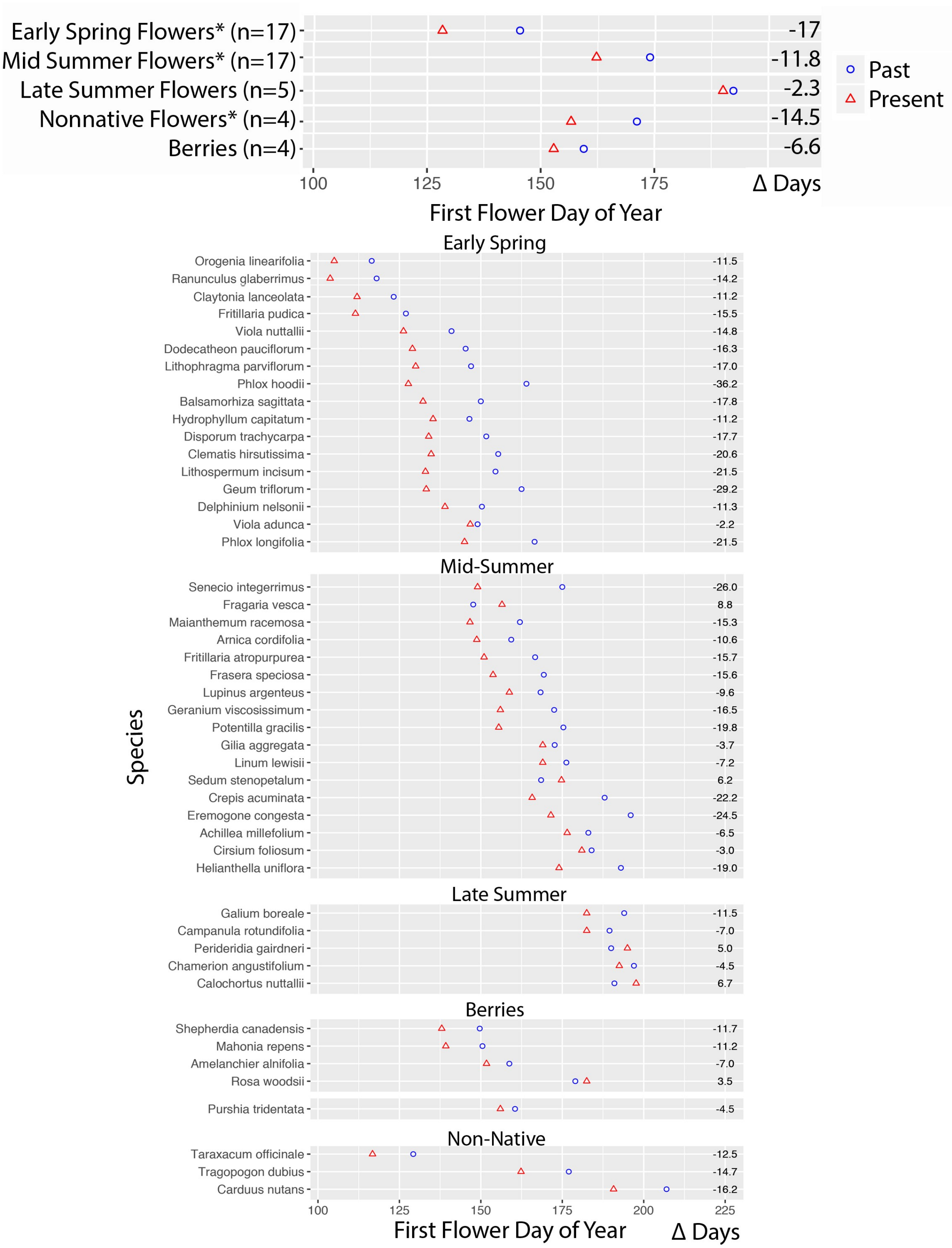


**Figure 5.** Comparison of first flowering dates for contemporary (2016-2019), represented as red triangles, versus historical records by Frank Craighead (1973-1979, 1988), represented as blue dots, at the same location in Grand Teton National Park (Figure 1). Significant differences (P<.05) indicated by an asterisk.

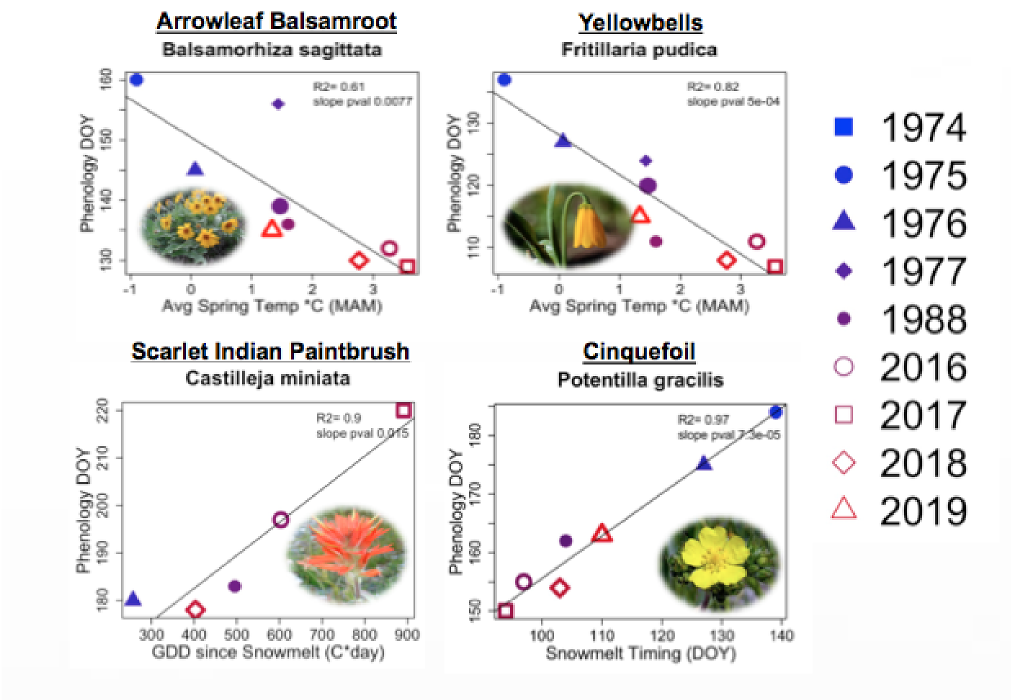


**Figure 6.** The date of first flower "Phenology DOY (Day of Year)" as a function of clockwise: mean spring temperature, snowmelt timing, and growing degree days (GDD) for four representative species. Observations made by Frank Craighead are indicated by a solid symbol, and observations made by authors are hollow. Average spring temperatures and snowmelt timing are correlated with earlier flowering dates for most, but not all, early spring flowering species in Grand Teton National Park, whereas flowering for later species is more tightly correlated with accumulated growing degree days. Mean spring (March, April, May) temperatures derived from PRISM; Growing Degree Days and Snowmelt timing derived from the Moose Weather Station.

these patterns, providing valuable insight on management decisions such as revegetation or assisted migration plans in the GYE.

## Citizen science and outreach

As a complement to our research program, we also aim to increase overall science literacy and awareness of climate change through continued outreach efforts. The reputation of Frank Craighead, a renowned biologist in the GYE and long-time resident of the Tetons, and the accessibility of our field sites, lend this project perfectly for citizen science and community engagement in climate change research. Citizen science, which engages non-professional scientists in one or more stages of scientific research, has made substantial contributions to scientific understanding and conservation management (McKinney et al., 2012) and is an effective form of science outreach.

In spring 2018 we launched Wildflower Watch, a citizen science project where volunteers collect phenology observations on approximately a dozen wildflower species in several location in Jackson Hole. We expanded partnerships to include more volunteers from diverse backgrounds and created a total of five phenology walks in Jackson Hole – Blacktail Butte, The Murie Center, Kelly Elementary, AMK Ranch and Cache Creek. We published a booklet of instructions using photos, diagrams, maps of collection sites, and step by step instructions for making field observations (Supplementary Materials: Wildflower Watch handout). We utilize the Nature's Notebook application, and all citizen science data is automatically uploaded to the USA National Phenology Network database.

In 2018 and 2019, a combined total of 502 volunteers uploaded a total of 6828 observations to the USA National Phenological Network (USANPN) database using the Nature's Notebook application. Most were one-time participants, yet many citizen scientists returned to the field repeatedly over the course of the season. We partnered with educational organizations including the Teton Science Schools and Kelly Elementary to bring hundreds of students of all ages into the field to participate as citizen scientists. We also partnered with Bridger Teton National Forest, Friends of Pathways, and Jackson Hole Wildlife Foundation to create a citizen science collaborative project at Cache Creek – the most popular trail system in the Jackson Hole region.

Preliminary examinations indicate that our citizen scientists are accurately collecting phenology data on target taxa that do not greatly differ from the observations of our primary researchers. Our efforts have proven the feasibility of a successful citizen science project in the Tetons, and we plan to grow our program over the coming years. By combining the Wildflower Watch program with the Nature's Notebook application, our volunteers automatically record their observations in a permanent, cloud-based repository, which offers many data visualization and interpretation tools for citizen scientists and educators to explore.

## Future work

### Continued collections

We will continue to gather contemporary phenology data at our study sites for the foreseeable future. This will allow us to answer robustly the question of whether and how much earlier plants are flowering now than in the past. We are also assembling a broader set of climatic data (e.g. growing degree days, snowmelt timing, precipitation as rain) to include in phenology modeling. This may allow us to better model other phenology indicators (e.g. peak flower, fruiting) with greater accuracy than using spring air temperature alone, particularly for late-blooming species that have weak phenological relationships with spring air temperature.

### Novel climate analyses

Our plot-based observations of phenology combined with the fine-scale data from our numerous climate stations will be used together to better understand the links between phenology and climate – and how these shift under global warming. Our dataset will support spatial models of species-specific spring greening, proposed by NSF and USGS researchers. Essentially if we can determine the specific mechanisms (temperature, growing degree days, snowmelt timing etc.) that drive phenology for specific species, we can use these metrics to train models of landscape level phenology. By serving as source data for model fitting and ground-truth observations for post-hoc validation, our observations will improve our understanding of phenology of the GYE beyond the Blacktail Butte study area.

### Cascading effects

We plan to continue monitoring of pollinators and create abundance emergence curves for important functional groups such as Bumble Bees (*Bombus* spp.) and Butterflies (*Lepidoptera* spp.), following principles and protocols described in Sprayberry et al. (2016) and Bloom et al. (2018*a*). We will link insect abundance and emergence with the phenology of flowering host plants, in an attempt to identify potential mismatches or novel synchronies. Beginning in summer 2018 we deployed game cameras at each of the six primary phenology sites shown in Figure 1. This may allow us to observe animal behavior including preferred forage species for important wildlife species such as moose, elk, mule deer, grizzly, and black bears. In addition, each game camera will be set up to capture snow-depth and snowmelt timing.

