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# Introduction

The purpose of this manual is to provide information on plant phenology events at the Imnavait Creek experimental site, Toolik Field Station, Alaska. Data, field observations, and photographs were collected in 2010 and 2011, and this information has been compiled to provide a resource for future phenology observations. Phenology observations are being made to determine how changes in seasonality affect plant life histories at the species and community level, as part of a larger experiment examining biogeochemical cycles in the tundra. Guidelines set out here are specific to this site and experiment; however, information and descriptions of plant life history events could be used to inform other phenology monitoring efforts in the Arctic tundra.

# Methods

## Imnavait Field Site

The Imnavait Creek experimental site is located north of Toolik Field Station, AK, in a moist acidic tussock tundra environment. Tussock tundra is dominated by *Eriophorum vaginatum*, commonly known as cottongrass. *E. vaginatum* forms mounds, or tussocks, by growing on top of dead leaves from previous years. The inter-tussock spaces are generally wetter and are covered by mosses (*Sphagnum spp.*, *Hylocomium spp.*) and lichens. Common plant species that were monitored at the site can be divided into four functional groups: graminoids, deciduous shrubs, evergreen shrubs, and forbs. This manual is generally organized by functional group. A complete species list is given in Appendix A.

## Experimental Setup

The experiment includes two approaches to changing the seasonality of the ecosystem: accelerating snowmelt and warming temperatures. In early May, we placed radiation absorbing fabric on the snow surface to accelerate the timing of snowmelt. We monitored the rate of snowmelt and removed the fabric when the accelerated plots were 80% snowfree. In addition, when the plots became snowfree, we placed open-top-chambers in areas with and without accelerated snowmelt. The chambers increased air temperatures especially during mid-day early in the growing season. In summary, the four treatment types, with field codes shown in parentheses, are: control (CN), early snowmelt (AN), warmed (CO), and combined treatments (AO).

## Phenology Protocols

Plant life history events happen quickly in the arctic summer, so phenology observations should be done frequently. From snowmelt to the onset of peak season, observations should be made every two or three days at a minimum. During peak season, there are less changes taking place, so observations can be done every three to four days. Although peak season may last four or more weeks, color changes may start occurring sooner. Once the first color changes are observed, the two to three day schedule should be reinstated.

Within each plot, two types of phenology observations are made: individual and community. Individual phenology observations are related to leaf growth and color change and are designed to track the vegetative growth of marked individuals throughout the season. The sum of these observations describes the onset and duration of greenness across the landscape. Community phenology observations combine vegetative and reproductive events for all plants within a plot. Reproductive phenology events are those related to flower growth, pollination and seed dispersal.

In addition to recording plant life history events, it is important to note other activities or external influences that might affect plant survival or reproduction. Individual plants might be affected by fungi, insect eggs, predation by caterpillars or other insects, or disease. Whole communities could be affected by weather events such as a late frost or snow.

### Individual Phenology Observations

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| **Table 1:** Species marked for individual phenology | | |
| **Species** | **Data Sheet Nickname** | **Bead Color** |
| *Eriophorum vaginatum* | Tussock | Yellow |
| *Carex bigelowii* | Carex | Red |
| *Betula nana* | Birch | Blue |
| *Salix pulchra* | Willow | White |
| *Vaccinium vitis-idaea* | Cranberry | Orange |
| *Polygonum spp.* | Bistort | Pink |
| *Cassiope tetragona* | Heather | Green |
| *Ledum palustre* | Ledum | Purple |

Within each experimental plot, there are up to five individuals of eight different species marked with colored beads (Table 1). Not all plots have five individuals for a species, and some plots are lacking a certain species altogether; these vacancies are noted on the data sheets. The species monitored for individual phenology are: *Eriophorum vaginatum*, *Carex bigelowii*, *Betula nana*, *Salix pulchra*, *Vaccinium vitis-idaea*, *Polygonum spp.*, *Cassiope tetragona*, and *Ledum palustre*. The events observed may include first leaf bud, first leaf expanded, first color change, whole leaf color change, total senescence, and leaf drop (Table 2).

