# TOS PROTOCOL AND PROCEDURE: PHE – PLANT PHENOLOGY

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# Change Record

| REVISION | DATE | ECO # | DESCRIPTION OF CHANGE |
|---|---|---|---|
| A_DRAFT | 10/03/2011 | ECO-00280 | Initial draft release |
| B_DRAFT | 01/10/2014 | ECO-01138 | Draft release, updates from field season |
| C | 03/25/2014 | ECO-01666 | Production release, template change, and other changes as detailed in Appendix C (rev C only) |
| D | 04/10/2014 | ECO-01792 | Updated Appendix E with site-specific information |
| E | 10/02/2014 | ECO-02334 | Migration to new protocol template |
| F | 02/24/2015 | ECO-02568 | Added three new growthForms, growthForm definitions, updated frequency table |
| G | 8/24/2015 | ECO-03047 | Protocol baseline. Removed phenophase codes throughout (except in Appendix), updated images, added measurement tolerances. Minor clarifications. |
| H | 2/09/2016 | ECO-03489 | Addressed error in Table B.1, added reference to foliar chemistry protocol for tissue collection. Clarified growth form definitions, clarified sampling triggers in Table 1. Updated colored leaves and colored needles phenophase descriptions and intensity question. |
| J | 03/06/2017 | ECO-04337 | Re-organized section 4.1 for clarity<br>Added Phenocam specific steps to SOP C<br>Added Appendix F: example sampling schedule at an arid site.<br>Added Appendix G: steps for dealing with phenocam plots that are constrained by site boundary<br>Specified thresholds of % of individuals transitioning phenophases to trigger frequency changes.<br>Added steps for selection and mapping of phenocam individuals.<br>Replaced diseaseStatus with plantStatus in annual data collection.<br>Added species, growth form, and sampling strategies to Appendix E.<br>Added option for larger patch size for woody species. |
| K | 03/16/2018 | ECO-05320 | Added new growth forms, evergreen broadleaf – no leaves, evergreen broadleaf – no leaf buds<br>Clarified measurement of % in patches<br>Removed reference to NEON WebUI<br>Clarified sampling interval for each specified frequency |

| REVISION | DATE | ECO # | DESCRIPTION OF CHANGE |
|---|---|---|---|
| | | | Added fulcrum app names to appropriate SOPs<br>Added phenocam GPS data folder location<br>Added term definitions for phenology db selectionStatus<br>Added new Appendix D scheduling table |
| L | 12/19/2018 | ECO-05944 | Reformatted Table of Contents<br>Removed obsolete RD for ATBD<br>Added description of scheduling for phenocam plots located in different sampling area from primary transect<br>Acknowledged that mid-season low frequency sampling may be skipped at sites with short growing season<br>added detail to table 3 contingent decisions for sampling delays<br>Re-organized SOP C<br>Added new procedure for selecting Phenocam individuals<br>Clarified that seasonal drop is optional and not appropriate for all scenarios<br>Added information about Field Observations vs. Ingest app load delays.<br>Updated error reporting instructions<br>Added references for MODIS datasets<br>Updated schedule dates for all sites utilizing MODIS data<br>Added field QA checklist to Appendix B<br>Added new species to Appendix E.<br>Added site specific Phase I and Phase II dates to Appendix E |
| M | 3/30/2021 | ECO-06522 | Partial move to new template<br>Revised Falling leaves phenophase definition, Appendix A<br>Added new Phase I/II schedule to Appendix C<br>Added Phase II species to Appendix D |

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# 1 OVERVIEW

## 1.1 Background

NEON plant phenology measurements record the seasonal progression of critical biological processes and the timing of ecological events. The NEON phenology measurements track sensitive and easily observed indicators of biotic responses to climate variability by recording and monitoring the timing and duration of phenological stages in plant communities. Phenology (a branch of science focused on relationships between climate and the seasonal timing of biological phenomena, such as bird migration and blooming dates) is one of the most sensitive and easily observed indicators of biotic response to climate variability. Plant phenology is affected by forces such as temperature, timing and duration of pest infestations and disease outbreaks, water fluxes, nutrient budgets, carbon sequestration, and food availability.