### Restoration and continued outreach

We are working closely with key partners to expand the utility of our research to inform restoration of federal lands. At Grand Teton National Park, we are communicating with ecologist, Kelly McCloskey, and addressing their priorities. Beginning in spring 2020, we hope to inform GTNP when and where to collect seeds (at the key phenophase) for native plants to then be reseeded elsewhere in the park, including the long-term Kelly Hayfields restoration project. We are also working with Bridger-Teton National Forest officials to inform the update of the Regional Forest Plan to include climate change. As always, we are working hard to nurture and grow Wildflower Watch – blossoming to include more citizen scientists from diverse backgrounds. We will continue our relationship with Teton Science Schools to build curricula around Wildflower Watch in order to increase science literacy and connect people with nature. Working with Bridger-Teton National Forest, Jackson Hole Wildlife Foundation, and Friends of Pathways, we will grow the Cache Creek program to engage an ever-broader audience in the issue of climate change and its impacts on natural communities. Together, our research and citizen science aim to advance our understanding of climate change's impacts on the ecology of the Tetons, inform management practices, and foster a more engaged and educated citizenship.

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## Supplemental Materials

### Table S1. Species List.

| Scientific name | Common name |
|---|---|
| Acer glabrum | mountain maple |
| Achillea millefolium | yarrow |
| Aconitum columbianum | monkshood |
| Actaea rubra | red baneberry |
| Agastache urticifolia | Cat mint |
| Alnus rubra | Red alder |
| Amelanchier alnifolia | Serviceberry |
| Antennaria rosea | Pussytoes |
| Arctostaphylos uva-ursi | kinnikinnick |
| Arnica cordifolia | heartleaf arnica |
| Artemisia tridentata | Big Sage Brush |
| Balsamorhiza sagittata | arrowleaf balsamroot |
| Bromus tectorum | Cheatgrass |
| Calochortus nuttallii | Sego Lily |
| Calypso bulbosa | fairy slipper |
| Campanula rotundifolia | harebell |
| Carduus nutans | musk thistle |
| Castelleja miniata | Giant red Indian Paintbrush |
| Castilleja linariifolia | Wyoming indian paintbrush |
| Castilleja sulphurea | Yellow sulphuric paintbrush |
| Centaurea stoebe | Spotted Knapweed |
| Chamerion angustifolium | fireweed |
| Cirsium arvense | Canada Thistle |
| Cirsium foliosum | elk thistle |
| Claytonia lanceolata | spring beauty |
| Clematis hirsutissima | hairy clematis; sugarbowl |
| Collinsia parviflora | blue eyed mary (tiny blue flowers) |
| Comandra umbellata | Pale comandra |
| Corallorhiza striata | Striped coralroot |
| Crepis acuminata | tapertip hawksbeard |
| Delphinium nelsonii | larkspur |
| Delphinium occidentale | Tall larkspur |

*Continued on next page*

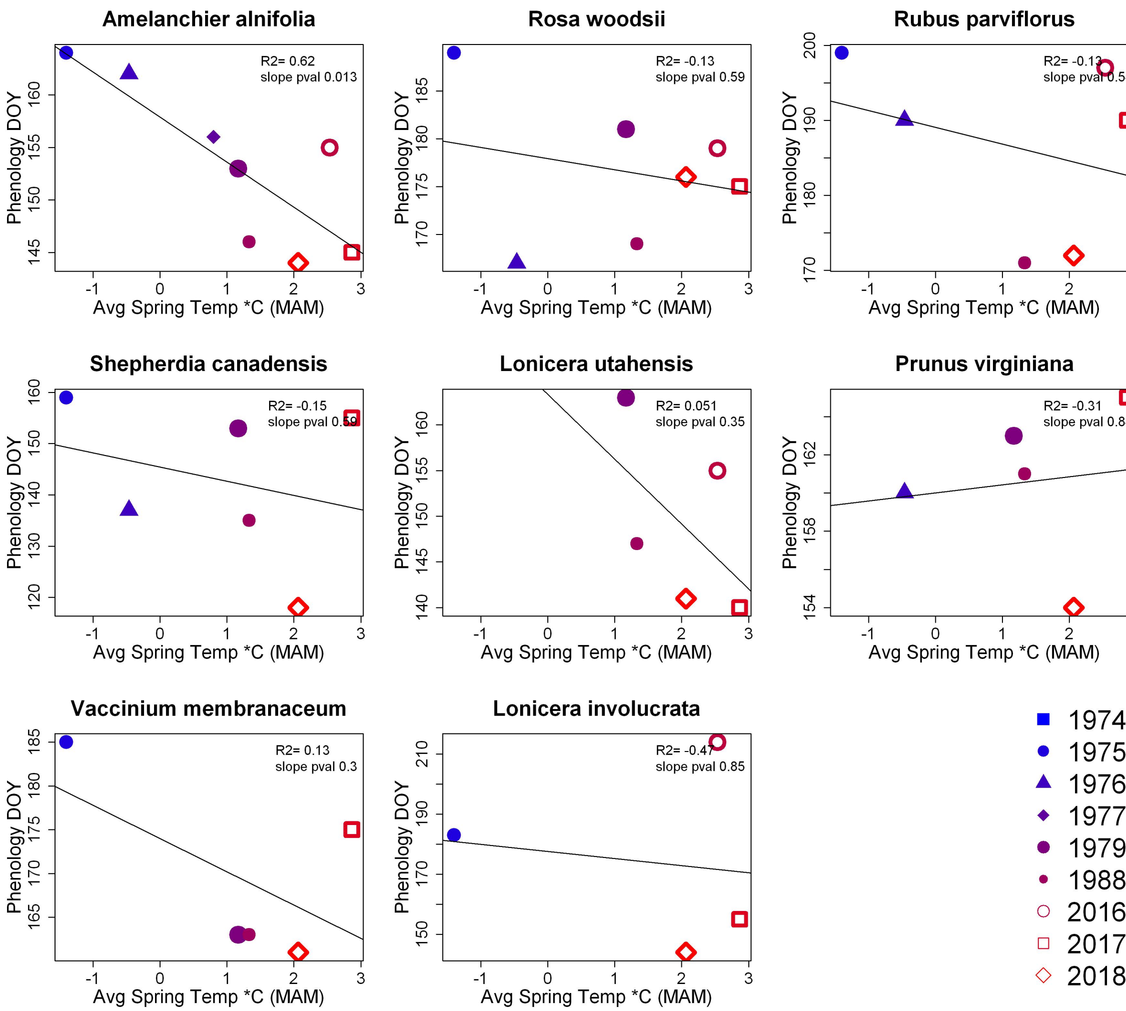
| Scientific name | Common name |
|---|---|
| Disporum trachycarpa | fairy bells |
| Dodecatheon pauciflorum | shooting star |
| Eremogone congesta | ballhead sandwort |
| Ericameria nauseosa | rubber rabbit brush |
| Eriogonum umbullatum | sulfer-flower buckwheat |
| Eucephalus engelmannii | Engelmann aster |
| Fragaria vesca | woodland strawberry |
| Frasera speciosa | green gentian |
| Fritillaria atropurpurea | leopard lily; spotted fritillary |
| Fritillaria pudica | yellow fritillaria |
| Galium boreale | Northern bedstraw |
| Geranium viscosissimum | sticky purple geranium |
| Geum triflorum | old man's whiskers; prairie smoke |
| Gilia aggregata | scarlet gilia |
| Grindelia subalpina | Gumweed |
| Helianthella uniflora | one flower sunflower |
| Heracleum maximum | cow parsnip |
| Heuchera villosa | Alumroot |
| Hydrophyllum capitatum | waterleaf; ballhead waterleaf |
| Iliamna rivularis | Holly Hock |
| Linaria dalmatica | YELLOW toadflax |
| Linum lewisii | Lewis/blue/prairie flax |
| Lithophragma parviflorum | star flower |
| Lithospermum incisum | narrowleaf stoneseed |
| Lomatium triternatum | desert parsley |
| Lonicera involucrata | Black twinberry |
| Lonicera utahensis | Utah honeysuckle |
| Lupinus argenteus | silvery lupine |
| Lupinus sericeus | silky lupine |
| Mahonia repens | creeping barberry; Oregon grape |
| Mahonia repens | Oregon grape |
| Maianthemum racemosa | feathery false lily of the valley |
| Maianthemum stellatum | wild lily of the valley |
| Medicago sativa | Alfalfa |

*Continued on next page*

| Scientific name | Common name |
| --- | --- |
| Melilotus officianalis | Sweet Yellow Clover |
| Mertensia ciliata | mountain bluebelle |
| Mimulus guttatus | Yellow monkey flower |
| Noccaea montana | Alpine penny cress |
| Opuntia fragilis | Fragile prickley pear |
| Orobanche ludoviciana | Broomrape Artemesia parasite |
| Orogenia linearifolia | Snow Drops, Indian potato |
| Penstemon cyaneus | large flowered blue penstemon |
| Penstemon procerus | Small flowered blue penstemon |
| Perideridia gairdneri | gardners yamha; common yampha |
| Phlox hoodii | Hood's phlox |
| Phlox longifolia | long-leaved phlox |
| Populus balsamifera | Cottonwood |
| Populus tremuloides | Aspen |
| Potentilla arguta | tall white cinquefoild |
| Potentilla gracilis | slender yellow cinquefoil |
| Prunus virginiana | black chokecherry |
| Purshia tridentata | antelope bitterbrush |
| Ranunculus glaberrimus | sagebrush buttercup |
| Ranunculus jovis | Utah buttercup |
| Ribes lacustre | prickly current |
| Rosa woodsii | woods' rose |
| Rubus idaeus | Rasberry |
| Rubus parviflorus | thimble berry |
| Rudbeckia occidentalis | Western Cone Flower |
| Sambuccus sp. | Elderberry |
| Sedum stenopetalum | spearleaf stonecrop; yellow stonecrop |
| Senecio integerrimus | Western Groundsel |
| Shepherdia canadensis | buffalo berry |
| Silene vulgaris | Bladder campion, white |
| Solidago canadensis | Golden rod |
| Streptopus amplexifolius | Twisted Stalk |
| Symphoricaros oreophilus | mountain snowberry |
| Symphyotrichum ascendens | Longleaf Aster |

*Continued on next page*

| Scientific name | Common name |
|---|---|
| Taraxacum officinale | dandelion |
| Thalictrum occidentale | Western Meadowrue |
| Tragopogon dubius | yellow salsify |
| Triflorum pratense | Red clover, cowgrass (introduced) |
| Vaccinium membranaceum | huckleberry |
| Valeriana occidentalis | Common valerian |
| Viola adunca | early blue violet, or hookedspur violet |
| Viola nuttallii | yellow violet; |
| Wyethia amplexicaulis | mule’s ear |
| Zigadenus elegans | Death camas |

