The California Phenology Project

Interpretive Guide

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Welcome!

This guide will assist you in describing the goals and activities of a new research and educational effort in your park: *The California Phenology Project* (CPP). We hope that you will use it to introduce the CPP to park visitors that you meet on a daily basis and with whom you spend time in both formal and informal settings. This guide also provides suggestions for ways in which — through hands-on activities — you can help visitors to learn how park scientists and volunteers are detecting the effects of environmental variation and climate change on the seasonal cycles of plants and animals. The study of these seasonal biological events is called ***phenology***, and examples of phenological events include the flowering and fruiting of plants, the spring arrival of migratory bird species, and the annual emergence of insect pollinators and pests.

This manual is designed for park-based educators (particularly those who have attended a workshop on CPP activities at their park), including:

- Education and interpretive staff at National Parks
- Informal science educators of students from grade 6 – adult
- Volunteers who have attended a CPP workshop
- Park staff who engage with park visitors on trails

Your role as a CPP educator:

Many visitors wonder what our national parks are doing to understand climate change. A lot, actually! In collaboration with park staff, the CPP is conducting research; educating the public about the effects of climate change on plants; and offering training to volunteers and park staff so that they can participate as citizen scientists, contributing data to a national database created by the *USA National Phenology Network.* A crucial goal of the CPP is to inform the public about our project and to invite them to participate in this long-term monitoring effort, which is being replicated in many of California's national parks and University of California Natural Reserves. The CPP really appreciates your help in spreading the word!

Your primary objectives as a CPP educator:

- Communicate the reality and significance of climate change
- Inform visitors of the ways in which wild species may respond to climate change
- Introduce the concepts and practice of phenological monitoring as a method for tracking the effects of climate change on the seasonal cycles of plant species
- Broaden visitors' science literacy through a hands-on demonstration of phenological monitoring
- Facilitate a fun and meaningful outdoor experience for visitors
- Enable visitors to learn more about, and to participate in, the CPP on their own and once they leave the park

<u>What this manual contains</u>:

I. Climate Change & Phenology Talking Points (bullets)

a. What is the CPP?
b. Geographic coverage of the CPP
c. Taxonomic coverage of the CPP: the species that are currently being monitored
d. Why monitor phenology?
e. *A Call to Action*: how the CPP is answering the C2A
f. What are the parks doing to learn how plants and animals are responding to climate change?

g. Talking points for introducing seasonal cycles and life history events with park visitors
h. Talking points for teaching the basics of phenology, the phenophases that are monitored, and the basic plant biology that will facilitate phenological monitoring

1) What is phenology?
2) Examples of phenological indicators used by indigenous people
3) What is phenological monitoring?
4) Basic plant biology: the basic botany you need to know in order to recognize plant phenophases

II. Interactive Activities and Discussions to Promote Visitor Education

III. Sample CPP Information Card

IV. Real-world stories of phenology and its link to climate

V. Example Interpretive Phenology Program: Taking Nature's Pulse (*based on the program developed by Julia Lynam, Seasonal Interpretive Ranger at Joshua Tree National Park)*

VI. A list of online resources

I. Climate Change and Phenology Talking Points

a. What is the CPP?

The *California Phenology Project* (CPP) is a research and education project designed to detect the effects of climate change on California's flora. It aims to incorporate public participation, education, and outreach along with sound scientific practices to inform natural resource management for National Park Service (NPS) units in California. From 2011 to 2013, the CPP is developing and testing protocols in seven pilot parks. Outcomes of the pilot project period will include protocols for establishing phenological monitoring sites and a web-based tool kit to support phenological monitoring in parks and other natural areas throughout California.

The CPP engages *citizen scientists* of all ages in observing, recording, and interpreting the response of plants to changing climatic conditions. The CPP uses monitoring protocols developed by the USA National Phenology Network (USA-NPN) and all CPP observations are uploaded to the USA-NPN database via *Nature's Notebook* (http://www.usanpn.org/participate/observe), a user-friendly online interface to which citizen scientists, educators, and professional scientists from all over the United States may contribute data and examine the data contributed by others.

To find out more about the CPP, the species being monitored, and links to educational resources for reaching a wide range of audiences, visit the CPP website at http://www.usanpn.org/cpp/ and view our most recent *newsletter* and *project update* at http://www.usanpn.org/cpp/news.

b. Geographic coverage of the CPP

The CPP has established trails and sites for the long-term monitoring of 30 species naturally occurring in seven National Park Service units in California: Joshua Tree National Park, Santa Monica Mountains National Recreation Area, Sequoia and Kings Canyon National Parks, Redwood National Park, Lassen Volcanic National Park, Golden Gate National Recreation Area, and John Muir National Historic Site. These seven parks represent desert, coastal, and montane biogeographic regions.

In the summer of 2012, the CPP is establishing new sites in additional National Parks (e.g., Lava Beds National Monument and Death Valley National Park), as well as UC Natural Reserves (e.g., Coal Oil Point Reserve and Sedgwick Reserve in Santa Barbara County).

c. Taxonomic coverage of the CPP: which species is the CPP monitoring?

The 30 plant species currently being monitored by the CPP are wild species growing in their natural habitats (see table below for the complete list). These species include flowering plants as well as conifers, and the list includes trees, shrubs, and perennial herbs. Most of these species are being monitored at more than one location, allowing the CPP to detect broad geographic patterns that reveal the relationships between climate and phenology. The broad geographic coverage will also allow the CPP to determine whether certain kinds of habitats (and the plants they support) may be more vulnerable to the effects of long-term climate change than others. To obtain the detailed species profile for each species, including photographs of the phenophases being monitored by the CPP, please go to:

http://www.usanpn.org/cpp/AllSpecies

Once you're at this webpage, clicking on the link to a given species will bring up a webpage dedicated to this species, and from which you can download its CPP species profile and USA-NPN datasheet.

Common name (Latin name)	Taxonomic Family (older family name)
Aspen (*Populus tremuloides*)	Salicaceae
Beach Pea (*Lathyrus littoralis*)	Fabaceae
Blackbrush (*Coleogyne ramosissima*)	Rosaceae
Blue Elderberry (*Sambucus nigra* ssp *cerulea*)	Adoxaceae
Blue Oak (*Quercus douglasii*)	Fagaceae
California Bay (*Umbellularia californica*)	Lauraceae
California Buckeye (*Aesculus californica*)	Sapindaceae
California Buckwheat (*Eriogonum fasciculatum*)	Polygonaceae
California Live Oak (*Quercus agrifolia*)	Fagaceae
California Poppy (*Eschscholzia californica*)	Papaveraceae
California Wild Rose (*Rosa californica*)	Rosaceae
Chamise (*Adenostoma fasciculatum*)	Rosaceae
Coast Rhododendron (*Rhododendron macrophyllum*)	Ericaceae
Common Cowparsnip (*Heracleum maximum*)	Apiaceae (Umbelliferae)
Common Snowberry (*Symphoricarpos albus*)	Caprifoliaceae
Coyotebrush (*Baccharis pilularis*)	Asteraceae
Creosote (*Larrea tridentata*)	Zygophyllaceae
Greenleaf Manzanita (*Arctostaphylos patula*)	Ericaceae
Honey Mesquite (*Prosopis glandulosa*)	Fabaceae
Joshua Tree (*Yucca brevifolia*)	Asparagaceae (Agavaceae)
Lodgepole Pine (*Pinus contorta*)	Pinaceae
Mojave Yucca (*Yucca schidigera*)	Asparagaceae (Agavaceae)
Mountain Pride (*Penstemon newberryi*)	Plantaginaceae
Pacific Trillium (*Trillium ovatum*)	Melanthiaceae (Trilliaceae)
Ponderosa Pine (*Pinus ponderosa*)	Pinacae
Red Elderberry (*Sambucus racemosa*)	Adoxaceae
Satin Lupine (*Lupinus obtusilobus*)	Fabaceae
Sticky Monkeyflower (*Diplacus aurantiacus*)	Phrymaceae (Scrophulariaceae)
Valley Oak (*Quercus lobata*)	Fagaceae

d. Why monitor phenology?