NEON employs status-based monitoring in which the phenological condition of an individual is reported any time that individual is observed. At every monitoring bout, records are generated for every phenophase that is occurring as well as for every phenophase not occurring. This approach is a departure from many historical phenological monitoring protocols, but has the advantage that events (such as leaf emergence in Mediterranean climates, or flowering of many desert species) that may occur multiple times during a single year, can be captured. Status monitoring also allows the explicit quantification of uncertainties in phenophase transition dates that are introduced by monitoring in discrete temporal bouts. Additionally, continuous reporting of phenophase status enables quantification of the duration of phenophases rather than just their date of onset.

## 1.2 Scope

This document provides a change-controlled version of Observatory protocols and procedures. Documentation of content changes (i.e. changes in particular tasks or safety practices) will occur via this change-controlled document, not through field manuals or training materials.

### 1.2.1 NEON Science Requirements and Data Products

This protocol fulfills Observatory science requirements that reside in NEON's Dynamic Object-Oriented Requirements System (DOORS). Copies of approved science requirements have been exported from DOORS and are available in NEON's document repository, or upon request.

Execution of this protocol procures samples and/or generates raw data satisfying NEON Observatory scientific requirements. These data and samples are used to create NEON data products, and are documented in the NEON Scientific Data Products Catalog (RD[03]).

## 1.3 Acknowledgments

This protocol is based largely on those defined by the USA National Phenology Network *(Denny et al. 2014)*; where pertinent (e.g., phenophase definitions, recommendations for marking plants), descriptive

material has been taken directly from their Nature's Notebook online monitoring program (www.usanpn.org/natures_notebook). The overall sampling framework was developed by the NEON plant phenology technical working group (AD[06]).

# 2 RELATED DOCUMENTS AND ACRONYMS

## 2.1 Applicable Documents

Applicable documents contain higher-level information that is implemented in the current document. Examples include designs, plans, or standards.

| | | |
|---|---|---|
| AD[01] | NEON.DOC.004300 | EHS Safety Policy and Program Manual |
| AD[02] | NEON.DOC.004316 | Operations Field Safety and Security Plan |
| AD[03] | NEON.DOC.000724 | Domain Chemical Hygiene Plan and Biosafety Manual |
| AD[04] | NEON.DOC.001155 | NEON Training Plan |
| AD[05] | NEON.DOC.050005 | Field Operations Job Instruction Training Plan |
| AD[06] | NEON.DOC.004104 | NEON Science Data Quality Plan |
| AD[07] | NEON.DOC.000907 | TOS Science Design for Plant Phenology |
| AD[09] | NEON.DOC.000912 | TOS Science Design for Plant Diversity |

## 2.2 Reference Documents

Reference documents contain information that supports or complements the current document. Examples include related protocols, datasheets, or general-information references.

| | | |
|---|---|---|
| RD[01] | NEON.DOC.000008 | NEON Acronym List |
| RD[02] | NEON.DOC.000243 | NEON Glossary of Terms |
| RD[03] | NEON.DOC.002652 | NEON Level 1, Level 2 and Level 3 Data Products Catalog |
| RD[04] | NEON.DOC.001271 | NEON Protocol and Procedure: Manual Data Transcription |
| RD[05] | NEON.DOC.001578 | Datasheets for TOS Protocol and Procedure: Plant Phenology |
| RD[06] | NEON.DOC.003282 | NEON Protocol and Procedure: Site Management and Disturbance Data Collection |
| RD[07] | NEON.DOC.000987 | TOS Protocol and Procedure: Measurement of Vegetation Structure |
| RD[08] | NEON.DOC.014042 | TOS Protocol and Procedure: Plant Diversity Sampling |
| RD[09] | NEON.DOC.001324 | Phenology quadrat assembly instructions |
| RD[10] | NEON.DOC.000987 | TOS Protocol and Procedure: Canopy Foliage Chemistry and Leaf Mass Per Area Measurements |
| RD[11] | NEON.DOC.003564 | NEON Standard Operating Procedure: Plant Voucher Specimen Preparation |
| RD[12] | NEON.DOC.001025 | TOS Protocol and Procedure: Plot Establishment |

## 2.3 Acronyms

| Acronym | Definition |
|---|---|
| DBH | Diameter at breast height (130 cm) |
| Ddh | Diameter at decimeter height (10 cm) |
| GPS | Global Positioning System |
| MDD | Main Drop Down (menu icon on GPS receiver) |
| SDD | Sub Drop Down (menu icon on GPS receiver) |