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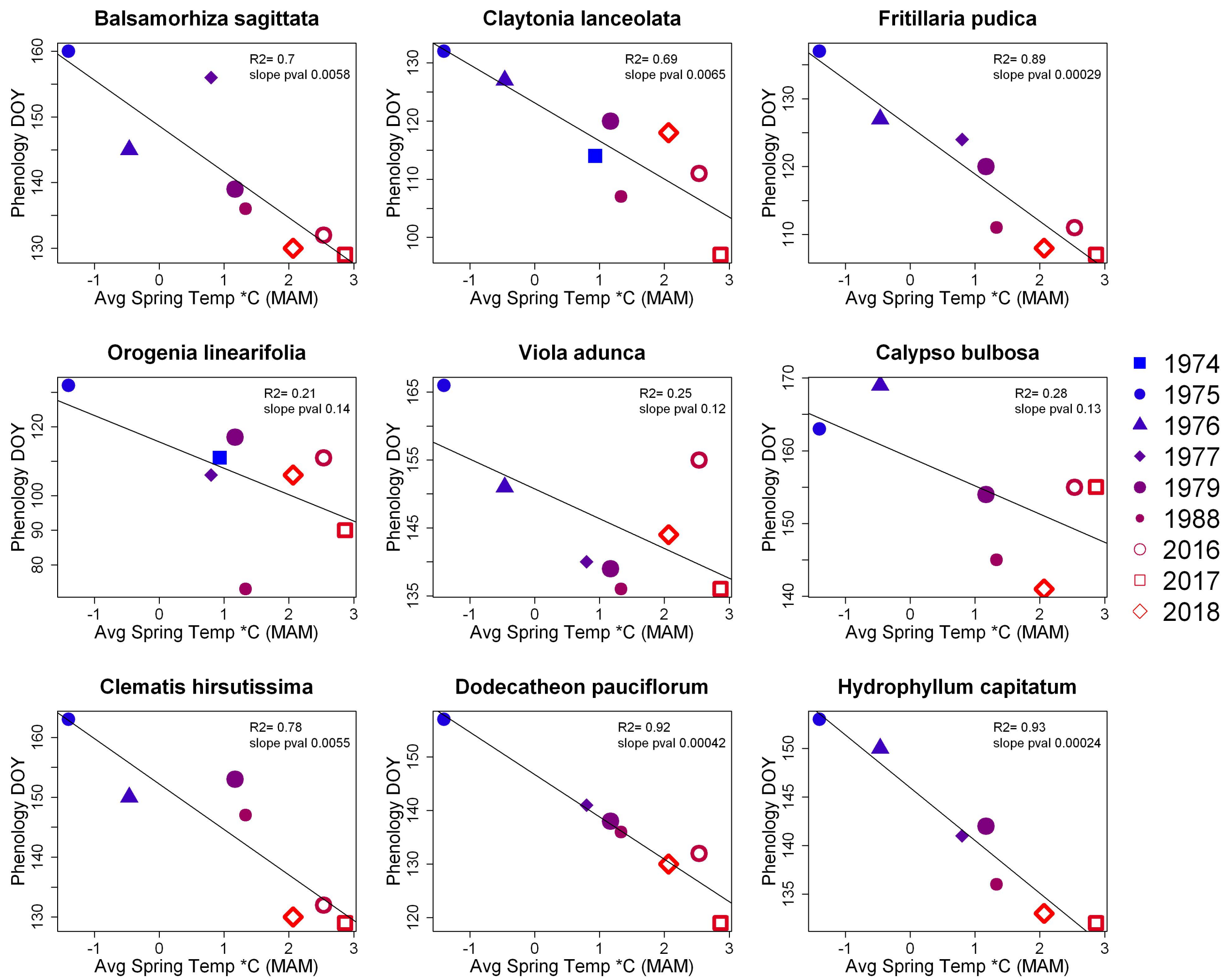


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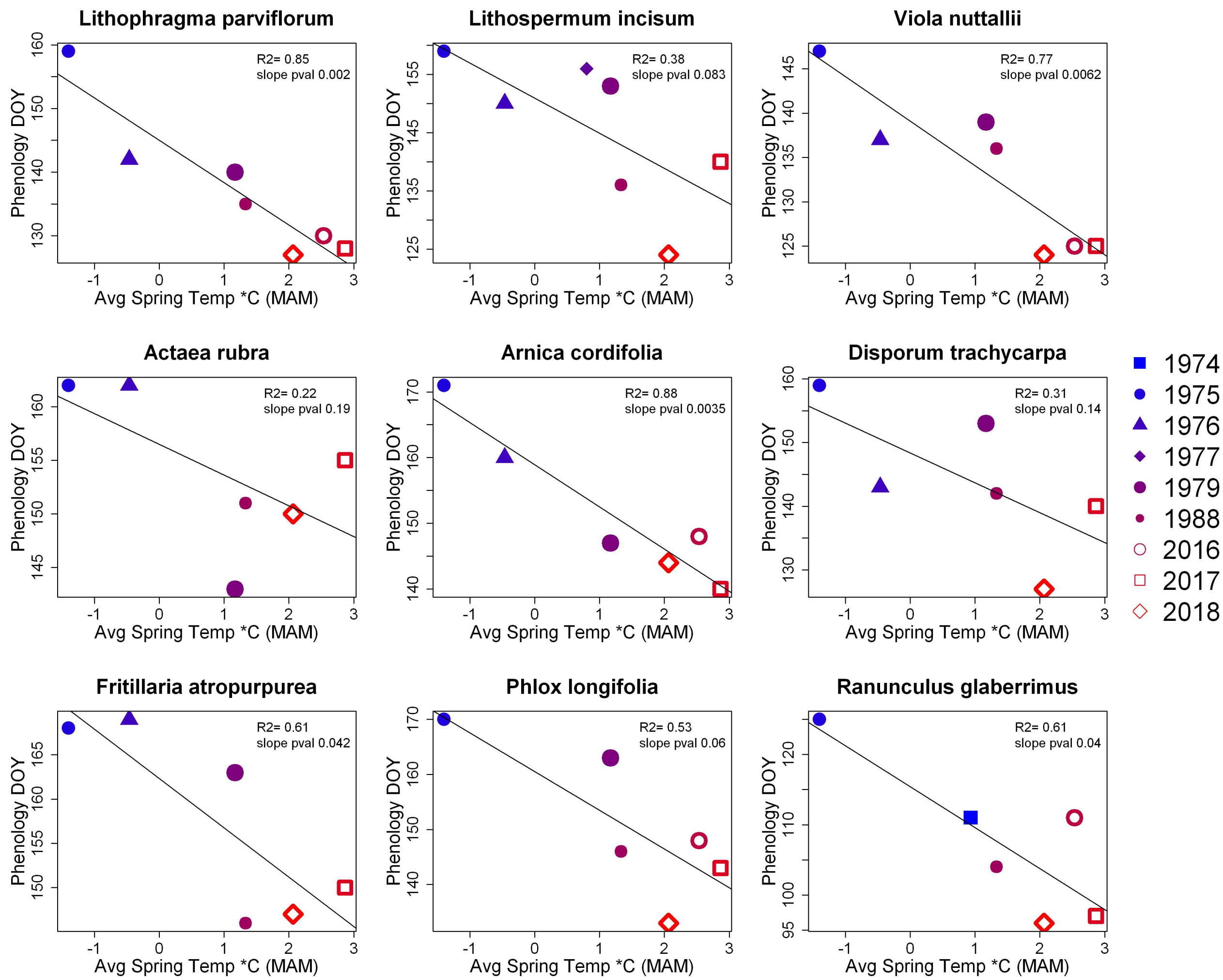


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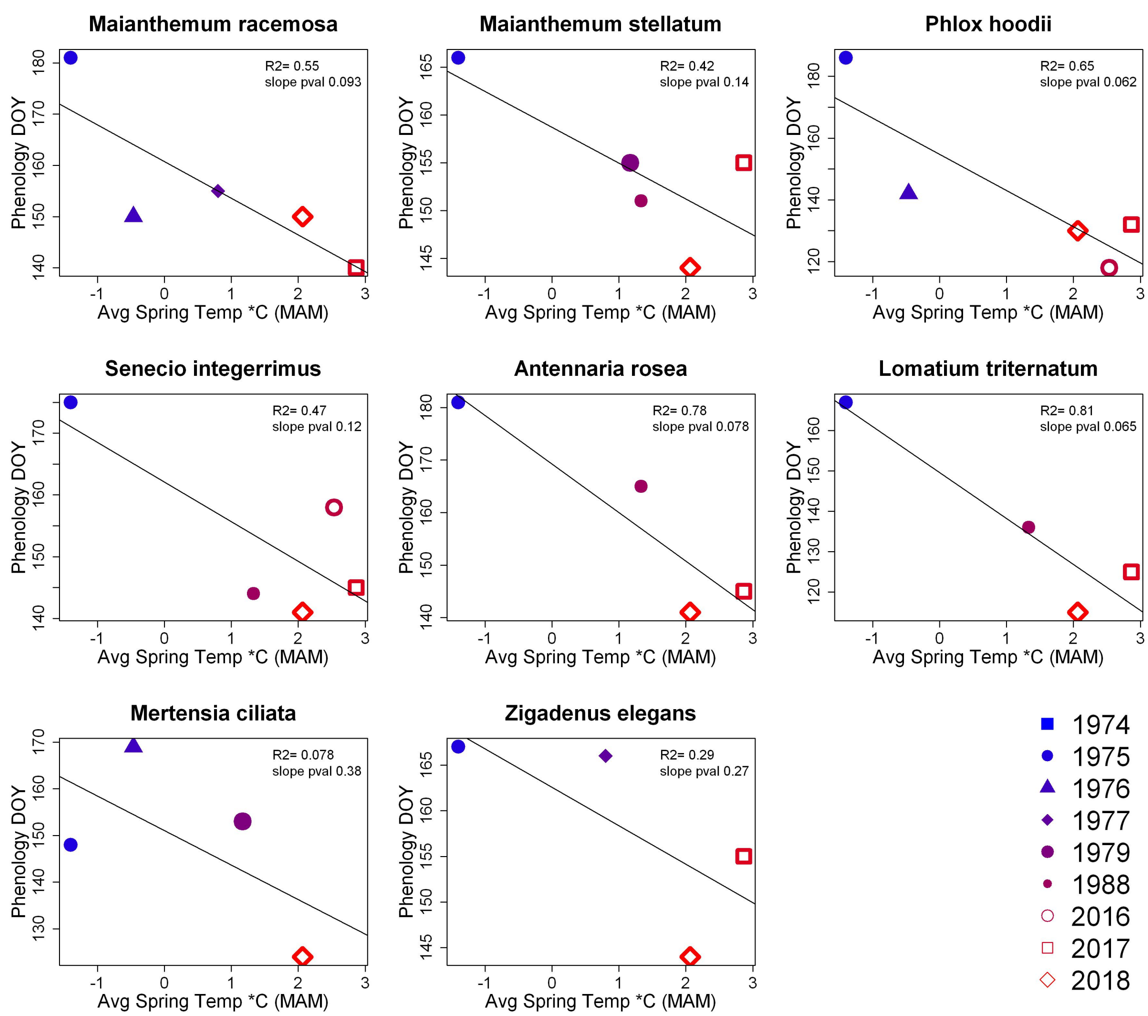


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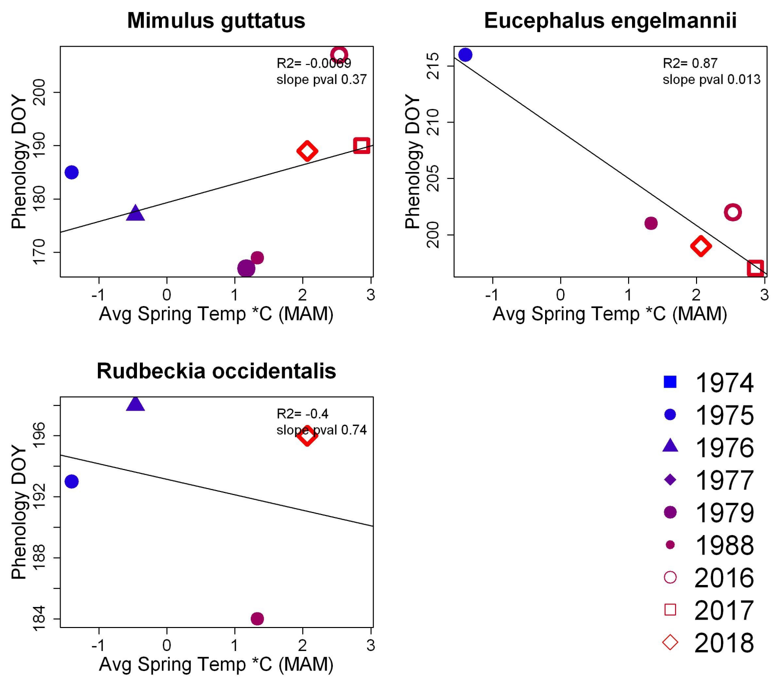