Monitoring phenology is a great way to:

- Become familiar with how to observe the growth and reproduction of wild species
- Learn about local plant species
- Explore national park trails and observe which species grow in which habitats
- See how landscapes change over the course of the seasons
- Observe the biological rhythms of the days and the seasons
- Meet new friends by creating a social network of phenological observers
- Participate in and contribute to a nationwide project (the USA National Phenology Network) in which widespread California plant species are also observed in other states and regions.



all photos above by Brian Haggerty

e. ***A Call to Action:*** In honor of the upcoming 100th anniversary of the National Park Service, Jon Jarvis, the Director of the National Park Service, released *The Call to Action* in summer 2011. In *The Call to Action* (or C2A), Jon Jarvis outlined his vision for the second century of NPS stewardship and identified 36 action items for NPS employees, partners, and friends to promote the preservation of the country's cultural, historic, and natural resources for the enjoyment of this and future generations.

What are the CPP participating parks doing to respond to the Call to Action?

- ***Action Item #7:*** Create a new generation of citizen scientists and future stewards of our parks by conducting fun, engaging, and educational biodiversity discovery activities in at least 100 national parks, including at least five urban parks. *The CPP is recruiting and training citizen scientists to assist in a long-term phenology monitoring effort across California. CPP participants learn how to identify and to record seasonal cycles of key species and to explain how local ecosystems function, thereby building their ecological and scientific literacy through direct experience. CPP participants are observing phenology in remote parks such as Lassen Volcanic NP and Joshua Tree NP, as well as urban parks such as Golden Gate NRA and Santa Monica Mountains NRA.*

- ***Action Item #14:*** Provide multiple ways for children to learn about the national parks and what they reveal about nature, the nation's history, and issues central to our civic life. We will accomplish this by reaching 25% of the nation's K-12 school population annually through real and virtual field trips, residential programs, teacher training, classroom teaching materials, online resources, and education partnerships. *The CPP is engaging with education partners, such as Naturebridge, to teach K-12 students how to record the phenological schedules of plants and animals. Participation in the CPP effort provides students the opportunity to learn and to apply STEM (Science, Technology, Engineering & Math) skills; to recognize and to measure the seasonal rhythms of their local environment; and to critique the evidence and the conclusions offered by scientists and by policy-makers who are debating climate change science.*

- ***Action Item #28:*** Assess the overall status of park resources and use this information to improve park priority setting and communicate complex park condition information to the public in a clear and simple way. *The phenological observations recorded by CPP participants will advance our understanding of how our natural resources are responding to climate change. CPP data will be used to guide resource management decisions and to demonstrate to park visitors how park resources are affected by climate change.*

f. What are the parks doing to learn what is happening to plants and animals in response to climate change?

> ***"Education and research about the effects of climate change on the parks and their natural resources (plants, animals, waterways, and soil) should be among the highest priorities for all national parks***. —Jon Jarvis, the Director of the National Park Service

To start, what are the ways in which plants and animals *might* react to a changing climate? We might predict **two kinds of responses** by animals and plants to a changing climate:

1) First, here at ___*Your Park*____, changes in climate may affect the **abundance** of our native plant and animal species as well as their **distribution** across the landscape. For example, if the climate becomes drier, then drought-tolerant species will become more common and moisture-requiring species will become less common. Scientists expect that some species will become less abundant, less widespread, or even go extinct. Some species may migrate out of the park and become less protected. New species may migrate into the park and occupy habitats that weren't here before but that developed with the changing climate. In other words, we're interested in how the **abundance** or **spatial distribution** of plants may change, depending on whether the climate becomes more or less hospitable to them.

Optional Note: Here at ___*Your Park*____, the distributions and abundance of *Joshua trees, monarch butterflies, migratory birds, raptors, tortoises, etc. (i.e. organisms at your park; fill in the appropriate species for your park, including any well-known species that are the focus of Inventory and Monitoring efforts or other research in the park)* are being monitored to see how they are changing over time.

2) Second, changes in climate may affect the **seasonal cycles** of plants and animals. *The California Phenology Project* is focusing on this kind of response by tracking the effects of climate change on the **timing** of plant seasonal cycles in California. In particular, we're interested in how changes in the climate from year to year may alter the timing of the most important events in a plant's life. These include: when new leaf buds start producing leaves during or after the winter rains; when flower buds open (providing pollen and nectar as rewards for the animals that pollinate them); when fruits can be seen developing from flowers; and when fruits or their seeds are dispersed from the plant that produces them. These different events or phases of development are called ***phenophases*****.**

The California Phenology Project is recruiting and training professional scientists *and* citizen scientists to track these changes. The CPP is a partner of the *USA National Phenology Network*. With the help of its citizen scientist volunteers across the U.S., this national organization collects, stores and shares phenological information on plants and animals (the CPP is currently focused on monitoring naturally occurring plants, but the USA-NPN has developed protocols for monitoring animal phenology as well).

g. Talking points for introducing seasonal cycles and life history events with park visitors

What are the most important events in a plant's life? Seed germination, the production of new leaves, the opening of its first flowers, being visited by pollinators, fruiting, and seed dispersal.

Most of these ***life history events*** *occur annually, during a specific period of the seasonal cycle. For example, the wildflower Farewell-to-Spring (Clarkia spp.) flowers yearly during the spring months in California.*

What happens if these events occur too early or too late? Plants may not be in synchrony with their pollinators or their seed dispersers. If a plant's flowers aren't pollinated, then they won't develop into fruits and no seeds will be produced. Also, if plants flower too early, they can risk fatal flower damage if there is an unexpected early spring frost.

h. Talking points for teaching the basics of phenology, the phenophases that are monitored, and the basic plant biology that will facilitate phenological monitoring

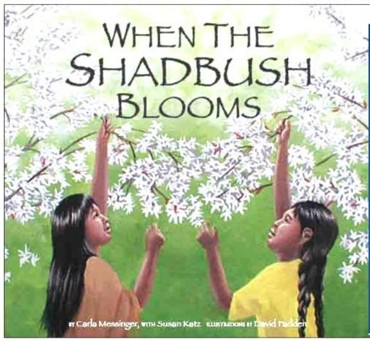
1) What is phenology? It is the science that studies the timing and duration of plant and animal **phenophases**, and the response of these phenophases to environmental change. So, the science of phenology is one approach to detecting the effects of climate change on plants and animals.

