ECOS Inquiry

1. CONTRIBUTOR'S NAME: ALISON PERKINS

2. NAME OF INQUIRY: PHENOLOGY OF FLOWERS

3. GOALS AND OBJECTIVES:

a. Inquiry Questions: Do all plants flower at the same time? Are all flowers on a plant at the same stage of development? How long will species flower? Does weather impact flowering?

b. Ecological Theme(s): Flower phenology varies across species, and this variation can affect the pollinators that are dependent upon them for food. In turn, without pollinators, flower reproduction can be affected. Abiotic factors, such as weather, play a crucial role in this interaction between flowers and their pollinators.

c. General Goal: (1) To understand that different species have different flowering phenologies, (2) to begin understanding pollination and the factors that affect it, whether those factors be biotic (e.g., the availability of pollinators) or abiotic (e.g., the influence of temperature), and (3) to begin thinking about the important interactions and co-evolution of plants and their pollinators.

d. Specific Objectives:

Academic: To learn about plant phenological phases, track the phenophases of flowering plants, and explore the co-evolution of plants and their pollinators.
Experimental: To conduct a basic comparison of two plant species. Students can be encouraged to expand the comparison, make predictions, and collect their own data.
Procedural/technical: To learn techniques for studying pollination.
Social: Working in small groups to collect biologically relevant data.
Communication: To be able to summarize data collected and apply results.

e. Grade Level: 3-12

f. Duration/Time Required: several weeks to collect data

4. ECOLOGICAL AND SCIENCE CONTEXT:

Background (for Teachers):

In this inquiry, students should be able to track phenological events in the Common Dandelion and in a flowering tree (such as Norway Maple, crabapple, and apple trees). These plants are important sources of pollen for Orchard Mason Bees, and by following the flowering phenology of these species, students should be able to compare and contrast two species and think about how phenology can affect food availability for pollinators.

Cloned Lilac (*Syringa chinensis*, 'Red Rothomagensis') phenological events from buds bursting to full bloom. (Photographs by Prof. Mark D. Schwartz, Dept. of Geography, UW-Milwaukee, Milwaukee, WI)
(http://www.windows.ucar.edu/citizen_science/budburst/phenology.php):

Phenology is the study of the timing of specific events in the life cycles of plants and animals. Scientists are following events such as budburst and first flower and relating these events to short- and long-term weather patterns. Weather patterns are abiotic factors that affect flowering in plants (other abiotic factors, like daylength, don't vary across years). Weather also can affect insect emergence (think about driving along any stream in Montana on a warm evening).

Temperatures on any day can range widely in Montana. We also can't use calendars as tools for predicting phenology because calendars aren't specifically tied to the weather. March is usually warmer than February, but anyone from Montana knows that we can experience 50° weather in February and 30° weather in April. Indeed, if temperatures are warmer than "normal" in March plants can advance from bud burst to flowering in short order. Plants require a specific amount of heat to develop from one phenophase to the next, and insects may have similar requirements to move into another stage of their life cycles or come out of winter dormancy. So if we can measure the heat accumulated over time, we may have a more accurate estimate of the abiotic factors organisms are responding to than looking at a calendar or using high or low temperatures. Scientists have developed a tool called "growing degree days" (GDD) as a way of determining the heat "accumulated" each day.

GDD is a function of the maximum and minimum temperatures experienced that day, minus a temperature at which development stops. The temperature at which development stops, the base temperature (T_{base}), varies from plant species to plant species, as well as insect species to insect species. Base temperatures have been estimated for a variety of plants, but 2, 5, and 10° C can be used for general estimates in Montana (P. Alaback, personal communication). So, to calculate GDD:

1. Take the average of the daily maximum and minimum temperatures, and
2. Subtract the base temperature.

$$GDD = \frac{T_{max} + T_{min}}{2} - T_{base}$$

A mild March day with a high of 9° C (48° F) and dropping to 2° C (35° F) would contribute 1.5 GDDs if the plant can grow above a base temperature of 2° C.

$$1.5 = \frac{9 - 2}{2} - 2$$

If the plant had a base temperature of 5° C or 10° C, then the GDD would be 0 (because subtracting 5 or 10 would result in a negative number for GDD, so it is simply rounded up to 0).