## 2.4 Definitions

**Cactus** - Any member of the family Cactaceae; plants typically have succulent stems and branches with scales or spines instead of leaves

**Deciduous broadleaf** (DBL)– Woody plants bearing flat leaves and dormant buds that are large enough to observe; leaves present during growing season then senesce and fall off during dormant periods (typically winter)

**Deciduous conifer** (DC)- Cone bearing trees; needles last through a single growing season then senesce and fall off during dormant periods

**Drought deciduous broadleaf** (DDB)- Dryland-adapted woody plants bearing flat leaves and dormant leaf buds that are too small to observe; leaves may be evergreen in most years or may regularly senesce and drop during dry periods; leaf tissue growth starts and stops opportunistically so a typical "full" leaf size is hard to identify

**Evergreen broadleaf** (EBL)- Woody plants bearing flat leaves; leaves may persist for multiple growing seasons, no distinct dormant period

**Evergreen broadleaf – no leaf buds** (EBL-NLB)- Woody plants bearing persistent flat leaves that lack dormant, leaf buds

**Evergreen broadleaf - no leaves** (EBL-NL)- Woody plants with no distinct dormant period; leaves may be inconspicuous, not present or leaf phenophase transitions are not easily observable and so are not reported

**Evergreen conifer** (EC) - Cone bearing plants where needles spread apart during stem elongation (unlike members of the genus *Pinus*); needles persist for multiple growing seasons

**Evergreen conifer – no needles** (EC) - Cone bearing plants, typically in the family Cupressaceae, that do not produce dormant overwintering buds and for which annual growth cannot be easily assessed.

**Evergreen forb** (EF) - Non-woody forbs with aboveground leaf or leaf-like structures that persist for multiple years

**Forb** - Annual, biennial, and perennial herbaceous flowering plants and sub-shrubs with no aboveground woody structures; typically die back to the ground in dormant periods

**Graminoid** (GRS) - Grasses and grass-like plants; includes all members of the families Poaceae (true grasses), Cyperaceae (sedges), and Juncaceae (rushes)

**Phenophase** - An observable stage or phase in the annual life cycle of a plant or animal that can be defined by a start and end point. (Definition from USA National Phenology Network)

**Pine** - Cone bearing plants of the genus *Pinus*; needles, bundled in sets of 1-6, spread apart after stem (candle) elongation; needles persist for multiple growing seasons

**Semi-evergreen broadleaf** (SEB) - Woody plants bearing flat leaves and dormant leaf buds that are large enough to observe; leaves are typically evergreen in mild climates but may senesce and drop leaves in more extreme climates or under stress conditions

## 3 METHOD

NEON Science will use analyses of site specific species abundance to determine target phenology species at each site. The strategy for phenology sampling is divided into two phases over the life of the Observatory. The first phase focuses on the phenology of dominant species and will last for the first three years of Observatory Operations (i.e., 2018-2020). Sites will transition to Phase II, community sampling in 2021 or after the site has completed three full years of observations, whichever is later (8Appendix C). Typically the first year of protocol implementation is only a partial year. Establishment will occur in the preceding year (2020, at many sites, see Appendix C for site specific dates) so that the first sampling year will be a full season.

**Phase I: Phenology of Dominant Species-**

- Three dominant species are selected at each site on the basis of a quantitative survey of the relative abundance of plant species in the tower airshed.
    - In sites with no overstory canopy, the three species with the greatest % cover shall be selected.
    - In sites with a distinct overstory, but <50% canopy closure, the single most abundant overstory species shall be selected along with the two most abundant understory species.
    - At sites with >50% canopy closure, the two most abundant overstory species shall be selected, along with the single most abundant understory species.