2) Examples of phenological indicators used by indigenous people: Phenology is an ancient science that has been used by native peoples across the world. Since phenological events generally occur in a reliable sequence, the occurrence of one event indicating the imminence of another, phenology can be used to time resource related activities. Aboriginal peoples have long recognized these phenological indicators.

Fisherman have used phenological indicators to predict the best time to fish and hunt

- Fishermen in w. Canada know that pickerel (*Esox lucius*) run when the southern cottonwood (*Populus balsamifera*) disperses its seeds. *References*: (1) Beaubien, E.G. 1991. Phenology of Vascular Plant Flowering in Edmonton and across Alberta. MS thesis, University of Alberta. (2) Lantz, T. C. and N. J. Turner. 2003. Traditional phenological knowledge of aboriginal peoples in British Columbia. Jornal of Ethnobiology 23: 263-286.

- Fishermen on the east coast of Canada would not fish for shad (*Alosa sapisissima*) until after the shadbush (*Amelanchier* spp.) flowered. *References:* (1) Beaubien, E.G. 1991. Phenology of Vascular Plant Flowering in Edmonton and across Alberta. MS thesis, University of Alberta.




- Okanagan Indians used blooming of mock-orange (*Philadelphus lewisii*) as an indicator that marmots were fat and ready to hunt. *References:* (1) Turner et al., 1980. Ethnobotany of the Okanagan-Colville Indians of British Columbia and Washington. Occ. Pap. Brit. Col. Prov. Mus. No. 21., Ministry of Provincial Secretary and Government Services Provincial Secretary, Victoria, B.C.


- Comox Indians use oceanspray (*Holodiscus discolor*) flowering as an indicator of the best time to dig for butter clams (*Saxidomus gigantea*). *References*: (1) Turner, N. 1997. “Le fruit de l’ours”: les rapports entre les plantes et les animaux dans les langues et les cultures améri-indiennes de la côte-ouest. Recherches amérindiennes au Quebec. 27: 311-48.


- The Nuu-Chah-Nulth tribe of Vancouver Island used the ripening of salmonberries (*Rubus spectabilis*) to predict the return of adult sockeye salmon (*Oncorhynchus keta*) to freshwater. *References*: (1) Bouchard & Kennedy, 1990. Clayoquot Sound Indian Land Use. Report prepared for MacMillan Bloedel Ltd. (2) Peacock, S. L. 1992 Piikani Ethnobotany: Traditional Plant Knowledge of the Piikani Peoples of the Northwest Plains. MS thesis, University of Calgary.

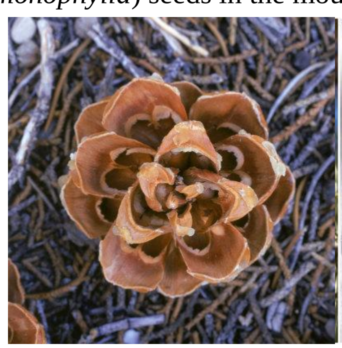


- The Blackfoot tribe of s. Alberta and Canada used the flowering of the buffalo bean (*Thermopsis rhombifolia*) to indicate that bison males (*Bison bison*) had eaten enough spring browse to be ready to hunt (their meat was sufficiently marbled with fat). *References*: (1) Johnston A. 1982. Plants and the Blackfoot. Prov. Mus. Alberta Nat. Hist. Occ. Pap. No. 4, Alberta Culture, Historical Resources Division, Edmonton, Alberta.



Plant phenophases at one location have been used to predict harvest times for plants at another location.

- The Tubatulabal tribe of Kern County (CA) used the ripening of coffeeberry fruits (*Rhamnus californica*) at low elevations to indicate that pinyon pine (*Pinus monophylla*) seeds in the mountains were ready to harvest.

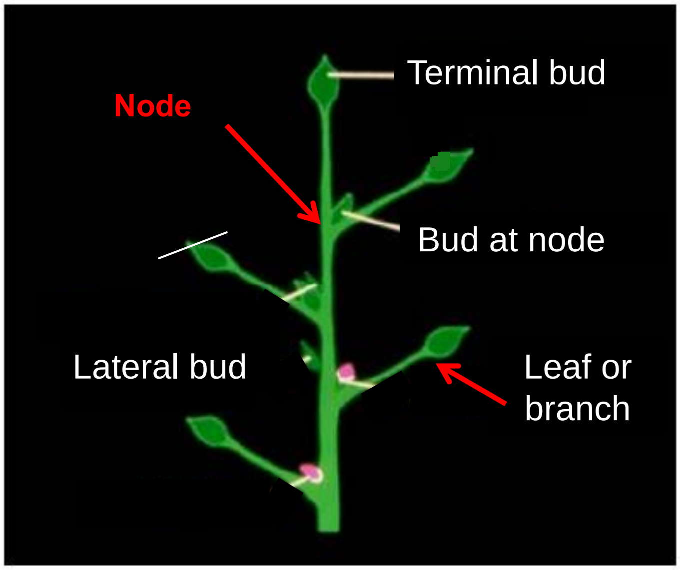

- Wampanoag tribe of Cape Cod (Massachusetts) claimed that the best time to plant corn was when the leaves of white oak (*Quercus alba*) were the same size as the footprint of a red squirrel (*Tamiasciurus hudsonicus*). *References*: Molitor, H. 1987. The great code: the folklore and science of using plants as timepieces.



3) What is phenological monitoring? Phenological monitoring involves recording the timing and duration of a suite of phenophases during the growing season of individual plant species. It can involve labeling and mapping individual plants, which are monitored throughout their growing season and year after year, or it can comprise recording the phenophase of an individual plant that is visited only once. Either way, phenological data can now be recorded in a standardized way and then entered into a national database (*Nature's Notebook*, managed by the USA National Phenology Network), where they can be freely retrieved for analysis by scientists and by the public.

4) What is the basic plant biology that you need to know in order to understand the sequence of biological changes that plants undergo within a single season or year (i.e. the botanical terms you need to know in order to recognize plant phenophases)?

General principles: New growth on plants can start from two types of buds: ***vegetative buds*** (which produce leaves) and ***reproductive buds*** (which produce flowers or flower heads). Both kinds of buds can be found at either (1) the tips of branches or (2) emerging from the stem surface, at the points where leaves are attached to the stem (that is, at the "nodes," illustrated in the cartoon below). In the cartoon below, note that there are both green *vegetative buds* and pink *reproductive buds* located at the nodes on stem.