Later in the spring, an April day may have a 13° C (55° F) and a low of 7° C (45° F). The day would contribute 8 GDDs if the plant had a temperature base of 2 (the plant can only grow if temperatures are above 2° C):

$$8 = \frac{13 + 7}{2} - 2$$

and 5 GDDs if the plant had a temperature base of 5 (the plant can grow only if in temperatures are above 5° C):

$$5 = \frac{13 + 7}{2} - 5$$

Be sure to convert to Celsius prior to calculating GDDs. GDDs are summed over time, so that over time the cumulative GDD could be something like:

date	GDD	cumulative GDD
1-Mar	0	0
2-Mar	0	0
3-Mar	0	0
4-Mar	0	0
5-Mar	1	1
6-Mar	1	2
7-Mar	1	3
8-Mar	2	5
9-Mar	0	5
10-Mar	1	6
11-Mar	3	9
12-Mar	1	10
13-Mar	0	10
14-Mar	3	13
15-Mar	5	18

The following table is from Wikipedia, and includes some phenological events of both plants and insects based on growing degree days. Some of the species can be found in Montana, and others are relatives, but the information provides a starting point to think about how GDD affects species in Montana.

Common name	**Number of growing degree days baseline 10 °C**
Red Maple *Acer rubrum*	begins flowering at 1-27 GDD
Forsythia spp.	begin flowering at 1-27 GDD
Sugar Maple *Acer saccharum*	begin flowering at 1-27 GDD
Norway Maple *Acer platanoides*	begins flowering at 30-50 GDD
White Ash *Fraxinus americana*	begins flowering at 30-50 GDD
Crabapple *Malus* spp.	begins flowering at 50-80 GDD
Common Lilac *Syringa vulgaris*	begin flowering at 80-110 GDD
Beach Plum *Prunus maritima*	full bloom at 80-110 GDD
Black Locust *Robinia pseudoacacia*	begins flowering at 140-160 GDD
Catalpa *Catalpa speciosa*	begins flowering at 250-330 GDD
Privet *Ligustrum* spp.	begins flowering at 330-400 GDD
Elderberry *Sambucus canadensis*	begins flowering at 330-400 GDD
Purple Loosestrife *Lythrum salicaria*	begins flowering at 400-450 GDD
Sumac *Rhus typhina*	begins flowering at 450-500 GDD
Azalea Lace Bug	emerges about 130 GDD
Black Cutworm larvae	start causing economic damage at165 GDD
European Corn Borer	first spring moths emerges about 207 GDD
Boxwood leaf miner	emerges about 250 GDD

5. MOTIVATION AND INCENTIVE FOR LEARNING:

Students get to go outside, learn about the plants and insects in their schoolyards and study the phenology of flowering plants.

6. VOCABULARY:

Phenology – the study of the timing of life cycle events in plants and animals
Growing Degree Days – a method of calculating the heat accumulated due to temperature variation over time
Abiotic factors – factors not related to living things (e.g., weather)
Biotic factors – factors related to living things (e.g., competition from other flowers)

7. SAFETY INFORMATION:

Because students will be examining flowers, bees and wasps may be present. Most observations can be made from a distance without bothering these important pollinators.

8. MATERIALS LIST (including any handouts or transparency masters):

- Data recording sheet handout (below)
- Pencils/pens
- Permanent markers
- Small marking flags or toothpicks with labels (use good quality tape to seal labels and make them somewhat weather resistant), flagging tape, floss, or string/rope, wire in different colors
- Plant guides (also see plant list provided at the end of this inquiry)
- Maximum / minimum temperature thermometer
- Maximum / minimum temperature data sheet (below)
- Common Dandelion Phenophase Data Sheet (below)
- Fruit Tree Phenophase Data Sheet (below)

9. METHODS/PROCEDURE FOR STUDENTS:

a. Pre-investigation work:

Discuss with students the different phenophases in the following table. Ask specificially what students think these phases should look like for the two species students will be identifying, Common Dandelions and a flowering tree like Norway Maple. For example, what does budburst look like for a dandelion? Will both species go through the phenophases in the same order? At the same time? Do Norway Maple flowers (or the flowers of a fruit tree) look like dandelion flowers?