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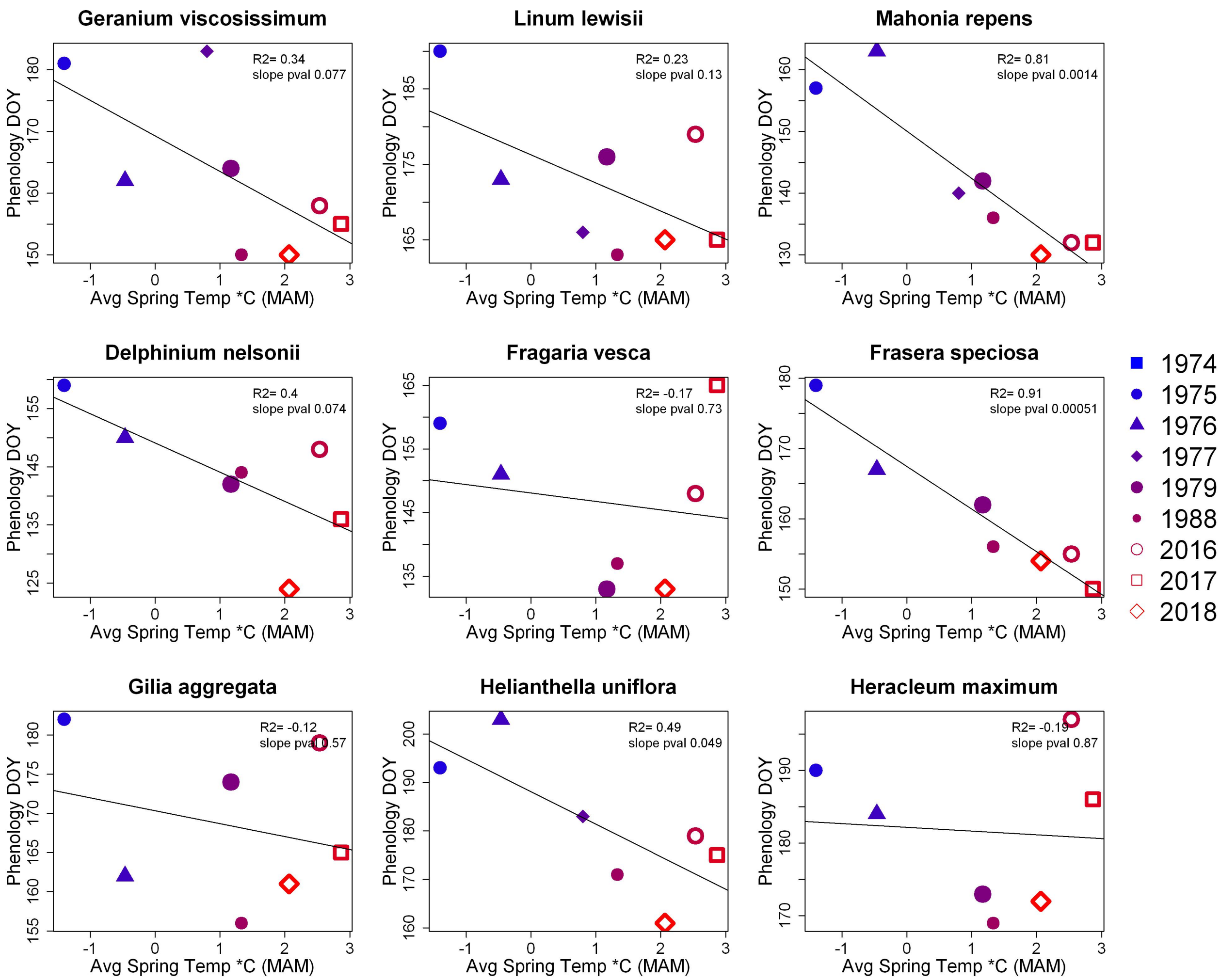


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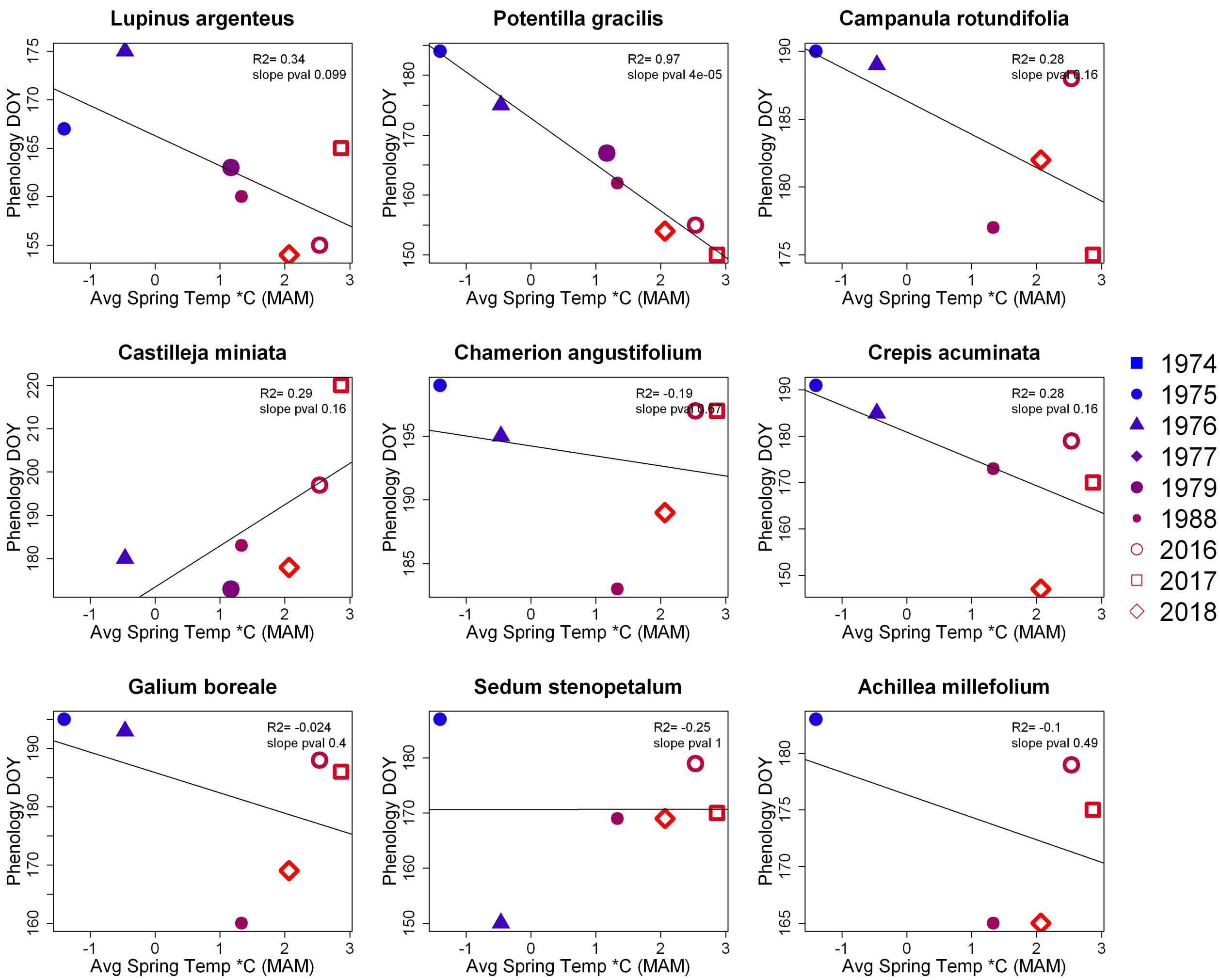


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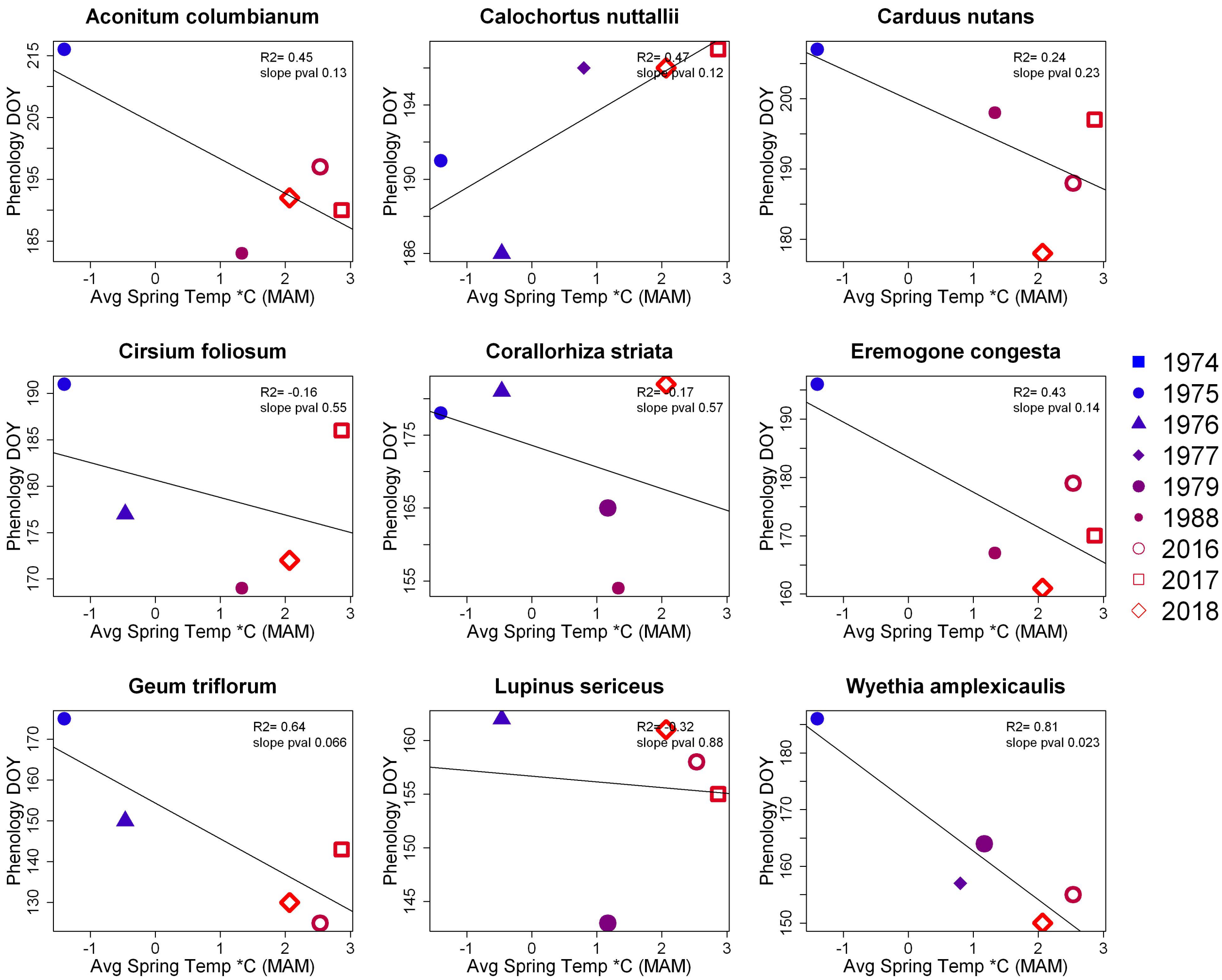