### Community Phenology Observations

Community phenology observations encompass the eight species observed for marked individuals as well as a number of other species: *Salix phlebophylla*, *Pedicularis lapponica*, *Pedicularis oederi*, *Petasites frigidus*, *Pyrola grandiflora*, *Rubus chamaemorus*, and *Vaccinium uliginosum*. Events are recorded when they are observed for the first time on any plant within the plot. The events observed include all of the vegetative growth events observed for individuals, as well as reproductive events that include first flower bud, first flower open, and seed dispersal (Table 2).

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| **Table 2:** Phenology events and description | | | |
| **Phenology Event** | **Code** | **Data Sheet Shorthand** | **Explanation** |
| First leaf bud | FLB | b | Day of first leaf bud observed on an individual. |
| First flower bud | FFB | b | Day of first flower bud observed on an individual. |
| Full leaf expansion | FLE | E | Day of first leaf observed on an individual that is as large as it will get for the entire season. |
| First flower open | FFO | O | Day of first flower on an individual that is open, i.e. able to be pollinated. |
| First color change | FCC | C | Day of first leaf color change observed on an individual, signifying the beginning of senescence. |
| Whole leaf color change | WLC | W | Day of first leaf on an individual that has wholly changed color. |
| Seed dispersal | SD | D | Day of first seed dispersal for an individual; varies between different growth forms (could be ripe berries, seeds falling off a catkin, or wind dispersal of seed tufts) |
| Total senescence | TS | S | Day of year that all leaves on an individual have wholly changed color. |
| Leaf drop | LD | L | Day of year that all leaves on an individual have fallen off. |

# Observations by Species

## Deciduous Shrubs

### *Betula nana*- Dwarf arctic birch; Individual & Community Phenology

Observable life history events include FLB, FLE, FFO, FCC, WLC, TS, SD, and LD. Leaf buds, expansion and color changes are clear and obvious. Leaves are fully expanded when they are flat and positioned away from the stem. Color change starts at the leaf margin and leaves will turn rich shades of orange, red and purple. Reproductive events (FFO, SD) are harder to observe. First flower open occurs when a catkin is open and pollen falls off when gently touched. Seeds generally hold tightly until the very end of the season, after the leaves have changed color, and many seeds will stay on overwinter. Where seed dispersal is observed, it may be the result of a direct disturbance to the catkin. At the end of the season, leaf drop can occur very quickly, over the space of a few days.

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| Early in the season; leaf buds have not expanded but catkin is open. | During peak season; leaves are fully expanded. | Late season; some leaves have fully changed color and others are beginning to change at the leaf margin. | Late season; seeds have formed on the catkin but have not dispersed. |

### *Salix pulchra*- Diamond-leaf willow; Individual & Community Phenology

Observable life history events include FLB, FLE, FFO, FCC, WLC, SD, TS, and LD. Leaf buds, expansion and color changes are clear and obvious. Leaves are fully expanded when they are flat and positioned away from the stem. Color change may begin anywhere on the leaf and often appears as spots of yellow or brown. Reproductive phenology is harder to observe for this species as many individuals do not produce flowers in a given year. When flowers are produced, they appear as catkins. Only one open catkin was observed in 2011, and seed dispersal was never observed. Leaf drop occurs slowly compared to *Betula* and some individuals may not lose all their leaves.

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| Early season leaf buds. | Full leaf expansion; peak season. | Beginning of color change; one leaf has fully changed color. | End of season; individual has reached total senescence but has not dropped any leaves. |

### *Salix phlebophylla*- Skeleton-leaf willow; Community Phenology

Observable life history events include FLE, FFO, FCC, WLC, SD, and TS. Leaf expansion occurs when leaves are flat. Flowers appear as catkins, which were observed in 2011, however, seed dispersal was not observed. First color change may occur on any part of the leaf, and whole leaf change will happen quickly due to the small size of the leaves. Leaves will not drop but cling to the plant overwinter, hence the common name skeleton-leaf willow.