Phenophase:	**Description**
First Flower	The date at which the first flowers are completely open. Stamens must be visible among the unfolded petals. For herbs (non-woody plants), use the date when the first flowers of one patch are blooming. For trees or large shrubs, make sure there are blooms on at least three places on the tree or shrub.
Full Flower	The date when 95% of the flowers are fully opened, but before many of the flowers have withered or died.
End Flower	The date when at least 95% of the flowers have withered, dried up, or died.
Seed or Fruit Dispersal	The date when the first fruits or seeds drop naturally from the plant.

Source: BudBurst (http://www.windows.ucar.edu/citizen_science/budburst/participate_phenophases.php)

Two other phases you might want to discuss with the students are related more to the phenology of the plant than to the sustenance it provides pollinators.

Budburst/First Leaf	The date at which the first leaves are completely unfolded from the bud. For trees or large shrubs, make sure there are at least three places on the tree or shrub where budburst has occurred. The leaves need to be opened completely and the leaf stem or leaf base must be visible (the new leaf might need to be bent backwards in order to see them).
Full Leaf	The date when nearly all (at least 95%) of the growing leaf buds have already reached the completely unfolded stage (Budburst/First Leaf).

Source: BudBurst (http://www.windows.ucar.edu/citizen_science/budburst/participate_phenophases.php)

Why might these be important phases to monitor?

b. Investigation work:

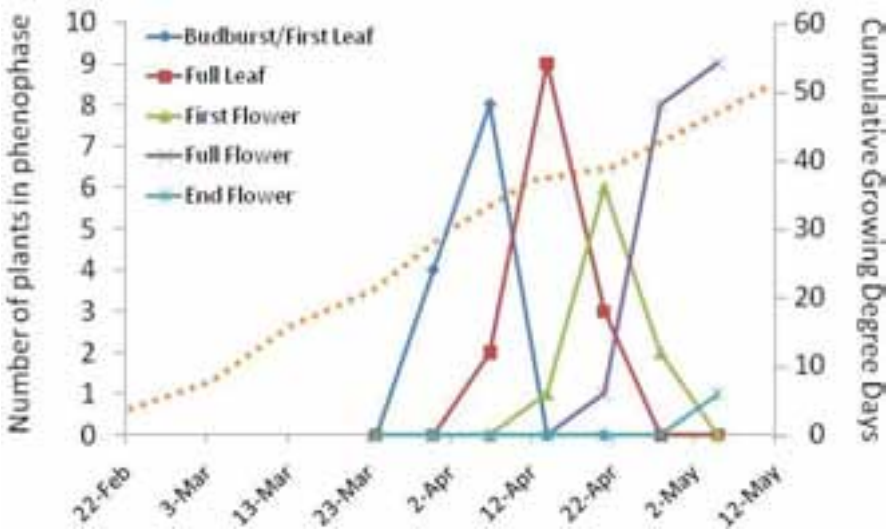
Plan your investigation with students (older students should be able to develop their own methods). The goal is to mark at least 10 dandelion plants and several branch tips of Norway Maple (or a fruit tree like crabapple or apple). Common Dandelions pose interesting questions because the plants may spend the winter very close to "Full Flower" plus they have two major disturbance factors: lawn mowers and school children running and playing on them. Think about locations you can mark for 2-4 weeks that won't be disturbed, or know that disturbance may affect your data and think about how it may affect pollinators as well. Individual plants can be marked with small tags, colored floss or some other hardy string, colored flagging tape, small stakes, whatever is handy and hardy enough to last in the outdoors for several weeks. For Norway Maples, or other fruit trees, select the ends of branches where numerous flowers will occur. Ideally, the plants should be marked before the emergence of Orchard Mason Bees in late February or early March, but plants can be examined after they have begun flowering as well (the data and graphs just won't be as complete). NOTE: This inquiry also can be done with any species of flowering plant, many of which flower late in the spring and into summer.

Flowers of the Norway Maple

Once the Common Dandelions plants and tree branches are marked, have students carefully examine the plants. If the Common Dandelions are already in flower, determine the phenophases present. Look to see whether the flowers are shedding pollen, with stigmatic surfaces not receptive (functionally male), or if pollen is all shed, but stigmatic surfaces are open and sticky (functionally female), or if both stamens and pistils are functional, or if both are finished. See if nectar is present, and try to determine whether the flower has a scent, and what kind of color patterns may serve as guides to the nectar.