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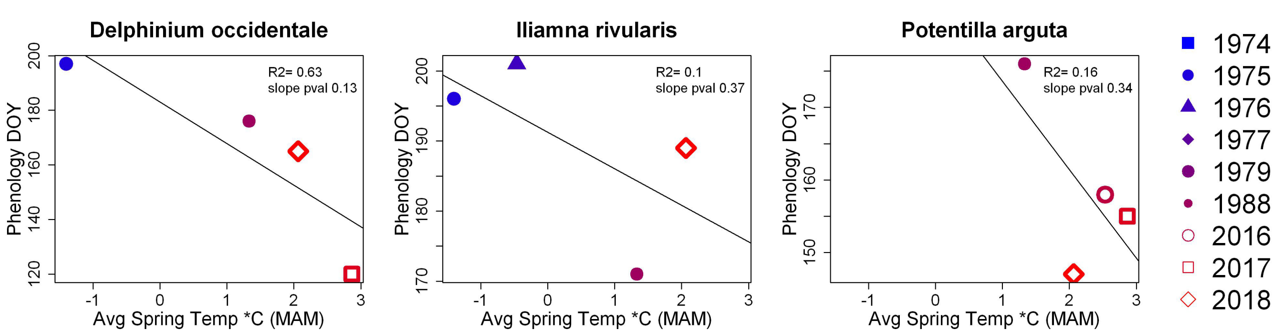


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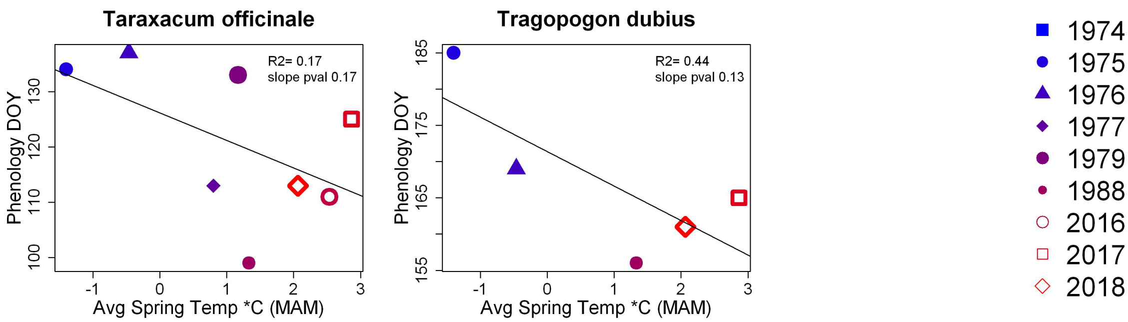


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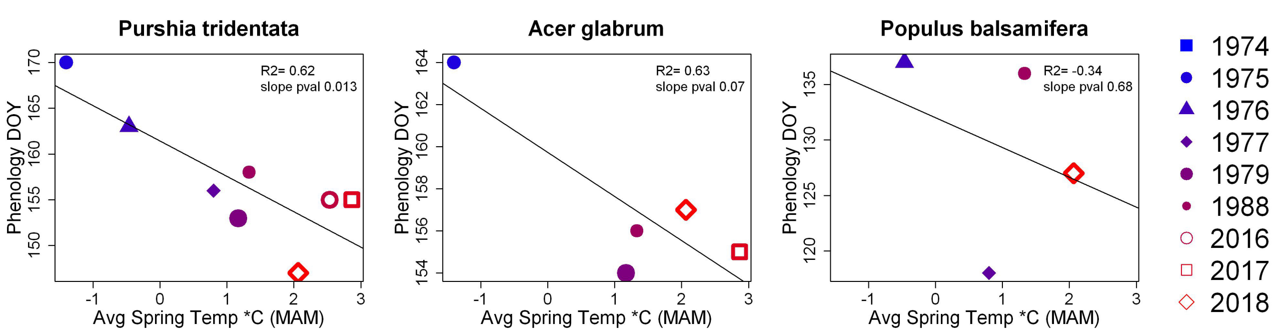



**Supplemental Materials, Figures S1** (cont.)

# Wildflower Watch

A Project of The Nature Conservancy in Wyoming and the
Northern Rockies Conservation Cooperative

## Field Guide for Citizen Scientists

The Nature Conservancy
Wyoming

Northern Rockies Conservation Cooperative

## Hello and welcome, wildflower and nature enthusiasts!

This booklet contains everything you need to begin collecting valuable data on the effects of climate on the seasonal timing of flowering plants in the Tetons. It will also teach you about local plants and their behavior in this amazing region. Even more importantly, you'll be assisting The Nature Conservancy in an important scientific study. Thank you for taking the time to join us.

### Nature's Cycles

Timing is everything. This is true within your own life, and in the natural community around you. In the spring, winter snow melts and wildflowers begin to bloom, including our state flower the Wyoming Indian Paintbrush. At the same time, bears begin to emerge from hibernation, the males often several weeks before the females. Migratory birds begin to flock north and spread out to their respective summer homes, and the bison, elk, mule deer, and moose start giving birth to their young. All the amazing wildlife we have in our region are dependent on ample plant-based food to nourish themselves and their offspring before the fall frost arrives and withers the leaves, foreshadowing another winter.

### New Threats

Climate change is one of the biggest threats facing the natural diversity of Earth and the wildlife of the Tetons. Snow is melting earlier each year, and spring temperatures continue to break record highs—leading to changes in plant and animal interactions and causing more disturbances such as wildfires. We already know from previous studies that increased temperatures have altered natural patterns worldwide, shifted the flowering season in parts of the Rocky Mountains forward by up to a month. Despite these changes in blooming, many birds still arrive at the same time each year because their migration habits are tied to the length of the day, instead of the temperature or snow. These mismatches in timing could have serious consequences. For example, what if migratory hummingbirds arrive after the best nectar-producing plants have bloomed? What if bears' favorite berries are ripe in the summer rather than the fall when bears need them most as they fatten for winter?

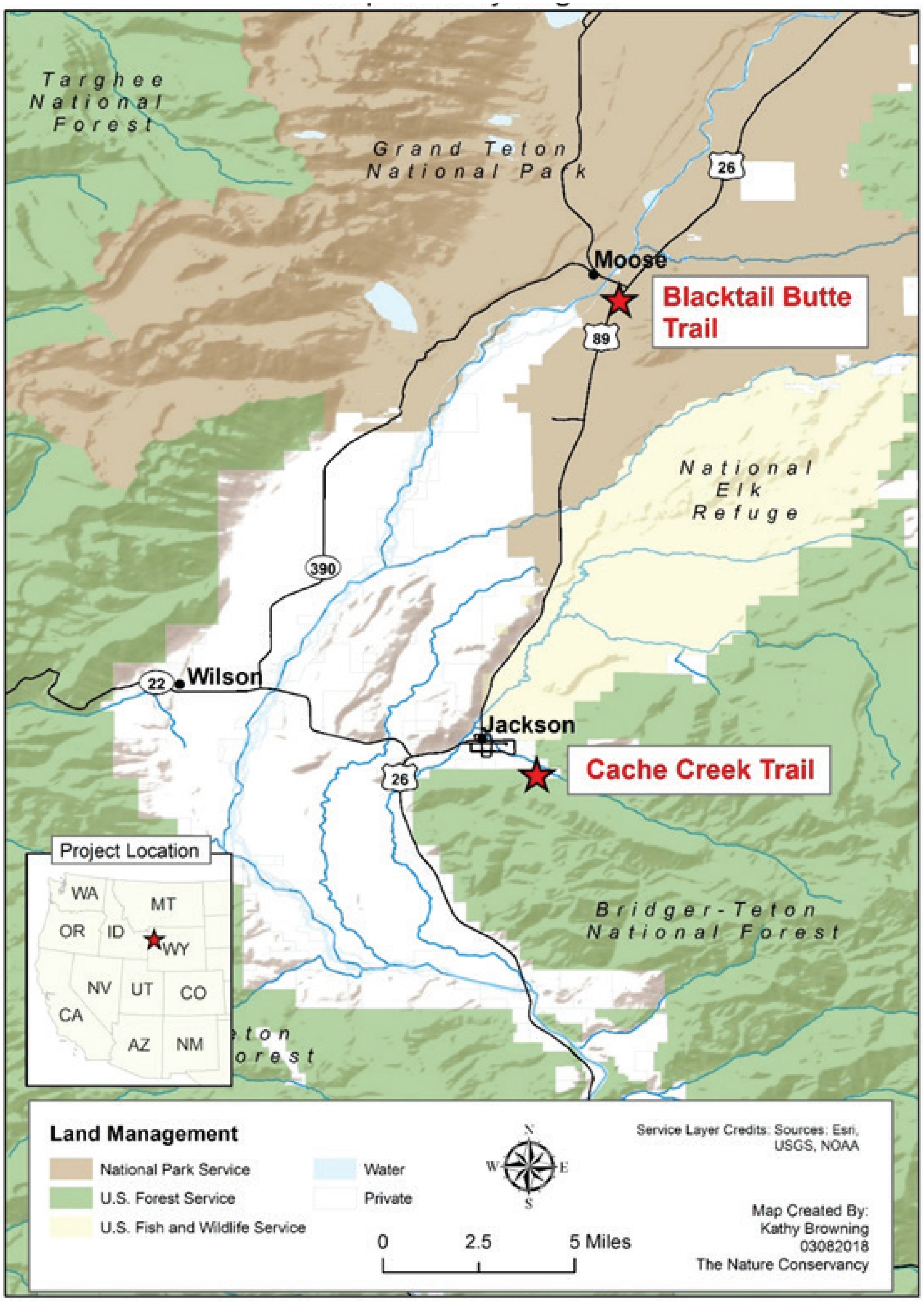
### Building on a Legacy

This project builds on the legacy of a local and internationally renowned biologist, Frank Craighead. Frank and his identical twin brother, John, were extraordinarily progressive biologists who defined their career in the Greater Yellowstone Ecosystem. Among many achievements, they invented radio tracking animals (telemetry) as part of their research on grizzly bears; this method soon was adopted for use across the world. Both Frank and John have since passed away but their legacy lives on. One of Frank's legacies is the detailed notes he kept on everything he saw in the outdoors around his home in Moose, Wyoming from 1975-79 and 1988. Frank's notes included when certain plants began to bloom, when migratory birds arrived, and when bears first started being seen in spring. This study of timing of biological events is known as phenology. Frank used these notes to write the popular book, *For Everything There is a Season: The Sequence of Natural Events in the Grand Teton-Yellowstone Area*. We are building on his legacy by conducting contemporary field observations, nearly 50 years later, to compare the timing of current ecological events to historic data. We hope that this project will continue to illuminate changes over many years to come.