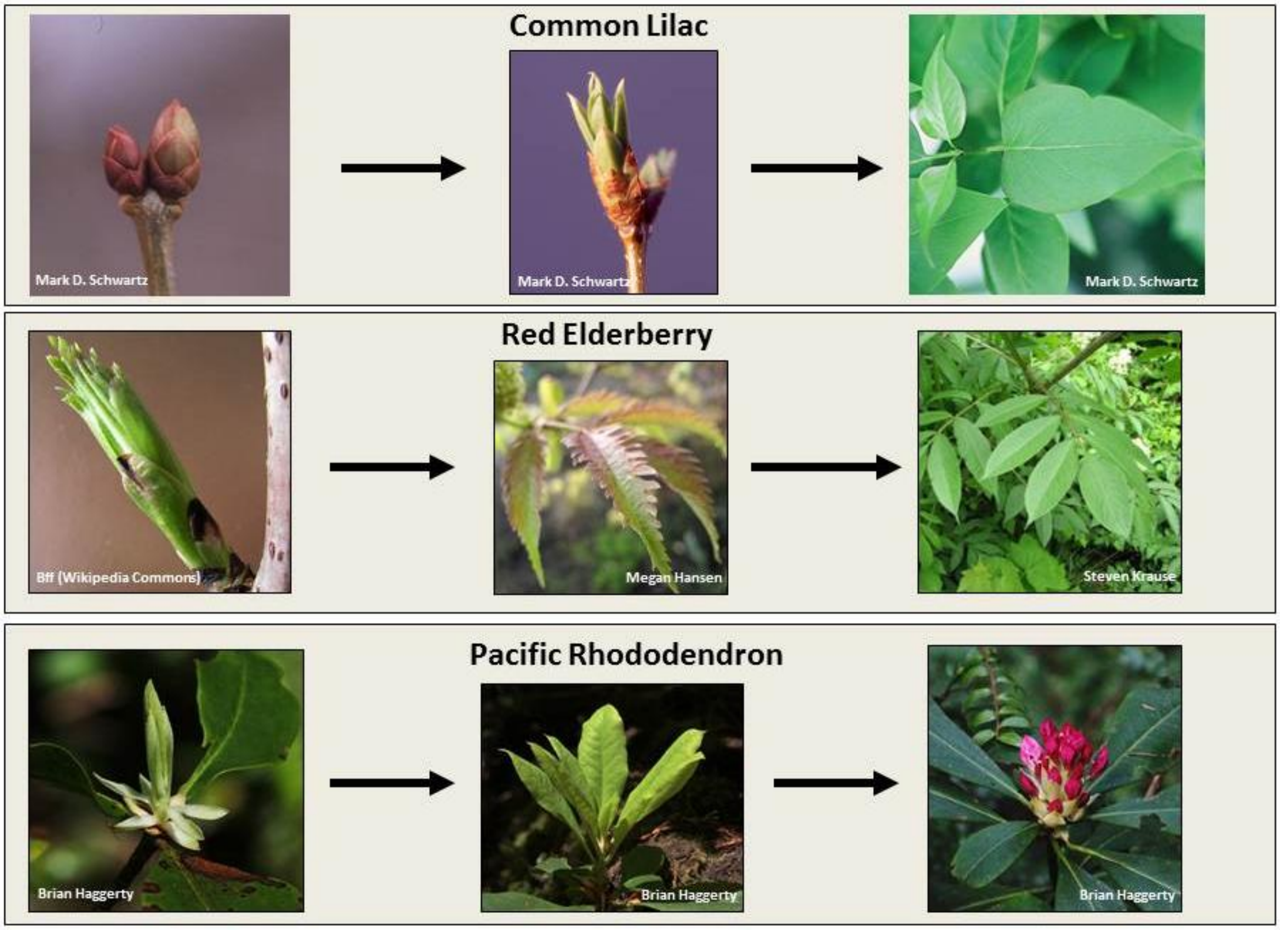


Buds may be found in several locations relative to leaves and stems. Generally, leaves ALWAYS have a bud in their axil, even though it may be very small

The position of a bud, in general, doesn't tell you whether it is going to produce leaves or flowers; you have to keep looking at it over time to see how it develops.

As you become familiar with the "architecture" (the positions of buds, leaves, and flowers) of a given species, you will soon be able to predict whether a bud will open up to produce leaves or flowers, based on its appearance, size, color, and position.

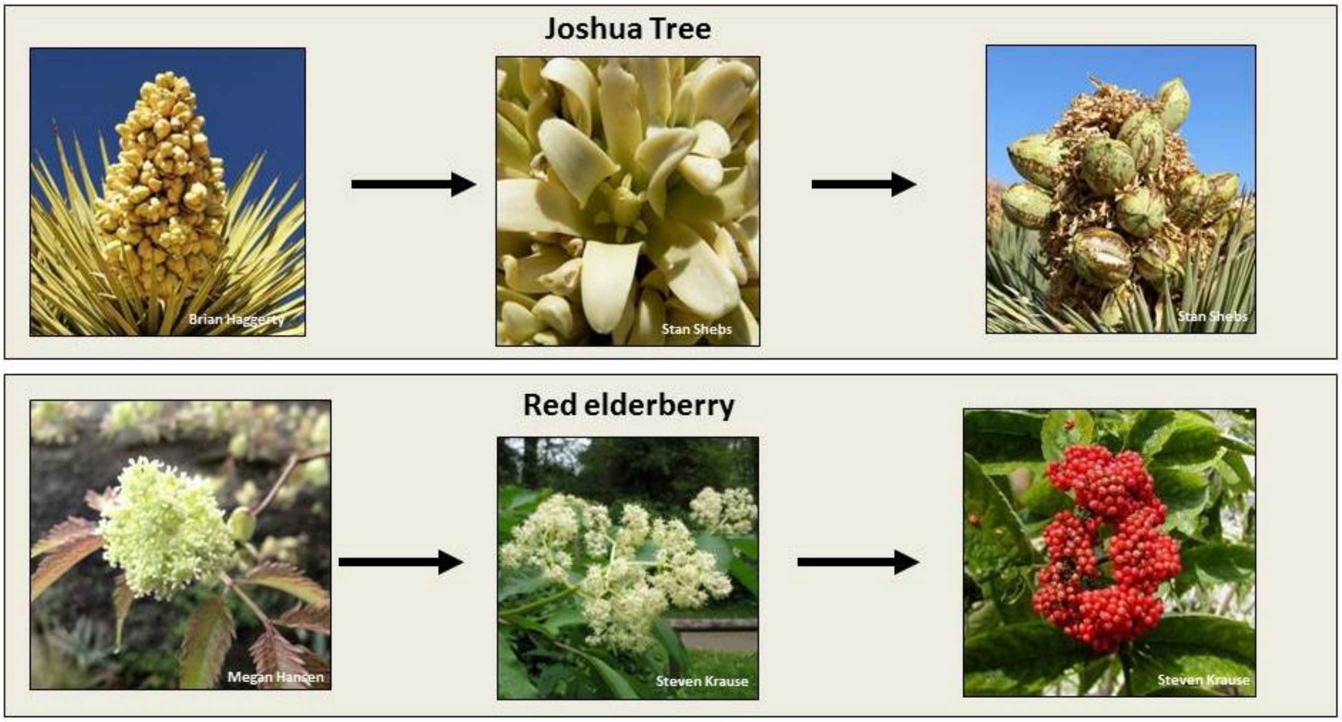
Vegetative Buds develop into…… **_Leaves_**!



The figure above includes photos of three phenophases (moving from left to right: vegetative buds, breaking leaf buds/expanding leaves, and full leaves) as they appear on three different plant species.