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| Catkins appeared very early in the 2011 season, even before full leaf expansion. | Fully expanded leaves. | This individual has reached whole leaf change. | Total senescence. |

### *Vaccinium uliginosum*- Alpine blueberry; Community Phenology

Observable life history events include FLB, FLE, FFO, FCC, WLC, SD, and TS. Although blueberry is a common species across the tundra, it only occurs in a few small patches at the Imnavait experimental site. Its small size and similarity in leaf shape to skeleton leaf willow and cranberry can make it difficult to find, especially before leaf expansion. However, FLB was observed in one plot in 2011. Flowers (small and pink) were observed, and although no berries formed in 2011, seed dispersal should still be looked for in fall. Color change can be difficult to determine because some leaves retain a bluish-purple color around the margin throughout the season. However, they do clearly change in the fall to a deeper red or purple color. The fall color change can also be distinguished from early season color because the entire leaf will change, rather than just the leaf margin.

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| Early season fully expanded blueberry leaves with purple color at the margins. | Expanded leaves at peak season are almost fully green. | Total senescence of a blueberry patch. |

## Graminoids

### *Eriophorum vaginatum*- Cottongrass; Individual & Community Phenology

Observable life history events include FLB, FLE, FFB, FFO, SD, FCC, WLC, and TS. Cottongrass will likely be green and already forming flowers at the time of snowmelt, and FLB and FFB are recorded at this time. Full leaf expansion is called when at least one green shoot of the tussock is 4cm tall. FFO occurs very quickly after snowmelt. Seeds are wind dispersed and this event is called by observing missing seeds on the inflorescence, or by observing the seeds falling off when the inflorescence is gently touched. Color change begins with the tips of the leaves turning yellow, and the change travels downward to the base of the plant. Whole leaf change is called when one whole leaf is yellow all the way to the base. Total senescence would occur when all the leaves in a tussock are completely yellow, but this was not observed in 2011.

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| Tussock at snowmelt with green leaves already showing. | Tussock inflorescence immediately following snowmelt (FFO). | Tussock inflorescence ready for seed dispersal. | This tussock has begun to change colors but none of the leaves are at whole leaf change. |

### *Carex bigelowii*; Individual & Community Phenology

Observable life history events include FLB, FLE, FFO, SD, FCC, WLC, and TS. Like cottongrass, Carex will likely have green leaves present at snowmelt. Full leaf expansion occurs when a single leaf is at least 4cm tall. Flowering occurs early in the season, and first flower open is called when the yellow anthers are present. Not all inflorescences may develop seeds, but it will be obvious on those that do. Seeds cling tightly to the inflorescence until late in the season and seed dispersal can be difficult to call, so it is important to closely examine the inflorescences around the time of expected dispersal. Color change occurs similarly to cottongrass, where the tips of the Carex leaves turn yellow-brown and the color change travels down. Unlike cottongrass, however, total senescence was observed by the end of the season for Carex.

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| An early season Carex with fully expanded leaves and an open flower. | Carex inflorescence with seeds growing. | Beginning of color change. | Carex plant at total senescence. |

## Evergreen Shrubs

### *Vaccinium vitis-idaea*- Rock cranberry; Individual & Community Phenology

Observable life history events include FLE, FFB, FFO, SD, FCC, and WLC. This evergreen plant does not reach total senescence; rather, it stays green under the snow all winter, and therefore already has green leaves at snowmelt. The first observable events are FFB and FFO. FLE happens later in the season and can be hard to distinguish. The new leaves that open are a shiny reddish color, especially around the leaf margin. When these new leaves are fully open and about the same size as the other leaves on the plant, they have reached FLE. Color change for cranberry is also a difficult event to distinguish, because some leaves retain the reddish color throughout the season; the color change indicating the onset of senescence is a darker red. Although individual leaves will fully change color, not all leaves on the plant are likely to change. Seeds form as bright red berries, not to be confused with the previous years’ berries that hang on to the plant. Since many berries will not simply fall off, seed dispersal is called when the berry is fully ripe.

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| Cranberry directly after snowmelt, before green-up. | Open cranberry flowers, still early in the season. | Cranberry with bright red new leaves opening; the ones on the far left are fully expanded. | The dark reddish-brown leaves are showing signs of senescence. |

### *Ledum palustre*- Labrador tea; Individual & Community Phenology

Observable life history events include FLE, FFB, FFO, FCC, WLC, and SD. Flower buds form at the top of the plant and are obvious large buds. Leaf buds are smaller and hard to distinguish, so they are not an observable event. Full leaf expansion is also relatively hard to distinguish, however, the new leaves will emerge together in a tight cluster and slowly unfurl. When the new leaves are pointing away from the stem, they are at full leaf expansion. Color change occurs on some of the leaves, which will turn bright reds and yellows. First color change and whole leaf color change may be the same event due to the small leaf size. Seed dispersal is difficult to observe because it is hard to tell new seedpods from those left on the plant from the previous year.