### What Can You Do?

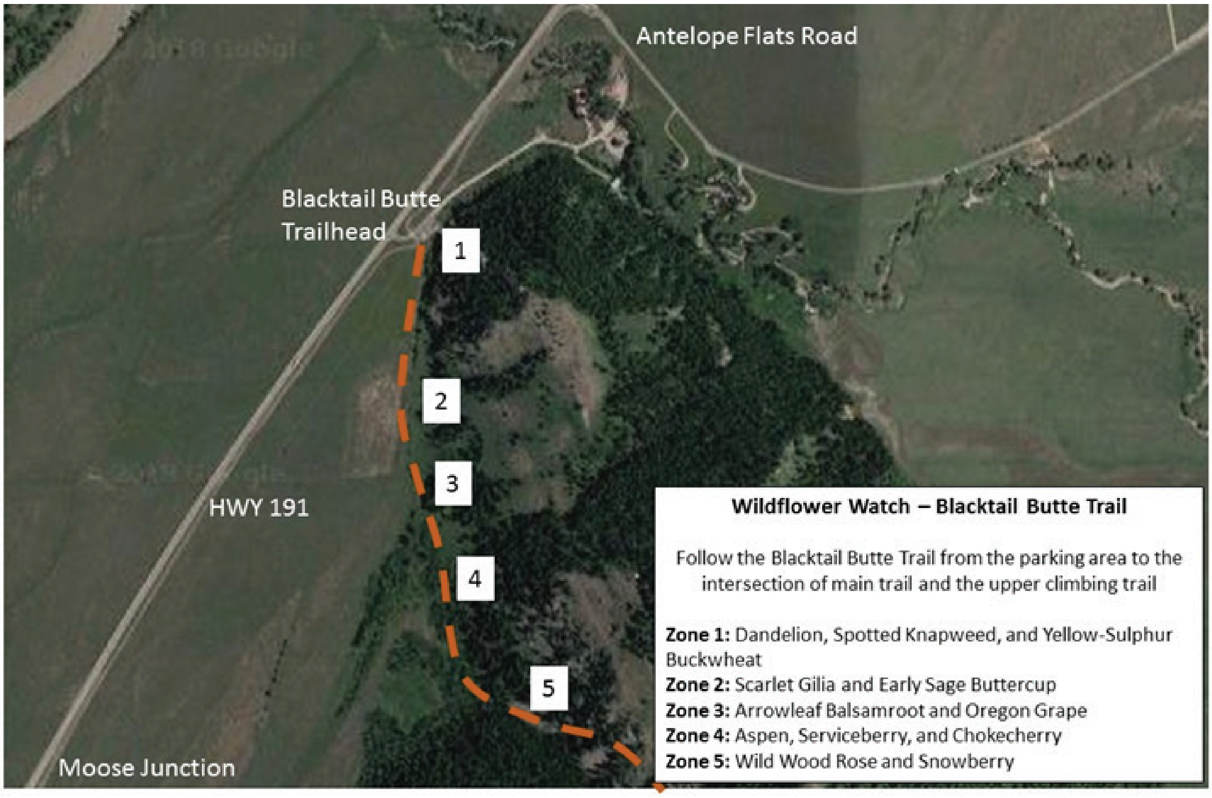
We are asking for your help, as citizen scientists, to learn the flowers and their fruit, to observe, and to collect valuable data that will be used to better understand and conserve the greater Teton community of plants, wildlife, and ourselves. Thank you for taking the time to be part of the solution!

# MAP OF THE STUDY REGION



## Blacktail Butte Trail, Grand Teton National Park

Blacktail Butte is one of the most accessible hiking trails in Grand Teton National Park. It boasts spectacular views of the Tetons and a big variety of wildflowers. The trailhead is just north of Moose Junction. Follow this mellow trail through wildflower meadows, sagebrush, golden aspens, and into a rich forest. 3 miles round-trip, moderate hike.




**Zone 1: Dandelion, Spotted Knapweed, and Sulphur-flower Buckwheat**
Begin at the Blacktail Butte Trailhead and monitor dandelion, spotted knapweed, and sulphur-flower buckwheat within 10 feet of the trailhead sign.

**Zone 2: Scarlet Gilia and Early Sage Buttercup**
Follow the Blacktail Butte trail for a few minutes south. From trailhead until you enter a mature aspen forest, keep your eyes out for early sage buttercup (until the end of May) and scarlet gilia along the trail.

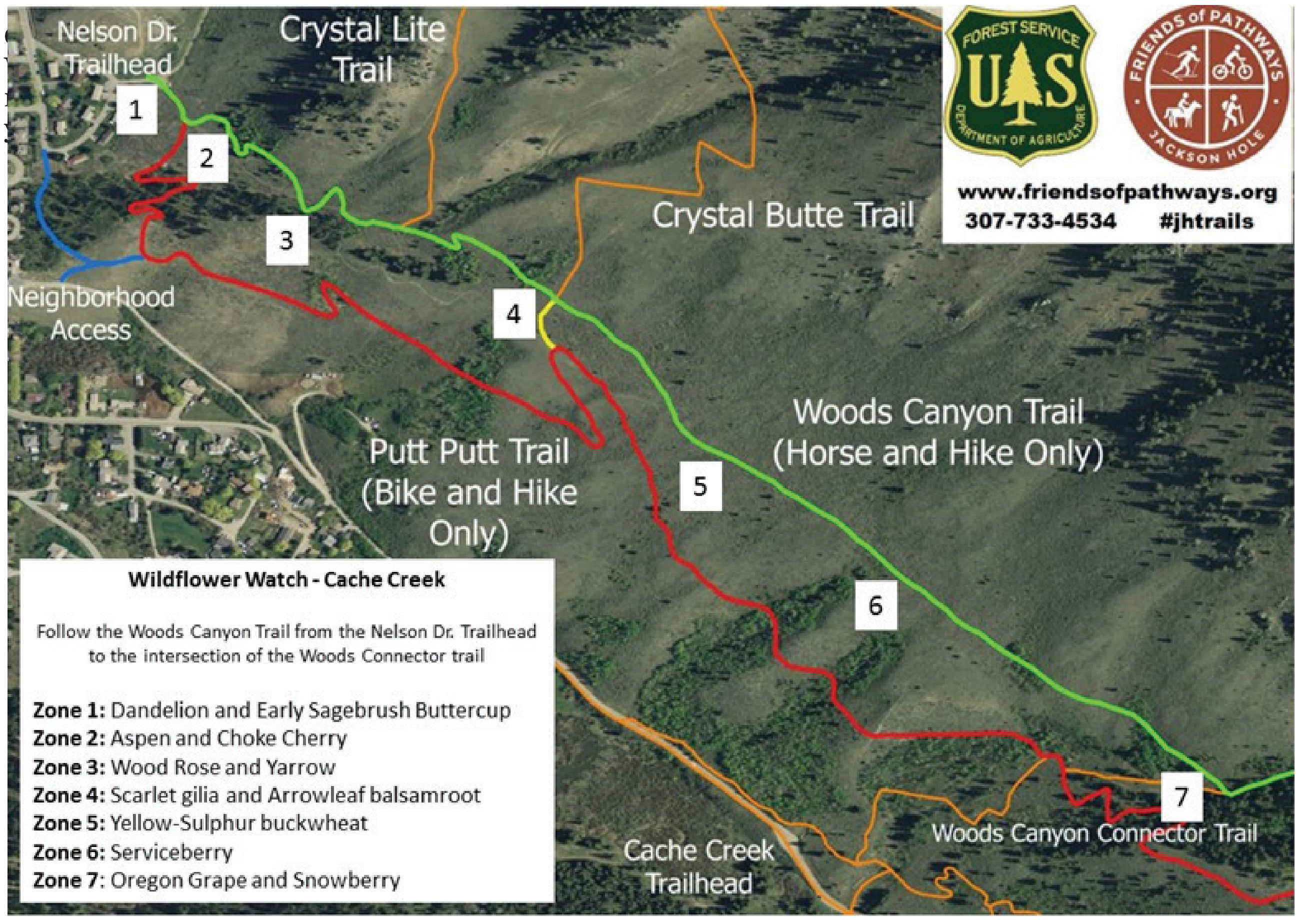
**Zone 3: Arrowleaf Balsamroot and Oregon Grape**
Follow the trail until it turns slightly and begins to gradually climb a west facing slope. On this hillside keep your eye out for arrowleaf balsamroot and Oregon grape.

**Zone 4: Aspen, Chokecherry, and Service Berry**
Zone 4 begins in the mature stand of aspens that shade both sides of the trail and ends in a large green wet meadow before the trail veers upwards into the mixed conifer forest. In this zone, monitor aspen, serviceberry, and chokecherry.

**Zone 5: Wild Wood Rose and Snowberry**
After the aspen grove, the trail opens into a lush green grass meadow with a small ephemeral stream running through it. This was the site of the old Smith homestead. From here the trail veers east and upwards into a dense mixed conifer forest along the stream. Zone 5 begins as soon as you enter the shade of this forest and ends at the intersection with the climber's trail beyond the second stream crossing. Monitor wild wood rose and snowberry here. If you are up for a larger hike, feel free to continue upwards towards the top of Blacktail Butte.

## Cache Creek Trail, Bridger-Teton National Forest

Cache Creek is the most popular hiking area in the Bridger-Teton National Forest. For Wildflower Watch we utilize the "horse and hike only" Woods Canyon Trail accessed via the Nelson Drive trailhead, minutes from downtown Jackson. Please stay on the trail and do not trample the vegetation. Also, if you use any other trails in the area, be mindful of mountain bikers. 2 miles round-trip from the Nelson Dr. trailhead via the Woods Canyon Trail to the intersection of the Woods Canyon Connector Trail and back, easy hike.




**Zone 1: Dandelions and Early Sagebrush Buttercup**
Start at the Nelson Dr. trailhead and begin on the Woods Canyon Trail. Within the first 100 feet of the start of the trail, keep your eyes out for dandelions, and if you are there before the end of May, early sagebrush buttercup.

**Zone 2: Aspen and Choke Cherry**
Within about a ¼ mile of the trailhead you will enter a nice, shady aspen forest. Here monitor the aspen trees. Remember that they will flower as early as late March and April before the leaves begin to emerge. Also monitor the choke cherry shrubs, which will produce buds at the same time as they leaf out.

**Zone 3: Wood Rose and Yarrow**
After the first aspen patch, you enter a drier hillside ecosystem briefly before ascending a series of switchbacks through a second aspen grove. In this forest, keep an eye out for the feathery leaves of yarrow and the thorny wild wood rose.

**Zone 4: Scarlet Gilia and Arrowleaf Balsamroot**
After you exit the aspens, meander through a dry open hillside dominated by Wyoming big sage and antelope bitterbrush. From here until the signed intersection with the Crystal Butte Trail (not to be confused with the Crystal Lite Trail) look for arrowleaf balsamroot with silver-tinted, arrow-shaped leaves, and scarlet gilia, which may be more inconspicuous until it produces its brilliant red flowers.

**Zone 5: Sulphur-Flower Buckwheat**
From the intersection of the Crystal Butte Trail, continue through dry sagebrush steppe vegetation past the Wilderness Boundary signs. In this stretch, keep your eyes out for the low-lying perennial leaves of the sulphur-flower buckwheat. Later in the summer, look for its showy yellow flowers, which are butterfly magnets!