Note: The full-sized leaves of the Pacific Rhododendron (photo on lower right in the image above) are borne on a branch that has a cluster of opening flowers at its tip! So, this photo shows two phenophases: full-sized leaves and flower buds.

Reproductive Buds open to produce ***Flowers*** ….which develop into ***Fruits***…which will either be dispersed from the plant or open to release their seeds (=seed dispersal)



The figure above includes photos of three phenophases (moving from left to right: flower buds, open flowers, and fruits) as they appear on two different plant species (both of these species are currently monitored by the CPP).

Note: these photographs aren't meant to be used to identify these phenophases in the field, but rather to illustrate the sequence of events. To be completely accurate, you'll use the CPP two-page species profiles to identify the phenophases of each species. The images above are meant simply to remind you that flowers and fruits both represent *different stages of development of the same structure*. In other words, flower buds open to reveal flowers; each flower has the capacity to develop into a fruit after the flower is pollinated, assuming that there are enough water and nutrients available to complete fruit development.

In some species, seeds are dispersed by animals (in the case of juicy, fleshy, soft fruits, or hard nuts). In other species, the seeds are dispersed by wind (in the case of dry fruits that disperse tiny or winged seeds).

II. Interactive Activities and Discussions to Promote Visitor Education: suggestions for ways to show visitors how phenological monitoring is done in practice

Action Item 1-- *Share the species*: Show visitors laminated CPP species profiles of the species that are available for you to demonstrate and/or for species that they may see in the park.

(Optional) Action Item 2-- *Share the datasheets*: Show visitors laminated USA-NPN data sheets for your sample species. Show them how to read the data sheets, first examining the phenophase descriptions and then filling out the Yes/No (or ?) records for individual plants. Laminated data sheets can be filled out with erasable markers, and then cleaned and re-used.

Action Item 3-- *Demonstrate phenological monitoring*: Provide a hands-on demonstration for visitors, volunteers, or students. Each week, interpreters at Visitor Centers (perhaps working in pairs to be most efficient) should familiarize themselves with the locations and current phenophases of 2-3 plants of one or more species close to the Visitor Center. Phenophases to look for include: the appearance of vegetative or reproductive buds, leaf expansion, flower or fruit production, and recent seed dispersal. Also look for old, dry fruits that may have been retained from the previous season.

→These action items can easily be incorporated into **ongoing interpretive programs**. During a wildflower walk, for example, an interpretive park ranger might:

- point out vegetative buds on three different species encountered on the walk and ask visitors to compare the buds (look for size, color, and texture differences)
- ask visitors to compare the phenological status of three individuals representing one species and discuss any differences you observe (e.g., is one individual in peak flower while the other is covered in fruits? why might these two plants differ in their phenological status?)
- demonstrate how to fill out a USA-NPN datasheet for a CPP species found on the walk.

After you've familiarized visitors with a range of phenophases in one or more species, engage them in a conversation by asking the following questions.

1. So, now you've seen some phenology; how do you imagine that the timing or duration of different phenological events or phases might respond to climate change?

    Most species that have been studied respond to climate warming by flowering earlier than they have in the past. In habitats where plants receive adequate rainfall, we might also expect that they will flower for longer periods. However, in habitats where late winter frosts can occur, plants that produce their leaf and flower buds earlier than usual in the spring have a high risk of bud death if they are exposed to a late frost.

2. If the deserts in California are getting drier, how might this affect the timing or the abundance of phenological events?

    Plants may flower less frequently if they don't have enough water, or they may flower for a shorter period of time. In some parks, plants may delay flowering if it's too dry (even if it's warmer).

3. If the deserts (or one of your local eco-regional habitats) are getting warmer, what will happen to winter?

It will become shorter, probably by ending earlier.

4. How do you think shorter winters will affect the park flora and fauna?

Some species may flower earlier in response to an earlier spring. Animals that hibernate may come out of hibernation earlier and have a longer active season (see the study on Marmots

5. What's happening to phenology in your home state?

Explore the USA-NPN website to see which species are being monitored in your home state. Please share printed information about the USA-NPN and CPP; distribute a brochure, website addresses, or the CPP newsletter or Project Update.

How to Learn More: Visit the CPP (www.usanpn.org/cpp) and the USA-NPN websites (www.usanpn.org), where you can obtain educational materials and instructions for carrying on your own research.

III. Sample Information Card

To learn more about phenology and phenological monitoring, visit the following websites:

USA National Phenology Network: www.usanpn.org

California Phenology Project: www.usanpn.org/cpp

To obtain phenology-themed educational materials for K-12, university, and informal science education:
www.usanpn.org/cpp/education

To contact the CPP field directors:
phenology@eemb.ucsb.edu

IV. Real-world stories: examples of phenological changes in response to climate change

Many of the following summaries are from www.sciencedaily.com. These articles have been edited to streamline the text and highlight the main points.

A. Climate Change Forces Early Spring in Alberta, Canada

Summary: Climate change over the past 70 years has caused some of Alberta's (the Canadian province) native wildflowers and trees to bloom much earlier in the spring than they used to. As a result, these plant species are more vulnerable to damaging frosts that regularly occur at the tail end of winter (but after these plants have already flowered), damaging the flowers and threatening their reproductive success. (July 2011)

Research Method: Investigators studied the seasonal cycle of spring blooms (the date of each species' first flower) in central Alberta spanning a 70-year period (1936 to 2006). They evaluated climate trends and the corresponding changes in bloom times for seven plant species.

Findings: Bloom dates for early spring species, such as prairie crocuses and aspen trees, had advanced by two weeks over the stretch of seven decades. Later-blooming species, such as saskatoon and chokecherry bushes, had advanced by up to six days. The average winter monthly temperature increased considerably over 70 years, with the greatest change noted in February, which warmed by 5.3 degrees Celsius.

Scientific articles that describe this research in detail:

Elisabeth Beaubien and Andreas Hamann. 2011. Spring Flowering Response to Climate Change between 1936 and 2006 in Alberta, Canada**.** *BioScience* 61(7): 514-524. doi: 10.1525/bio.2011.61.7.6

Elisabeth Beaubien and Andreas Hamann. 2011. Plant phenology networks of citizen scientists: recommendations from two decades of experience in Canada. *International Journal of Biometeorology* 55: 833-841. doi: 10.1007/s00484-011-0457-y

B. Where Have All the Flowers Gone? High-Mountain Wildflower Season Reduced, Affecting Pollinators, Like Bees and Hummingbirds

Summary: During the summer wildflower season in the Rocky Mountains, high-elevation meadows are dotted with riotous color. But for how long? Wildflower season in montane meadow ecosystems once extended throughout the summer months, but now scientists have found a fall-off in wildflowers at mid-season.

Research methods: Investigators examined the number of species blooming throughout the spring and summer in the Rocky Mountains to see whether their phenology has been changing over time.

Findings: As mid-summer temperatures have warmed in the southern Rocky Mountains, the researchers have found that the early-season is becoming warmer and drier in the high altitudes. These changing climatic conditions are altering soil moisture availability, which in turn influences flowering time in sub-alpine meadows. The result is a mid-season decline in the number of wildflowers in bloom.