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| Early in the season, showing large flower bud and no leaf buds or new leaves. | Flower is open. | A leaf bud in the process of opening; the new leaves are visible but have not expanded. | Seed pods from the current year; one is open, indicating seed dispersal. |

### *Cassiope tetragona*- White mountain heather; Individual & Community Phenology

Observable life history events include FFB, FFO, FLE, SD, FCC, and WLC. For this species, first flower bud is the most easily observed early season event and was used as a proxy for first leaf bud since that event was not observed in 2011. First flower bud is called when the bud emerges from the stem and can be seen on its own stalk. A number of flowers for this species failed, but one seed dispersal event was observed. First leaf expansion was clearly observed for only one individual in 2011, so this is another difficult event to observe for this species. Color change occurs when a single leaf turns bright red or orange, and since the leaves are so small, first color change and whole leaf change are essentially the same event. This is an evergreen species, so total senescence and leaf drop do not occur.

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| First flower bud that has clearly emerged. | Seed dispersal. | New leaves on Cassiope emerge bright green. | First color change/whole leaf change starts at the bottom of the spikes and travels upward. |

## Forbs

### *Polygonum sp.* – Bistort; Individual & Community Phenology

Observable life history events include FLB, FLE, FFO, SD, FCC, WLC, and TS. First leaf bud is called when the straight green shoot can be seen coming out of the ground. Full leaf expansion is more difficult to call because leaves may grow to different sizes. To be sure FLE is called correctly, the leaf can be measured and then measured again the next time phenology is done; when the leaf stops growing, it is at FLE. In 2011, fully expanded leaves ranged in size between 5 and 9 cm. Leaves change to deep purple and brown colors in the fall.

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| The beginning of a bistort flower pushing up in the spring. | Bistort flower, not open. | Bistort flower that has fully opened. | Bistort leaves turning purple in the fall. |

### *Petasites frigidus*- Arctic sweet coltsfoot; Community Phenology

Observable life history events include FLE, FCC, and WLC. Full leaf expansion can be estimated by comparing to the dead leaves from last year. Leaves will also be fully uncurled. It may be useful to mark an individual and measure leaf length to more accurately determine full leaf expansion. Color change starts at the leaf margin and is a dark purple to brown.

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| New coltsfoot leaf that is not fully expanded; the leaf edges are curled back. | This coltsfoot leaf looks fully uncurled, but may still get larger. |

### *Pedicularis lapponica*- Lousewort; Community Phenology

Observable life history events include FLE, FFO, FCC, and WLC. FLE occurs when a plant is observed for the first time, since the leaflets remain tiny and difficult to find throughout the season. Although there were only a couple individuals that produced flowers in 2011, these events were clear and obvious. FFB was called when flower buds were first apparent, and FFO was called when the flowers opened. Color change and other end of season events are difficult to observe because individuals are already a purplish color. There is a change to a darker color and then the leaves turn brown and shrivel up; however, they may be nearly impossible to find by this point.

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| *Pedicularis* leaves from early in the season; most likely will not get much bigger throughout the season. | *Pedicularis* that has sent up a flower shoot, no flowers apparent yet. | *Pedicularis* with open flowers. |

### *Pedicularis oederi*- Oeder’s lousewort; Community Phenology

Observable life history events include FLE, FFO, FCC, WLC, and TS. Because the leaves appear and expand very quickly, FLE is called when the plant is first observed. There were a small number of individuals in 2011 and none of them produced flowers. However, if flowering occurs, it will be an obvious event with large, showy flowers. Color change occurs when the leaves begin to turn bright yellows and reds. By the time of senescence, the leaves are darker purples and browns. These are gradual changes and are not always obvious.