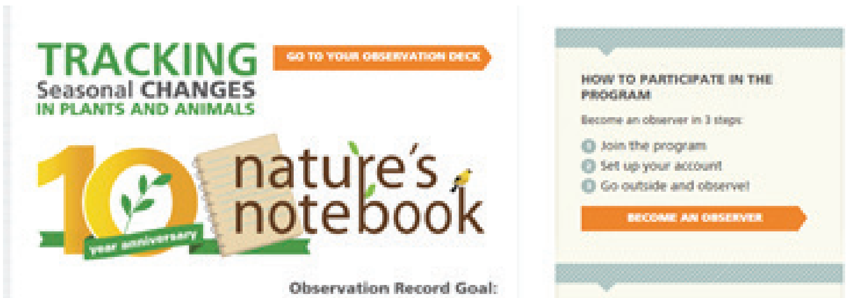
**Zone 6: Serviceberry**
After a rather long stretch of wandering slightly uphill through a sagebrush dominated landscape, you will enter another shady grove of aspens before cresting this hill and descending towards the trail junction. Here in this aspen grove, monitor service berry – an important late summer/fall food for bears and birds.

**Zone 7: Oregon Grape and Snowberry**
Within 100 feet or so of the junction of the Woods Canyon Trail and the Woods Canyon Connector Trail, keep your eyes out for the leathery, spiny leaves of Oregon grape and snowberry shrubs. There is a large snowberry shrub located directly at the intersection – be aware that the white berries are poisonous. Here you have reached the end of the Wildflower Watch trail, so great job! Feel free to return the same way you came or continue on a nice day hike on other trails. Be mindful if you hike anything other than the Woods Canyon Trail-- you must be vigilant for mountain bikers!

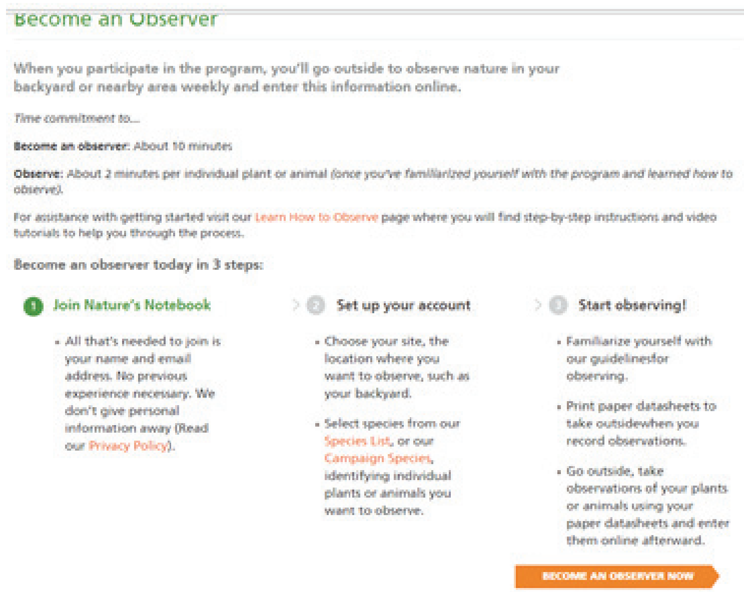
Photo: Julia Huggins

## How to get started on Nature's Notebook and join TNC's Wildflower Watch

1) Go to https://www.usanpn.org/natures_notebook
2) Click "Become an Observer"



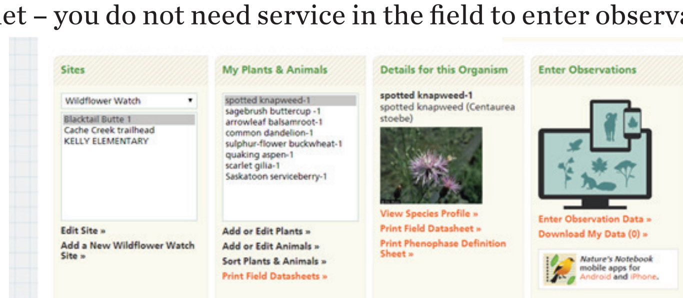

3) Follow steps 1-3



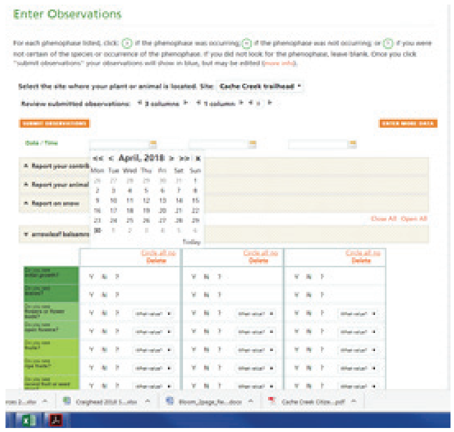

Enter email address and choose a password

Under "Partner Groups", scroll down and select "Wildflower Watch"

4) Now you are ready to make observations! You will be directed to your observation deck, here you can select the site for which you would like to make an observation, print a datasheet, or track your observations over time. To make an observation via the Nature's Notebook website, click Enter Observations. Better yet, download the Nature's Notebook Application on your smart phone or tablet – you do not need service in the field to enter observations using the app.



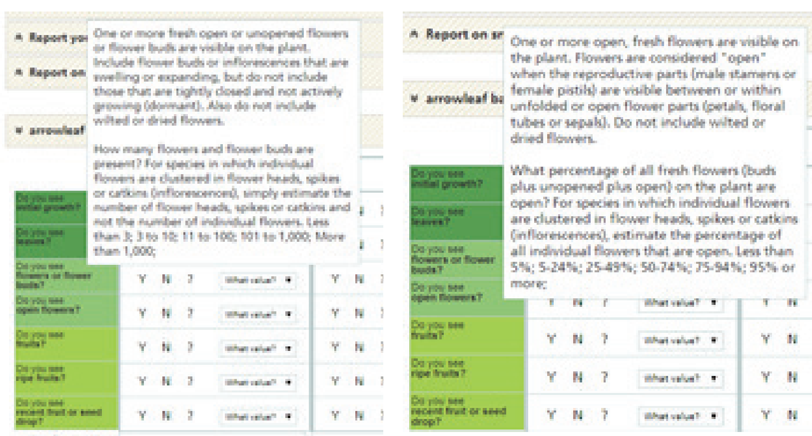
5) Three ways to record data
   - Download Nature's Notebook app from your app store on your phone/tablet – Preferred method
   - Print datasheets from Observation Deck, and later input the data in the app or website
   - Or enter data on the Nature's Notebook website - from your Observation Deck, select Enter Observation Data, then select the date (or up to 3 dates) and enter data



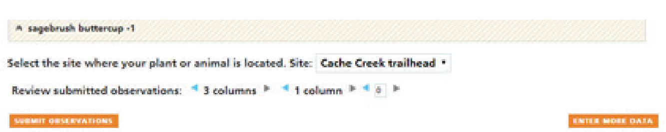

6) For all methods, be sure to record the correct date, and the correct data. For each species on the list you will be asked a series of Yes/No/Don't Know questions, for example for arrowleaf balsamroot "Do you see initial growth," "Do you see leaves," "Do you see flowers or flower buds," "Do you see open flowers," etc. Answer each question carefully and if you are unsure, mark it with a "?"

   For "Do you see flowers or flower buds," you may be asked "What Value" – for example, fewer than 3, 3-10, 11-100, 101-1000, or more than 1000. These numbers refer to how many buds or flowers you have seen along the trail.

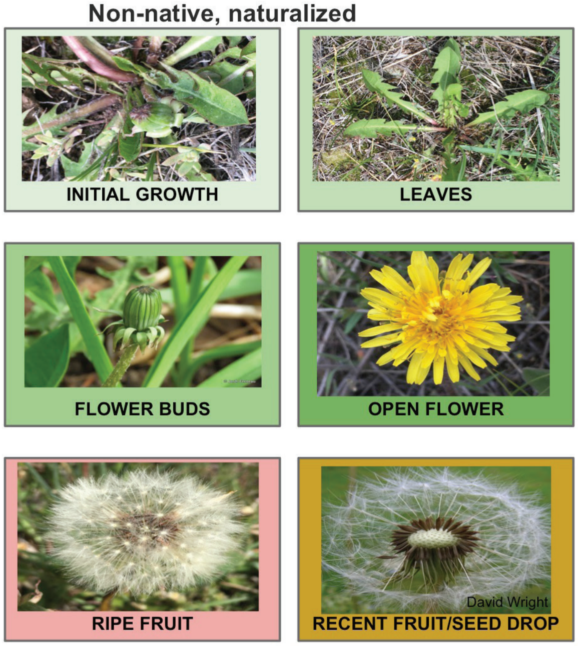
   - For "Do you see open flowers", you will be asked "What Value." This is asking what percentage of all the buds (open and unopened) you see are open. Possble answers are: Less than 5%, 5-24%, etc. If you are unsure, you can leave this "What Value" blank (but be sure to answer the "Do you see open flowers" question with a yes or no or ?).



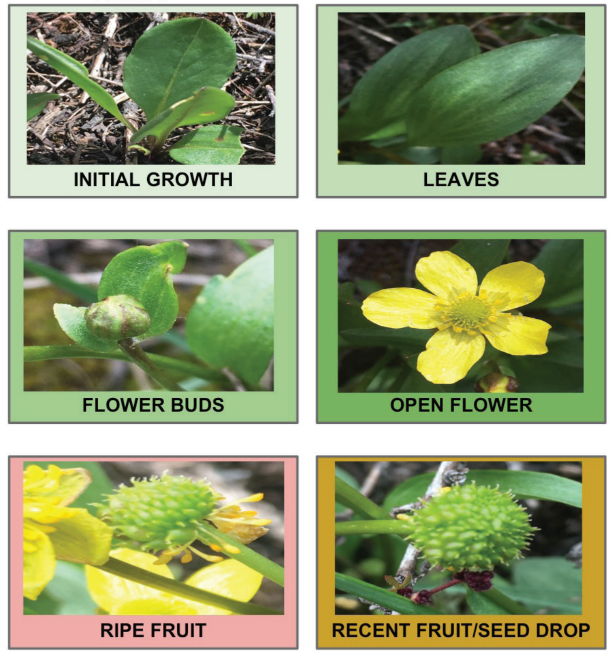

7) Once you have entered all the wildflower data for that date, you can enter "Submit Observation," or if you want to add another site or more data, hit "Enter More Data"



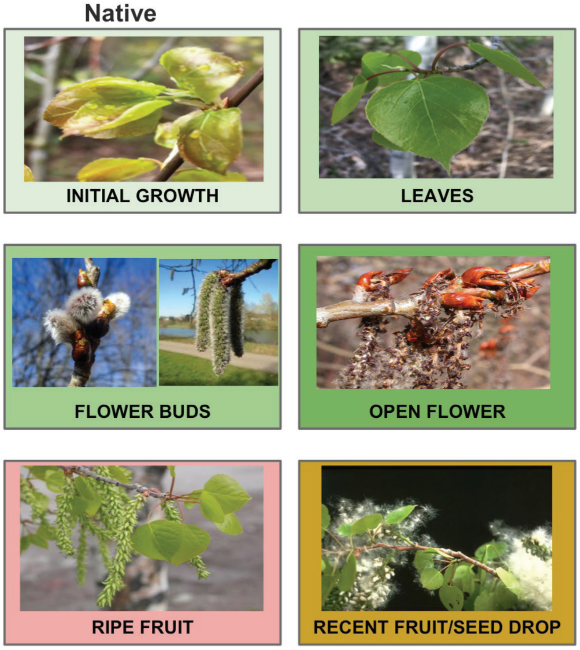
Common Dandelion
*Taraxacum officinale*
**Non-native, naturalized**