Changes in the number and diversity of flowering plants in mountain meadows could affect the resources (such as nectar and pollen) available to pollinators, such as bees. In particular, a mid-summer decline in the number of wildflowers could negatively affect bumblebee populations that depend on these mountain meadows.

Long-term Consequences: Changes in seasonal flower availability could have serious consequences for entire pollinator populations, including hummingbirds, bees, and a variety of insects. Over the long term, the changes in flower abundance could affect animal-pollinated plant relationships (*mutualisms*). Bees and hummingbirds need flowers, but flowers also need hummingbirds and bees so that their flowers are pollinated and develop into fruits and produce seeds.

Scientific article that describes this research in detail:

George Aldridge, David W. Inouye, Jessica R. K. Forrest, William A. Barr, and Abraham J. Miller-Rushing. 2011. Emergence of a mid-season period of low floral resources in a montane meadow ecosystem associated with climate change. *Journal of Ecology* 99 (4): 905-913. doi: 10.1111/j.1365-2745.2011.01826.x

C. Is Climate Change Altering Humans' Vacation Plans?

Summary: Many scientific studies have shown that the seasonal cycles of plants and animals, such as flowering dates and migration patterns, have shifted in recent decades due to climate change. Now a new study seems to indicate that some human climate-related behavior also is being influenced by global warming.

Research Methods: Using park records to track the timing and number of visitors to U.S. national parks over the last 30 years, researchers examined changes in park visitation patterns and their relationship to climate change.

Findings: The researchers found that for U.S. national parks that have experienced climate change, peak attendance is happening earlier in the year when compared to visitation 30 years ago. No such change in the timing of attendance was found at parks that did *not* experience significant climate change during this interval.

Of the nine parks that experienced significant increases in mean spring temperatures since 1979, seven also saw shifts in the timing of peak attendance. For example, peak attendance at Grand Canyon National Park shifted from July 4 in 1979 to June 24 in 2008. Over the same period of time at Mesa Verde National Park, peak attendance changed from July 10 to July 1. The average shift was four days. In contrast, of the 18 parks without significant temperature changes, only three exhibited attendance shifts.

"While the public continues to debate whether global warming is real, it appears that they are already adjusting their behavior," said Lauren Buckley, Ph.D., an assistant biology professor in the College of Arts and Sciences. "Visiting parks earlier may not be a big deal, but it may serve as a bellwether for more severe human adjustments required to cope with climate change."

"We can't say for sure that global warming is causing this swing in visitation trends," Buckley said. "But this discovery does complement rapidly accumulating evidence showing how other organisms have had to alter their behavior in response to climate change. National and state park agencies may need to plan for shifts in when users and tourists visit, as well as how wildlife respond to changes in the environment."

Scientific article that describes this research in detail:

Buckley, L. and M. Foushee. 2011. Footprints of climate change in U.S. National Park visitation. International Journal of Biometerology. doi: 10.1007/s00484-011-0508-4

D. As Climate Change Sets In, Plants and Bees Keep Pace

Summary: A new analysis of bee collection data from museum specimens collected over the past 130 years in the northeastern United States shows that spring arrives about 10 days earlier than in the 1880s and bees have adjusted their phenology by emerging earlier. The study also found that plant species in the study region are flowering earlier, indicating that phenological changes in the bees have paralleled changes in the plants they visit.

Findings: Both bees and plants have responded to temperature increases by shifting their emergence and flowering dates earlier in the northeastern U.S.
The study also found that most of this shift has occurred since 1970, when the change in mean annual temperature has increased most rapidly, according to Bryan Danforth, Cornell professor of entomology.

Consequences: Phenological shifts of generalist bee species (species that interact with many plant species) in the northeastern U.S. region have closely paralleled shifts in plant phenology and thus may not be strongly affected by a climate change-driven mismatchs. However, this may not be the case for bee species that are more specialized in their relationships with plants or for bee species found in other geographic regions.

Scientific article that describes this research in detail:

I. Bartomeus, J. S. Ascher, D. Wagner, B. N. Danforth, S. Colla, S. Kornbluth, R. Winfree. 2011. Climate-associated phenological advances in bee pollinators and bee-pollinated plants**.** *Proceedings of the National Academy of Sciences* doi: 10.1073/pnas.1115559108

E. Has climatic warming altered spring flowering date of Sonoran desert shrubs?

Summary: Because the northern Sonoran Desert of the southwestern United States and northwestern Mexico has experienced a steady increase in average annual temperature since the late 1890s, it is likely that flowering has also advanced in this region. In this study, herbarium specimens were assessed for evidence of the predicted shift in flowering time.

Findings: The study found that over time there was a significant increase in shrub specimens collected in flower in March and a significant decrease in specimens collected in flower in May. Thus, the flowering curve – the proportion of individuals in flower in each spring month – shifted earlier between 1900 and 1999.

Consequences: Earlier bloom dates eventually could have substantial impacts on plant and animal communities in the Sonoran Desert. For example, migratory hummingbirds move north across the

Sonoran Desert in spring, and their arrival typical coincides with flowering of nectar-producing plants. If the flowering of these species is pushed earlier, there could be a phenological mismatch between the arrival of hummingbirds and the availability of their food source. Earlier flowering might also result in earlier seed ripening and dispersal, which in turn, means that seeds will be exposed to predation for longer periods of time before the spring rains begin. Increased loss of seeds to predators could diminish seed banks and alter shrub population dynamics.

Scientific article that describes this research in detail:

Janice E. Bowers. 2007. Has climatic warming altered spring flowering date of Sonoran desert shrubs? *The Southwestern Naturalist* 52: 347-355.

F. Phenology of British butterflies and climate change

Summary: Data from a national butterfly monitoring network in Britain were analyzed to test for relationships between temperature and three phenophases: the duration of the flight period and the timing of both first appearance and the peak appearance (when populations are largest) of butterflies.

Findings: First appearance date of most British butterflies has advanced in the last two decades and is strongly related to earlier peak appearance and longer flight periods.

The authors also examined the average dates of first and peak appearance in relation to central England temperatures. They predict that climate warming of the order of 1 °C could advance first and peak appearance of most butterflies by 2–10 days.

Scientific article that describes this research in detail:

D. B. Roy and T. H. Sparks. 2000. Phenology of British butterflies and climate change. *Global Change Biology* 6: 407-416. doi: 10.1046/j.1365-2486.2000.00322.x

G. Effects of climate change on phenology, frost damage, and floral abundance of montane wildflowers

Summary: Recent changes in the timing of environmental events attributable to climate change, such as the date of snowmelt at high altitudes, which initiates the growing season, have had important repercussions for some common perennial herbaceous wildflower species.

The phenology of flowering at the Rocky Mountain Biological Laboratory (Colorado, U.S.) is strongly influenced by date of snowmelt, which makes this site ideal for examining phenological responses to climate change.