Monitor the high and low temperatures in the area over the next several weeks (use the data sheet provided below). Return to collect data on the phenological phases of the marked plants at least four more times over the course of several days or weeks (until the Norway Maples or fruit trees are no longer in flower).

Have the students summarize their results (either graphically or in words). Compile the data and graph the number of plants in each phenophase for Common Dandelions and Norway Maples and the cumulative Growing Degree Days on the y-axis of the phenophase graph. Below is an example of what Norway Maple could look like.



Discuss the differences in the phenology of the two plants. Which plant is a better food source for Orchard Mason Bees and other pollinators? Why do students think that?

c. Extension:

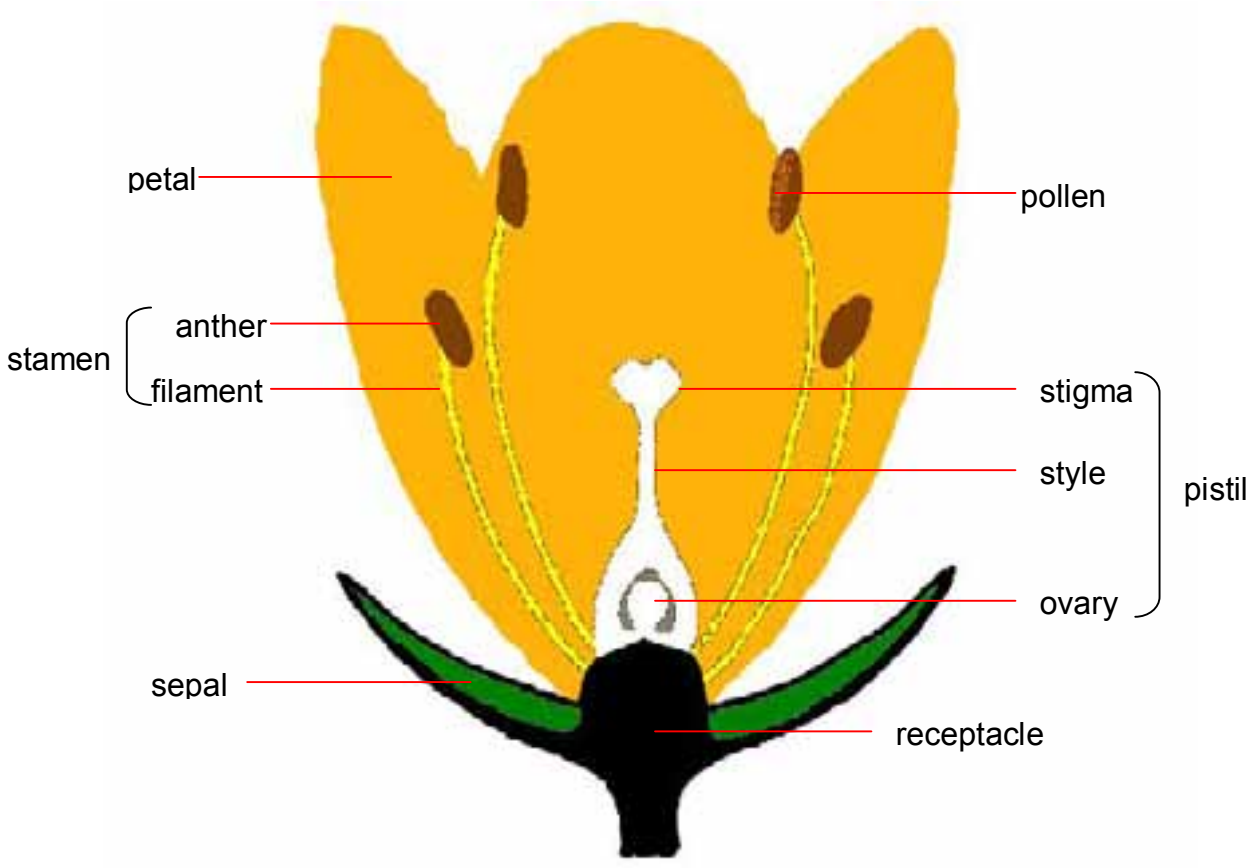
Students can study how long specific flowers are receptive to potential pollinators (the Common Dandelion is actually a composite of number of different "flowers" on one stalk, and the specific parts of each flower may be more difficult to see than in the Norway Maple or a fruit tree flower). Important information to note is whether flowers are shedding pollen, if the stigmatic surfaces are not receptive (hence the flower is functionally male), or if pollen is all shed but stigmatic surfaces are open and sticky (so the flower is functionally female), or if both stamens and pistils are functional, or if both are finished. Pollinators, like Orchard Mason Bees looking for pollen, will be more attracted to flowers that provide pollen, but if the stigma is not receptive to pollen (say late in the afternoon), pollination functionally cannot take place. If neither the anthers or the stigma are functional, the flower can't provide food to Orchard Mason Bees.