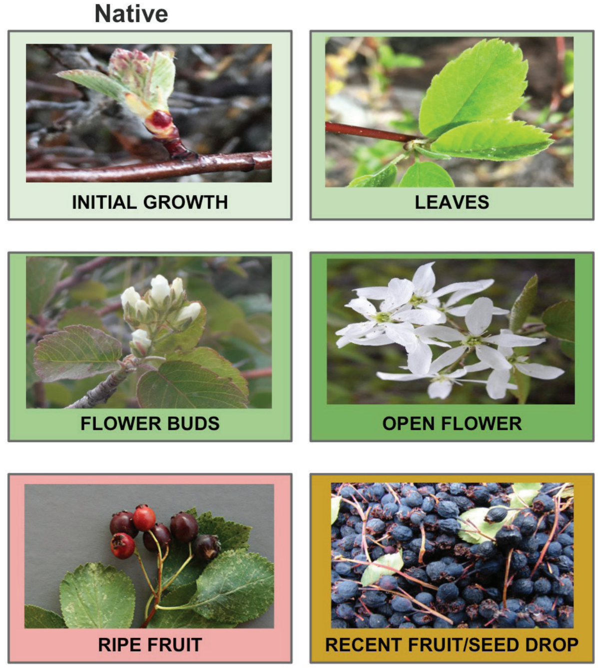

Sagebrush Buttercup
*Ranunculus glaberrimus*
**Native**



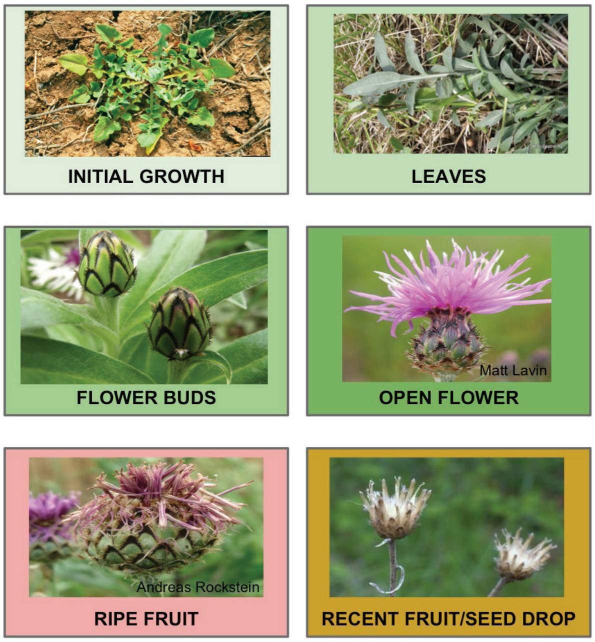

Quaking Aspen
*Populus tremuloides*
**Native**



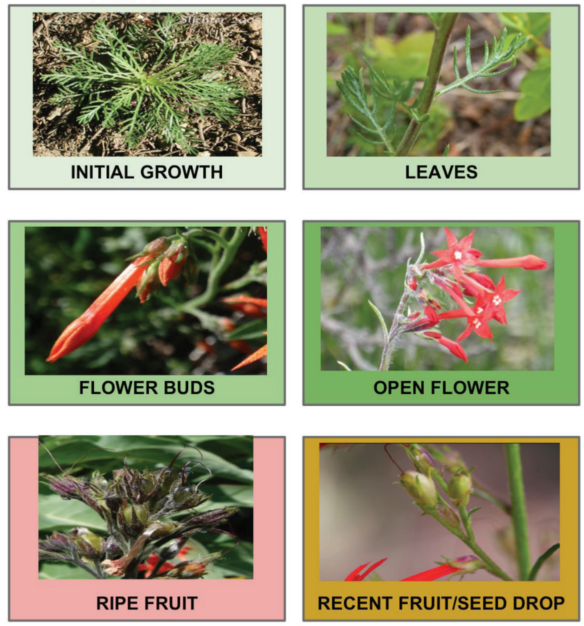

Saskatoon Serviceberry
*Amelanchier alnifolia*
**Native**



Spotted Knapweed
*Centaurea maculosa*
**Invasive**

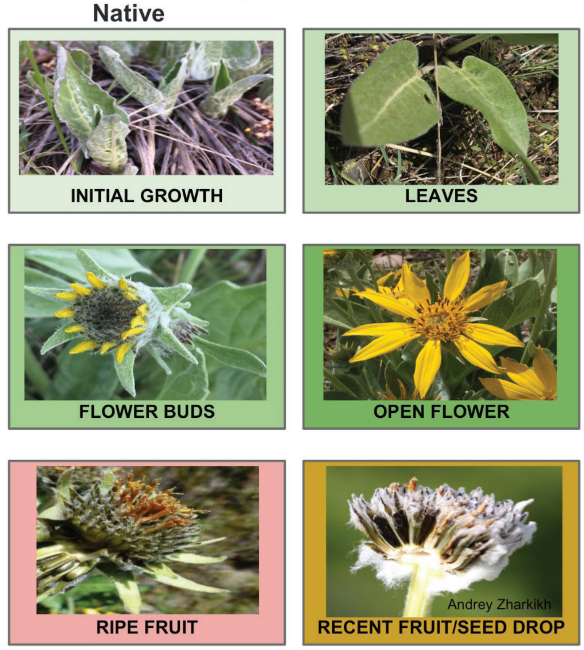



Scarlet Gilia
*Ipomopsis aggregata*
**Native**



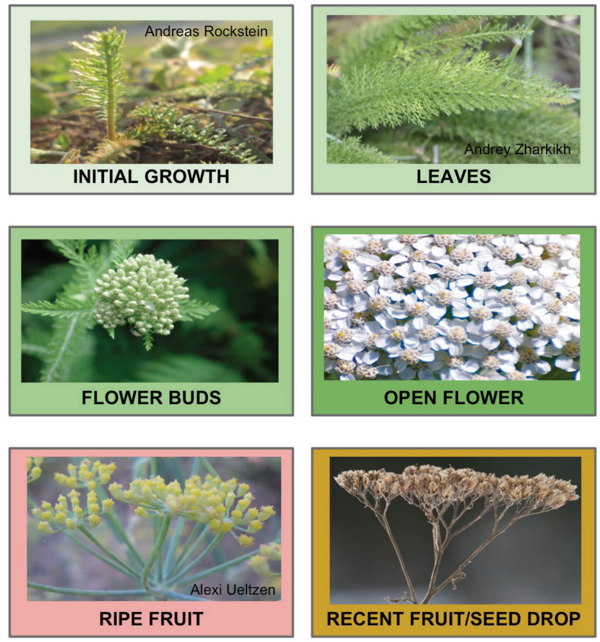

Sulphur-flower Buckwheat
*Eriogonum umbellatum*
**Native**


Arrowleaf Balsamroot
*Balsamorhiza sagittata*
**Native**

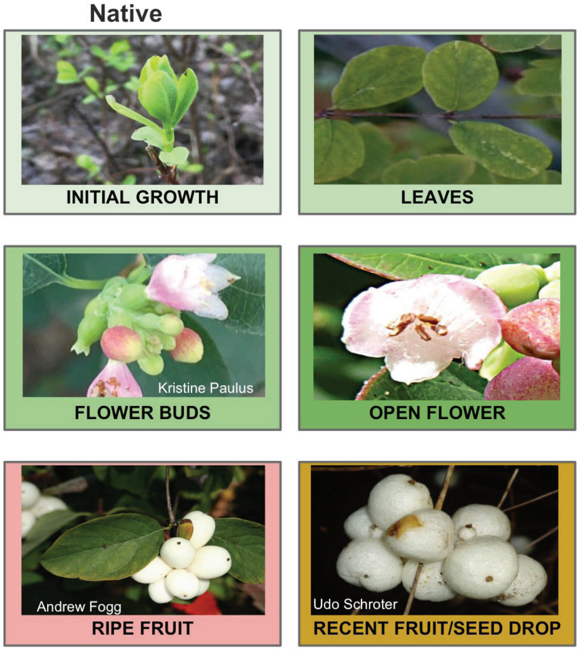


Wild Wood Rose
*Rosa woodsii*
**Native**

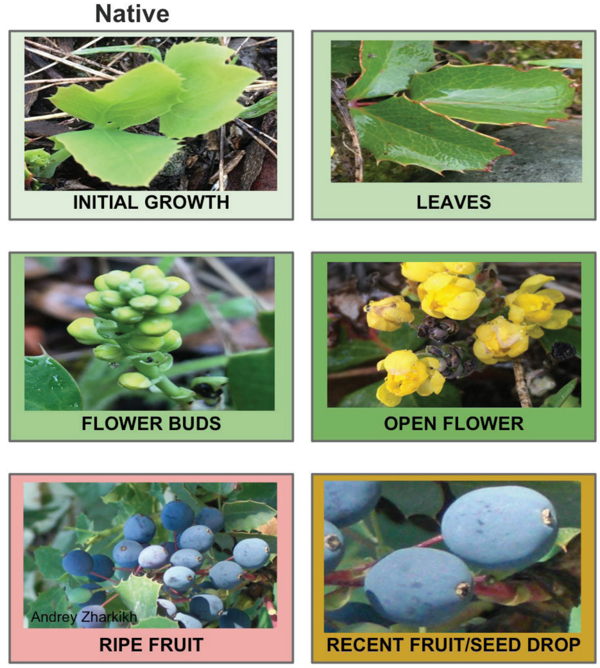

Yarrow
*Achillea millefolium*
**Native**



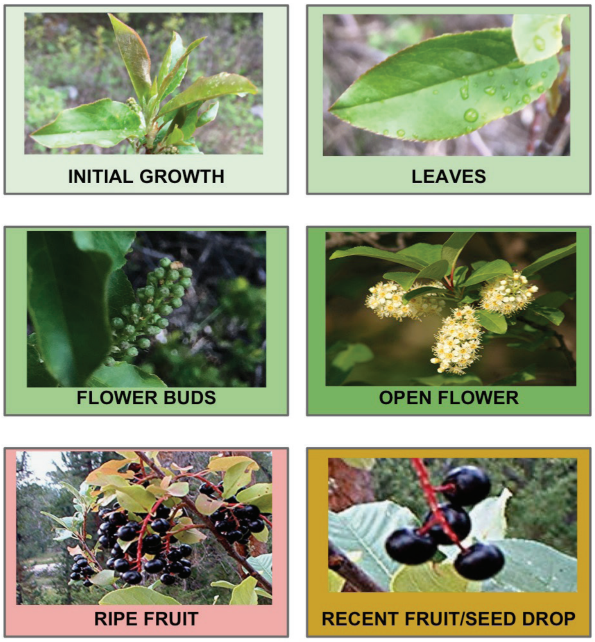

Snowberry
*Symphoricarpos albus*
**Native**




Oregon Grape
*Mahonia repens*
**Native**



Chokecherry
*Prunus virginiana*
**Native**




Cheatgrass
*Bromus tectorum*
**Invasive**


## What to Bring on the Walks

- Water
- Hiking shoes
- Snacks
- Small notebook (optional)
- Camera (optional)
- Hand lens (optional)
- Bear spray (recommended)

## Great job!
## Now get out there and watch those wildflowers!

Email Trevor with any questions or comments at trevor@nrccooperative.org