Findings: Flower buds of *Delphinium barbeyi*, *Erigeron speciosus*, and *Helianthella quinquenervis* are sensitive to frost, and the earlier beginning of the growing season in recent years has exposed them to more frequent mid-June frost kills. From 1992 to 1998, on average 36.1% of *Helianthella* buds were frosted, but for 1999–2006 the mean is 73.9%; in only one year since 1998 have plants escaped all frost damage.

For all three of these perennial species, there is a significant relationship between the date of snowmelt and the abundance of flowering that summer. Greater snowpack results in later snowmelt, later beginning of the growing season, and less frost mortality of buds.

Consequences: The loss of flowers and therefore seeds can reduce recruitment in these plant populations, and affect pollinators, herbivores, and seed predators that previously relied on them. *These findings point out the paradox of increased frost damage in the face of global warming.*

Scientific article that describes this research in detail:

David W. Inouye. 2008. Effects of climate change on phenology, frost damage, and floral abundance of montane wildflowers. Ecology 89:353–362. doi: http://dx.doi.org/10.1890/06-2128.1

H. Global warming and flowering times in Thoreau's Concord: a community perspective

Summary: As a result of climate change, many plants are now flowering earlier than they did in the past. However, some species' flowering times have changed much more than others. Data on multiple species in a single plant community can reveal variation in flowering responses to climate change.

Research methods: In order to determine how North American species' flowering times respond to climate, the authors of this study analyzed historical records of the dates of first flowering for over 500 plant taxa in Concord, Massachusetts, U.S. These records began with six years of observations by the famous naturalist Henry David Thoreau from 1852 to 1858, continued with 16 years of observations by the botanist Alfred Hosmer in 1878 and 1888–1902, and concluded with our own observations in 2004, 2005, and 2006.

Findings: From 1852 through 2006, Concord warmed by 2.4°C due to global climate change and urbanization. Using data for the 43 most common species, the authors found that plants are now flowering seven days earlier on average than they did in Thoreau's times.

Plant flowering times were most strongly related to the mean temperatures in the one or two months just before flowering, but they were also correlated with January temperatures.

Consequences: Differences in flowering responses to warming could affect relationships in plant communities as warming continues. Common St. John's wort (*Hypericum perforatum*) and highbush blueberry (*Vaccinium corymbosum*) are particularly responsive to changes in climate, are common across much of the United States, and could serve as indicators of biological responses to climate change.

Scientific article that describes this research in detail:

Abraham J. Miller-Rushing and Richard B. Primack. 2008. Global warming and flowering times in Thoreau's Concord: a community perspective. Ecology 89:332–341. doi:http://dx.doi.org/10.1890/07-0068.1

I. Walnut Trees May Not Be Able to Withstand Climate Change

Summary: Warmer, drier summers and extreme weather events associated with climate change may be especially troublesome -- possibly fatal -- for walnut trees, according to research at Purdue University.

Research Method: Over five years, Dr. Douglass Jacobs and Dr. Martin-Michel Gauthier studied the physiology of walnut trees and found that the trees are especially sensitive to particular climates.

"Walnut is really restricted to sites not too wet or dry. It has an extremely narrow range," said Jacobs. "We suspect and predict that climate change is going to have a real impact on walnuts. We may see some type of decline of the species."

Findings: Walnuts are predicted to have difficulty tolerating droughts that could be associated with a changing climate. Almost all climate change models predict that climates will become drier.

Walnuts are also sensitive to cold and have evolved a defense mechanism to protect themselves against late frosts: walnut trees don't begin sprouting leaves until almost a month after other trees in the spring. That defense mechanism could be compromised by extreme weather events associated with climate change scenarios. *Late spring frosts after walnuts have developed leaves could kill trees.*

"That, on top of the increase in temperatures, would be a problem for walnut," Gauthier said. "The trees would basically shut down."

In California, more than 500,000 tons of walnuts were sold for more than $1 billion in 2010, according to the U.S. Department of Agriculture.

Scientific article that describes this research in detail:

Martin-Michel Gauthier, Douglass F. Jacobs. 2011. Walnut (*Juglans* spp.) ecophysiology in response to environmental stresses and potential acclimation to climate change**.** *Annals of Forest Science* 68 (8): 1277-1290. doi: 10.1007/s13595-011-0135-6

J. Phenological mismatches: Adjustment to climate change is constrained by arrival date in a long-distance migrant bird

Summary: Spring temperatures in temperate regions have increased over the past 20 years, and many organisms have responded to this increase by advancing the date of their growth and reproduction. However, phenological responses to climate change differ across trophic levels, and some species may not cope with climate change because their response differs from the response of organisms at lower levels on the food chain; this could result in a *mismatch* between the timing of reproduction and the main food supply.

The authors of this study show that adaptation to climate change in a long-distance migrant (the Dutch pied flycatcher) is constrained by the timing of its migratory journey. Climate change has advanced the phenology of their **breeding area**, but the timing of their spring migration relies on environmental triggers that are not affected by climate change. Thus, the spring migration of these species will not advance even though they need to arrive earlier to their breeding grounds to breed when resources are plentiful.

Findings: In this study, the authors show that the migratory bird, the Dutch pied flycatcher (*Ficedula hypoleuca*), has advanced its egg laying date over the past 20 years. However, the timing of its spring arrival in the Netherlands has not advanced, constraining the potential shift in egg-laying. The temporal shift in egg-laying has been insufficient to track an earlier peak in caterpillar abundance over the same period (caterpillars are an important food source for the nestling flycatchers).

Consequences: Some of the numerous long-distance migrants may suffer from climate change either because their migration strategy is unaffected by climate change or because the climate in breeding and wintering areas is changing at different speeds, preventing adequate adaptation.

Scientific article that describes this research in detail:

C. Both and M. E. Visser. 2001. Adjustment to climate change is constrained by arrival date in a long-distance migrant bird. *Nature* 411: 296-298. doi:10.1038/35077063

K. Increases in size and abundance of Yellow-bellied Marmots in response to climate change

Summary: Researchers have tracked the population of a hibernating mammal, the yellow-bellied marmot *Marmota flaviventris*), for more than thirty years in the Upper East River Valley region of Colorado. This study found that warming temperatures are driving an *increase* in the average weight of the marmots and in the total population size.

Findings: The authors found that warmer winter and early spring temperatures have increased the length of the growing season for the marmots, which now emerge earlier from hibernation. Mother marmots are able to wean their young earlier, and as a consequence, these babies have more time to get big and fat before the hibernation season begins. The increase in weight makes the marmots stronger and results in higher survival rates and, subsequently, increased reproduction rates, resulting in a larger population size. Over the period of the study (1976 to 2009), the marmot population grew from fewer than 50 individuals to more than 150 marmots.

Consequences: While warming temperatures have resulted in a boon for the marmots, over the long-term, this trend may or may not continue. Warmer temperatures and more frequent summer droughts may negatively affect plant growth in the region, which could reduce the food resources available to the marmots. In addition, any significant change in marmot abundance could have domino-like effects on other species – both plant and animal – in their environment. For example, larger numbers of marmots may reduce levels of their favorite foods and/or it may give the marmots' predators a boost.

Scientific article that describes this research in detail:

Ozgul, A., D.Z. Childs, M.K. Oli, K.B. Armitage, D.T. Blumstein, L.E. Olson, S. Tuljapurkar, &T. Coulson. 2010. Coupled dynamics of body mass and population growth in response to environmental change. Nature 466: 482-487.