Students should discuss what each phase on each species may look like. They can begin with the five phases of the Spring Beauty (from closed bud to flower finished) described by Judy Parrish in Pollination Ecology: Field Studies of Insect Visitation and Pollen Transfer Rates http://tiee.ecoed.net/):

1. Flower enclosed in bud
2. Flower open, streaked pink, stamens very pink and erect
3. At least 2 stamens appear less pink, pistil obvious
4. Stamens folded back against petals, style clearly splits into 3 stigmas
5. Ovary swollen, petals wilting

Flowers need to be examined carefully to determine the phase. Cotton swabs can be good tools to look for pollen or the stickyness of the pistil. Hand lenses may help determine the position of stamens and pistils.

10. ASSESSMENT:



Students could write their ideas about phenology in a story about how important these two species are to Orchard Mason Bees using the Orchard Mason Bee life cycle and comparing events such as emergence and egg provisioning as periods where food is important. Older students can compile and graph data, develop their own questions about plant phenophases, and develop their own monitoring schemes for plants.

11. EXTENSION IDEAS:

Older students can compile data and graph the sequence of each phenophase. They can also calculate the average longevity of each phenophase, and how long the flower is open for visitation.

To determine the overall availability of flowers at a specific time you need an estimate of the size of the flower population. Students can estimate population size by randomly selecting at least 10 one meter squared plots and counting the number of individual plants of the target species that are in specific phenophases. Students can graph the average number of flowers in each phenophase over time.

12. SCALABILITY:

This activity can be scaled to younger students by splitting into large groups and each group monitoring a number of the plants. Older students should be able to monitor their own plants, thus increasing sample size. Data can be pooled and analyzed and graphed as a class. High school students should be able to choose their own species to monitor, monitor several species, and compare flower phenologies.

13. REFERENCES AND SOURCES FOR ADDITIONAL INFORMATION:

This inquiry is modified from Pollination Ecology: Field Studies of Insect Visitation and Pollen Transfer Rates, by Judy Parrish. The complete inquiry can be found on the Teaching Issues and Experiments in Ecology website at http://tiee.ecoed.net/.

14. LIST OF EXPERTS AND CONSULTANTS

Paul Alaback, an expert in local plants and phenology
John Holbrook, an expert in Orchard Mason Bees

15. EVALUATION/REFLECTION BY FELLOWS AND TEACHERS OF HOW IT WENT

This activity has not been tested.

Maximum / Minimum Temperature Data Sheet

Date	High temperature	Low temperature

Common Dandelion Phenophase Data Sheet

Name: _____

Date: _____

Time of observations: _____

Brief description of weather:

Are there any buds bursting on the plant (circle one)? Yes No

Are there any leaves on the plant (circle one)? Yes No

In the box, count the number of flowers on each dandelion plant in each phase.

Dandelion plant #	First Flower	Full Flower	End Flower	Seed / Fruit
example plant #1	2	1	1	0
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				

Fruit Tree Phenophase Data Sheet

Name: _____

Date: _____

Time of observations: _____

Brief description of weather:

Are there any buds bursting on the branch tip (circle one)? **Yes** **No**

Are there any leaves on the branch tip (circle one)? **Yes** **No**

In the box, count the number of flowers on each branch tip in each phase.