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| Early season *Pedicularis oederi* with full green leaves; easily distinguished from *Pedicularis lapponica*. | Late season *Pedicularis oederi*; leaves have begun to change colors. |

### *Pyrola grandiflora*- Arctic wintergreen; Community Phenology

Observable life history events include FLE, FFO, FLC, and WLC. As with the other forbs, FLE can be difficult to determine. In general, if the plant is easily observed, it may be appropriate to call FLE. With Arctic wintergreen, the leaves will expand out and towards the ground, so if they are all pointed upward, it may be too soon to call FLE. Color change is red and brown.

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| Arctic wintergreen that is flowering; not observed in the experimental plots. | Arctic wintergreen towards the end of the season; just beginning to change color. |

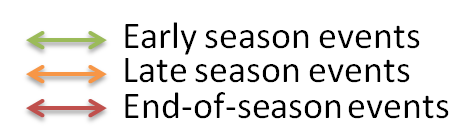
### *Rubus chamaemorus*- Cloudberry; Community Phenology

Observable life history events include FLE, FFO, SD, FCC, and WLC. Cloudberry may flower early, even before leaves are fully expanded. Open flowers may only last a few days, so this is a very quick event to observe. Expanding leaves may have bright red around the edges. No berries were produced in the experimental plots in 2011; however, this would be an obvious event with bright orange berries. In the fall, leaves turn a dark purple before senescence.

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| Cloudberry before leaf expansion. | Flower bud is visible and leaf is partially expanded. | Fully open flower and fully expanded leaf. | Beginning of color change. |

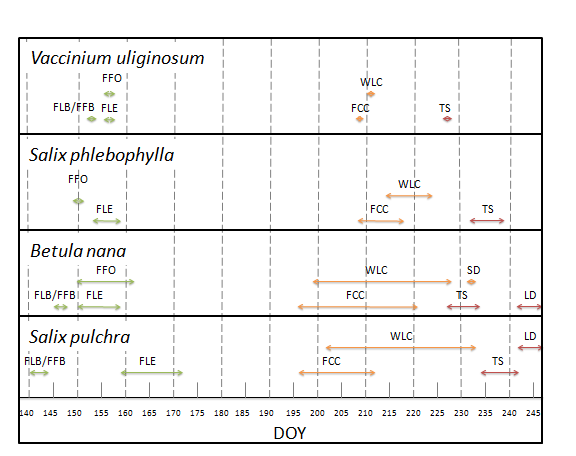
# Timelines

Dates for phenology events are from the 2011 data for control plots only. These dates are meant to provide a guideline for when to expect events throughout the season; they are not the only dates on which an event might occur. Many things can change the timing of plant events, including seasonal weather patterns, individual variation, and the effect of the experimental treatments. For all timelines, the following color scheme describes early, late and end-of-season events.



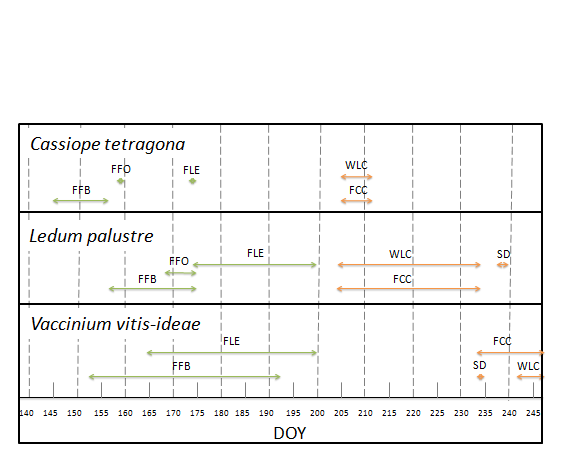
## Deciduous Shrubs

Timeline of events for the deciduous shrubs. Deciduous shrubs all began to form leaves shortly after snowmelt, but *Salix pulchra* took longer for the leaves to fully expand. It also has the largest leaves of any of these species. Color changes began at similar dates for all species. The smaller leaved species, *Vaccinium uliginosum* and *Salix phlebophylla*, did not have much of a delay between first color change and whole leaf color change. No flowering or seed dispersal was observed for *Salix pulchra*. For this group, there is a clear period of peak season, where no new events are occurring until color change in the fall.