V. Example Interpretive Phenology Project: Taking Nature's Pulse

*This example is based on an interpretive program, **Taking Nature's Pulse,** developed by Julia Lynam, Seasonal Interpretive Ranger at Joshua Tree National Park (JOTR). The program was developed to introduce phenology and the CPP to park visitors and to engage visitors in monitoring plant phenology at the JOTR Cottonwood Visitor Center.*

Taking Nature's Pulse: Interpretive Phenology Program Outline

Location: Cottonwood VC patio and Botanical trail

Length: One hour program

Resources: *CPP Interpretive Guide*; "Phenology" binder in CWVC office.

Equipment: Laminated photos of phenophases of CPP species profiles; USA-NPN data sheets; CPP program summary handouts; Handout describing *Nature's Notebook* and data entry; USA-NPN handouts –cards and bookmarks; Clipboards; Pencils; (*optional*) Hand lenses or magnifying glasses

Park Theme or sub-theme addressed: Primary Interpretive Theme #1
JOTR encompasses two desert ecosystems within its boundaries: the higher, cooler, Mojave Desert in the northwestern portion of other park merges with the Colorado Desert, a region of the lower, warmer, Sonoran Desert, creating an unusual transition zone rich in desert biodiversity.

Program Theme Statement: *Individuals can contribute to the investigation of climate change by helping to track changes in the seasonal timing of phenophases of plants near their own homes.*

Objectives:

- Visitors will identify and reflect on the cyclic nature of natural processes.
- Visitors will understand that observing phenology can advance our understanding of how biological systems are responding to climate change.
- Visitors will achieve an appreciation of the importance of detailed observations.
- Visitors will experience some of the difficulties of making observations of living plants in natural ecosystems.
- Visitors will learn to identify up to four desert plant species on the CWVC Botanic Trail.
- Visitors will be introduced to the concept of *phenology* and will be able to explain what the word *phenology* means.
- Visitors will be inspired to connect with the USA-NPN or the CPP and become citizen scientists.

Tangibles: *What do I want visitors to care about?*
Climate change, plant species, phenophases, citizen science, natural cycles

Universal Concepts: *the meanings that MOST people can understand and relate to:*
Change, natural cycles, connections

Link Tangibles to Intangibles and Universal Concepts to make Connections:
*Intellectual connections – opportunities for **greater understanding***
*Emotional connections – opportunities to **feel differently***

Tangible	**Intangible/Universal**	**Method or Technique**
Climate change	Change, involvement	Discussion, statistics, questioning how they can be involved in the CPP effort
Plant species		Photographs, explanation, demonstration, examination of live demonstration plants
Phenophases	Natural cycles	Explanation, questioning, photographs, examination of live demonstration plants

Cohesively develop the idea of the theme statement:

1. **Introduction, 10 minutes**

Activity to introduce the idea of natural cycles

Give the visitors a packet of laminated photos representing a location through the seasons (e.g., a deciduous forest through spring, summer, fall, and winter) or an organism through the seasons (e.g., a sunflower seed germinating, a growing sunflower plant, a sunflower plant in full flower, a sunflower plant with ripe, dispersing seeds). Ask the visitors to put the photos "in order"-- note that because each photo represents a phenophase or season in a continuous cycle, the visitors should arrange the photos in a circle! *(Note: just give visitors instructions and let them figure this out on their own – don't coach them!)*

2. **Taking Nature's Pulse, 5 minutes**

(Have visitors sit if possible – this is the talk section)

Introduce the concept of taking nature's pulse: by recording the date of phenological events (e.g. budburst, flowering, fruit set) over many years, we can detect trends. Describe a few examples of long-term, scientific studies (e.g. lilac study).

- These phenomena are known as phenophases and their study as ***Phenology*.**
- Our climate is changing, but it's difficult to see the trends in the short term. We are part of a long-term study to track changes in the seasonal cycles of plants.
- Throughout this country and in other countries, scientists are collecting data. Some is collected from old photographic records, some from dated herbarium specimens but most by direct observation.

3. **What JOTR is doing, 5 minutes**

JOTR is working with the *California Phenology Project (CPP)* to observe the phenology of a few plant species that are ecologically important. In every state, focal plant species are being tracked, and you can join in with this project in your own home state – or country.

- We have several phenology trails throughout the park, one of them here in Cottonwood.
- We've identified and tagged several individuals representing four species that are targeted by the CPP. *Show USA-NPN data sheets of the species being tracked at Cottonwood Visitor Center*.
- Today, you can help to collect data that will be entered online into the national database and available for scientists to study the effects of climate change on our natural flora and fauna.
- I will give you instructions for submitting your observations online when you get home.

4. **<u>The Trail, 10 minutes:</u>** Walk part of the trail to point out the plants being studied and how they are tagged. Let visitors look at the plants carefully.

5. **<u>Data Collection, 20 minutes</u>**
   - Have visitors select a plant for data collection.
   - Hand out clipboards with datasheets and pencils
   - Hand out hand lenses to those who want them.
   - Explain how to collect data.
   - Spend as much time as needed to collect data – many questions will arise!

6. **<u>Conclusion , 10 minutes</u>** (back in seating area)
   - Give out data entry information sheet and CPP program summary sheet
   - Ask for questions and allow a few minutes for discussion
   - Conclude – using theme statement.

VI. Online Resources

1. ***The Phenology Handbook:*** A guide to phenological monitoring for students, teachers, families, and nature enthusiasts. Available for download on the USA-NPN website at: http://www.usanpn.org/phenologyhandbook
2. ***The USA-NPN's Educator's Clearinghouse*** (http://www.usanpn.org/education/clearinghouse): The Educators' Clearinghouse holds educational materials (lesson plans, activity guides, syllabuses, project design plans), to provide a convenient and growing collection of resources on phenology learning both inside and outside of the traditional classroom setting.
3. ***Phenology Wheels: Earth Observation Where You Live:*** This activity was developed by Partner's in Place (http://partnersinplace.com/) to help students explore and fully inhabit the places that sustain our bodies, minds, and spirits by tracking the continuous rhythms of nature. The ***phenology wheels*** activity is summarized here: http://www.earthzine.org/2011/02/14/phenology-wheels-earth-observation-where-you-live/
4. ***California Native Plant Society's Opening the World through Nature Journaling***: This curriculum, written for CNPS by John Muir Laws and Emily Brueunig, teaches children to become keen observers of the natural world by drawing and writing about the plants and animals in situ. In a set of nested exercises, students use games to gain confidence in drawing and writing as a way to gather information. Many of these exercises lend themselves to introducing seasonal cycles of plants and animals. The curriculum is available through this page: http://www.cnps.org/cnps/education/curriculum/index.php
5. ***Project BudBurst's Classroom activities:*** These activities can be easily adapted for use in a variety of settings (both informal and formal) and for a range of ages (from elementary school students to adult learners!). A general description of each activity and a link to a detailed description (in a downloadable pdf) is available here: http://neoninc.org/budburst/educators/activitydescriptions.php