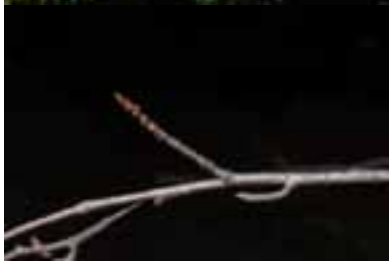
Branch tip #	First Flower	Full Flower	End Flower	Seed / Fruit
example branch 1	14	3	0	0
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				

Flowering plants you can track using the BudBurst website (http://www.windows.ucar.edu/citizen_science/budburst/index.html):

American pasqueflower, *Pulsatilla patens*
Antelope bitterbrush, *Purshia tridentate*
Aspen, *Populus tremuloides*
Beaked hazelnut, *Corylus cornuta*
Big sagebrush, *Artemisia tridentate*
Bigleaf lupine, Wyethís lupine, *Lupinus polyphyllus*
Bitter root, *Lewisia rediviva*
Black locust, *Robinia pseudoacacia*
Blue elder, Common elderberry, *Sambucus mexicana*
Boxelder, *Acer negundo*
Chokecherry, *Prunus virginiana*
Colorado blue columbine, *Aquilegia caerulea*
Common dandelion , *Taraxacum officinale*
Common snowberry, *Symphoricarpos albus*
Common yarrow, *Achillea millefolium*
Creeping barberry, *Mahonia repens*
Curl-leaf mountain mahogany, Mountain mahogany, *Cercocarpus ledifolius*
Darkthroat shooting star, *Dodecatheon pulchellum*
Douglas-fir, *Pseudotsuga menziesii*
Field mustard, turnip, *Brassica rapa*
Kinnikinnick, *Arctostaphylos uva-ursi*
Lanceleaf springbeauty, *Claytonia lanceolata*
Lewis' mock orange , *Philadelphus lewisii*
Pacific trillium *Trillium ovatum*
Paper birch, *Betula papyrifera*
Ponderosa pine, *Pinus ponderosa*
Red osier dogwood, *Cornus sericea*
Rocky mountain maple, *Acer glabrum*
Scarlet gilia, *Ipomopsis aggregate*
Shrubby cinquefoil, *Dasiphora floribunda*
Silverleaf phacelia, *Phacelia hastata*
Spiderwort, *Tradescatia ohiensis*
Western serviceberry, *Amelanchier alnifolia*
White clover, *Trifolium repens*
Woods' rose, *Rosa woodsii*
Woods strawberry, *Fragaria virginiana*

Flowering plants that may be important to breeding Orchard Mason Bees in western Montana from the **ECOS Guide to the Ecology of the Northern Rockies** (http://www.bioed.org/nhguide/):

Trees and shrubs

common name	scientific name		flowering time
alder, gray	*Alnus incana*		April-May
ash, green	*Fraxinus pennsylvanica*		April-May
bitterbrush, antelope	*Purshia tridentate*		April-June BudBurst species
boxelder	*Acer negundo*		April-May
chokecherry	*Prunus virginiana*		April-July BudBurst species

currant, wax	*Ribes cereum*		April-May
dogwood, red osier	*Cornus sericea*		May-July BudBurst species
elderberry, black	*Sambucus niger*		May
hawthorn, black	*Crataegus douglasii*		May
locust, black	*Robinia pseudoacacia*		May BudBurst species

mahogany, curl-leaf mountain	*Cercocarpus ledifolius*		April BudBurst species
maple, Norway	*Acer platanoides*		May
maple, Rocky Mountain	*Acer glabrum*		April-July BudBurst species
mock orange, Lewis'	*Philadelphus lewisii*		May

ninebark, Eastern	*Physocarpus opulifolius*		May
ninebark, mallow	*Physocarpus malvaceus*		May
serviceberry, Saskatoon	*Amelanchier alnifolia*		May