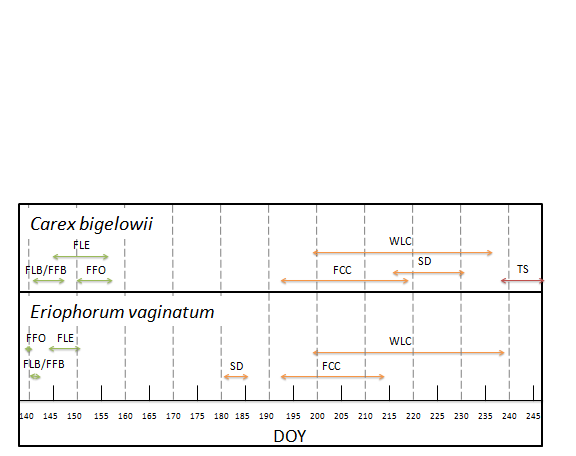
## Evergreen Shrubs

Timeline of life history events for the evergreen shrub functional group. Timing of events for the evergreen shrubs varies throughout the season compared to deciduous shrubs and graminoids. In general, flowering and leaf expansion occurs much later, and over a longer time period. Color change for *Vaccinium* was a difficult event to observe, but clearly occurred much later than the other species in this group. For *Cassiope*, only a few open flowers were observed and one clear example of leaf expansion. For these events, there may be a wider range of dates over which they occur. For *Cassiope* and *Ledum*, first color change and whole leaf color change occurred on the same day because the leaves were so small. The evergreen species do not reach the late season events of total senescence or leaf drop because they stay at least partially green throughout the winter; this means that they also have green leaves at snowmelt in the spring.



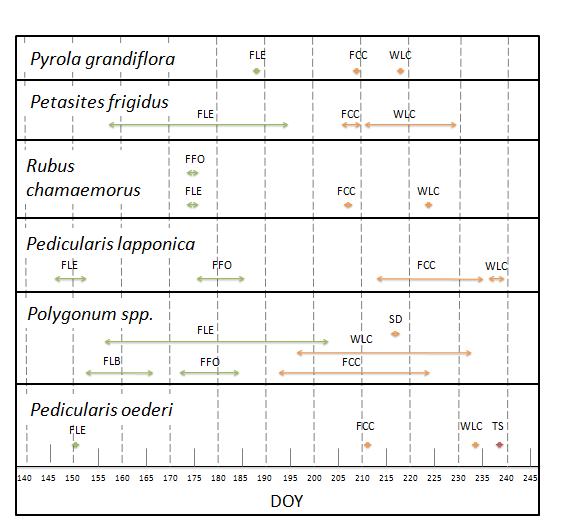
## Graminoids

Timeline of life history events for graminoids. All of the *Eriophorum* plants and many *Carex* had green leaves at the time of snowmelt; these species are able to begin growth in the spring underneath the snowpack. Consequently, both of these graminoids have leaf expansion and flowering that happens very quickly after snowmelt. The timing of color change is also very similar for these two species. However, they differ in the timing of seed dispersal. *Carex* developed seeds more slowly, and the seeds tended to cling to the plant until late in the season. Some *Carex* plants that flowered did not produce seeds, and many seeds that formed did not disperse at all. However, *Eriophorum* flowered very quickly, and the light seed tufts all dispersed together in a short window of time. This is also the earliest seed dispersal event among all the plants observed.



## Forbs

Timeline of life history events for forb species. For forbs in general, there is less of a pattern with timing of events than observed for deciduous shrubs or graminoids. Leaf expansion occurred quickly after snowmelt for some species (*Pedicularis*), but much later and over a long period of time for other species (*Polygonum*, *Petasites*). It should be noted that for some of the forb species, only one or two individuals were observed in all the plots, so events may occur over a wider range of dates than is shown here. This is true for *Pyrola*, *Pedicularis oederi*, and *Rubus*.