Other flowering plants

common name	scientific name	flowering time

arnica, twin	*Arnica sororia*		May
barberry, creeping	*Mahonia repens*		April-June BudBurst species
beardtongue, Alberta	*Penstemon albertinus*		May
besseya, Wyoming	*Besseya wyomingensis*		May
bindweed, field	*Convolvulus arvensis*		May

bindweed, hedge false	*Calystegia sepium*		May
biscuitroot, bigseed	*Lomatium macrocarpum*		April-May
biscuitroot, cous	*Lomatium cous*		April-May
biscuitroot, fernleaf	*Lomatium dissectum*		April-May

biscuitroot, nineleaf	*Lomatium triternatum*		May
biscuitroot, Wyeth	*Lomatium ambiguum*		April-May
bitter root	*Lewisia rediviva*		March-June BudBurst species
bluebells, oblongleaf	*Mertensia oblongifolia*		May
buckwheat, cushion	*Eriogonum ovalifolium*		May

buttercup, sagebrush	*Ranunculus glaberrimus*		April-May
chickweed, common	*Stellaria media*		April-May
chickweed, common mouse-ear	*Cerastium fontanum*		April-May
chickweed, field	*Cerastium arvense*		April-May
clematis, western white	*Clematis ligusticifolia*		May

clover, white	*Trifolium repens*		April-July BudBurst species
columbine, Colorado blue	*Aquilegia coerulea*		May BudBurst species
daisy, cutleaf	*Erigeron compositus*		April-May
dames rocket	*Hesperis matronalis*		May
dandelion, common	*Taraxacum officinale*		April-May

deathcamas, meadow	*Zigadenus venenosus*		May
deerhorn	*Clarkia pulchella*		May
fairybells, roughfruit	*Disporum trachycarpum*		April-May
fireweed	*Chamerion angustifolium*		May

fleabane, shaggy	*Erigeron pumilus*		May
forget-me-not, small	*Myosotis stricta*		April-May
fritillary, yellow	*Fritillaria pudica*		April-May
gilia, scarlet	*Ipomopsis aggregata*		April-June BudBurst species

honeysuckle, Tatarian	*Lonicera tatarica*		May
Hound's tongue	*Cynoglossum officinale*		May
Indian paintbrush, harsh	*Castilleja hispida*		April-May
Indian paintbrush, giant red	*Castilleja miniata*		May

larkspur, little	*Delphinium bicolor*		April-May
lily, pointedtip mariposa	*Calochortus apiculatus*		May
lupine, silky	*Lupinus sericeus*		April-May
kinnikinnick	*Arctostaphylos uva-ursi*		May

medick, black	*Medicago lupulina*		April-May
mustard, field	*Brassica rapa*		March-May BudBurst species
mustard, tall tumble	*Sisymbrium altissimum*		April-May
mustard, small tumbleweed	*Sisymbrium loeselii*		April-May

old man's whiskers	*Geum triflorum*		April-May
pasqueflower, American	*Pulsatilla patens*		March-May BudBurst species
pepperweed, common	*Lepidium densiflorum*		April-May

pepperweed, Virginia	*Lepidium virginicum*		May
pennycress, field	*Thlaspi arvense*		April-May
phacelia, silverleaf	*Phacelia hastata*		May
phacelia, threadleaf	*Phacelia linearis*		April-May

pussytoes, umber	*Antennaria umbrinella*		April-May
rockcress, Nuttall's	*Arabis nuttallii*		April-May
salsify, yellow	*Tragopogon dubius*		May
saxifrage, wholeleaf	*Saxifraga integrifolia*		May
shepherd's purse	*Capsella bursa-pastoris*		April. May

shooting star, Bonneville	*Dodecatheon conjugens*		April-May
sorrel, common sheep	*Rumex acetosella*		April-May
springbeauty, lanceleaf	*Claytonia lanceolata*		April-July BudBurst species
spurge, leafy	*Euphorbia esula*		May
stoneseed, western	*Lithospermum ruderale*		April-May

strawberry, broadpetal (woods)	*Fragaria virginiana*		May
strawberry, woodland	*Fragaria vesca*		May
sweetclover, yellow	*Melilotus officinalis*		May
tiny trumpet	*Collomia linearis*		May
toadflax, bastard	*Comandra umbellata*		April-May

trillium, Pacific	*Trillium ovatum*		March-May BudBurst species
violet, Nuttall's	*Viola nuttallii*		May
waterleaf, ballhead	*Hydrophyllum capitatum*		April-May
yarrow, common	*Achillea millefolium*		May

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