# Appendix A: Imnavait Species List

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Family** | **Genus** | **Species** | **Functional Group** | **Code** | **Common name** | **in Exp** |
| Asteraceae | *Hieracum* | *spp* | forb | HIEspp | hairy forb | yes |
| Asteraceae | *Petasites* | *frigidus* | forb | PETFRI | Arctic sweet coltsfoot | yes |
| Betulaceae | *Betula* | *nana* | deciduous shrub | BETNAN | dwarf arctic birch | yes |
| Cyperaceae | *Carex* | *bigelowii* | graminoid | CARBIG |  | yes |
| Empetraceae | *Empetrum* | *nigrum* | evergreen shrub | EMPNIG | Crowberry | yes |
| Ericaceae | *Andromeda* | *polifolia* | evergreen shrub | ANDPOL | Bog Rosemary | yes |
| Ericaceae | *Cassiope* | *tetragona* | evergreen shrub | CASTET | white mountain heather | yes |
| Ericaceae | *Ledum* | *palustre* | evergreen shrub | LEDPAL | Labrador tea | yes |
| Ericaceae | *Oxycoccus* | *microcarpus* | evergreen shrub | OXYMIC | bog cranberry | yes |
| Ericaceae | *Pyrola* | *grandiflora* | evergreen shrub | PYRGRA | arctic wintergreen | yes |
| Ericaceae | *Vaccinium* | *uliginosum* | deciduous shrub | VACULI | alpine blueberry | yes |
| Ericaceae | *Vaccinium* | *vitis-idaea* | evergreen shrub | VACVIT | rock cranberry | yes |
| Poaceae | *Calamagrostis* | *laponica* | graminoid | CALLAP |  | yes |
| Poaceae | *Eriophorum* | *vaginatum* | graminoid | ERIVAG | cotton grass | yes |
| Poaceae | *Poa* | *artica* | graminoid | POAART |  | yes |
| Polygonaceae | *Polygonum* | *bistorta* | forb | POLBIS | bistort | yes |
| Polygonaceae | *Polygonum* | *viviparum* | forb | POLVIV | alpine bistort | yes |
| Rosaceae | *Rubus* | *chamaemorus* | deciduous shrub | RUBCHA | cloudberry | yes |
| Salicaceae | *Salix* | *phlebophylla* | deciduous shrub | SALPHL | skeleton-leaf willow | yes |
| Salicaceae | *Salix* | *pulchra* | deciduous shrub | SALPUL | diamond-leaf willow | yes |
| Saxifragaceae | *Saxifraga* | *punctata* | forb | SAXPUN | heart-leaved saxifrage | yes |
| Scrophulariaceae | *Pedicularis* | *lapponica* | forb | PEDLAP | lousewart | yes |
| Scrophulariaceae | *Pedicularis* | *oederi* | forb | PEDOED | Oeder's lousewart | yes |
| Valerianaceae | *Valeriana* | *capitata* | forb | VALCAP | mountain heliotrope | yes |
| Asteraceae | *unknown* | *unknown* | forb | ASTER1 | succulent, lanceolate basal leaves | no |
| Asteraceae | *Senecio* | *atropurpureus* | forb | SENATR |  | no |
| Asteraceae | *Tephroseris* | *frigida* | forb | TEPFRI |  | no |
| Ericaceae | *Arctostaphylus* | *alpina* | deciduous shrub | ARCALP |  | no |
| Poaceae | Arctagrostis | latifolia | graminoid | ARCLAT |  | no |
| Poaceae | *unknown* | *unknown* | graminoid | POA1 | purple tip with few basal leaves (3-4) | no |
| Salicaceae | *Salix* | *reticulata* | deciduous shrub | SALRET |  | no |

# Appendix B: Example Data Sheets

## Individual Phenology Data Sheet:



## Community Phenology Datasheet:

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# Appendix C: Phenology Resources

1. USA National Phenology Network ([www.usanpn.org](http://www.usanpn.org))
2. University of California, Santa Barbara Phenology Stewardship Program- Phenology Handbook

(<http://www.ucsbphenology.christophercosner.com/The_Phenology_Handbook-Haggerty_Mazer_2008_v1.pdf>)

1. International Tundra Experiment (ITEX) (<http://www.geog.ubc.ca/itex/>)

Chapter 8: Plant Response Variables (<http://www.geog.ubc.ca/itex/PDFs/ITEXchapter8.pdf>); protocols are specific to the ITEX experiment, but has useful information on species growth and reproduction.