**Phase II: Community Phenology-**

- Up to 20 species are selected at each site based on a combination of relative abundance and research interest.The three dominant species from Phase I
- Any species present already targeted by an existing phenology monitoring network (USA-NPN) and
- According to relative abundance based on quantitative surveys of plant community in the tower airshed

Target species will be observed from multiple points along a fixed transect; observations will be made on either an individual plant (e.g., a single tree, shrub or bunch grass), or in the case of low growing

herbaceous species or dense continuous cluster of woody plants, on a representative patch of the target species (e.g., mat forming annual grasses, wild strawberry or salal thickets). In the first phase, a target of thirty replicates for each selected species shall be marked for regular observation. In the next phase, a more diverse suite of species will be monitored at each site with fewer replicates per species. In this phase the target number of species is 20 with 5 replicates each. In some cases, the total number of species monitored may be constrained by diversity at the site (e.g. in agricultural setting it is likely that only one species will be monitored at a time). The total number of individuals shall not exceed 100 and the replicates of any given species shall not exceed 30. The basic sampling protocol, however, will remain the same.

For sites where the tower phenocam field of view does not cover the phenology transect, NEON crews will select and mark an additional 3 individuals of each dominant species within the phenocam view in order to make explicit linkages between phenocam greenness metrics and *in situ* phenophase observations. In these cases, a secondary phenology plot will be established to the north of the tower, outside the required disturbance buffer zones but within the field of view of the phenocam; additional individuals will be selected for monitoring from within this designated area. Selection of additional individuals to monitor will occur once processed phenocam images become available (**Figure 1**).

The NEON plant phenology protocol consists of three procedures, which are assumed to begin following plot establishment (see RD[12]):

- Initial selection of individuals/patches for phenological monitoring (occurs twice/site for perennial plants, once/season for annual plants)
- Collection of phenology status per monitored individual/patch
- Collection of annual data (location, size) on monitored individuals

Refer to RD [07] for details on phenology transect delineation, placement of permanent markers and steps for annual establishment of the loop.

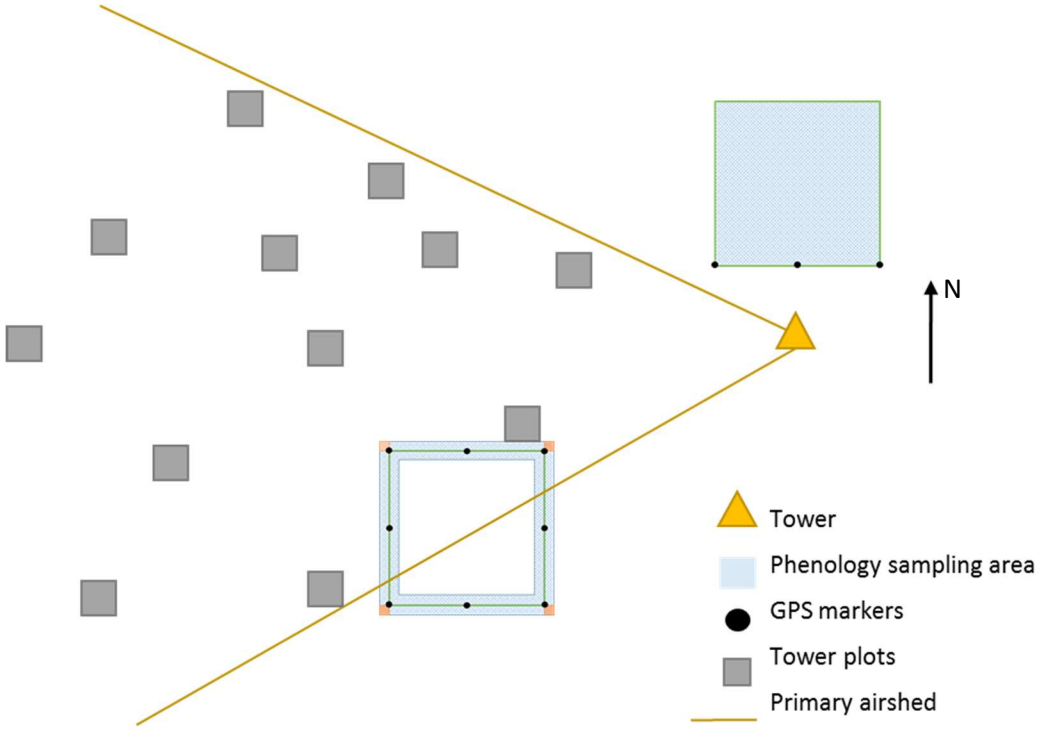



**Figure 1**. Generic site layout for plant phenology including the primary transect (lower left) and phenoCam plot (top right) in relation to Tower plots and primary airshed.

Standard Operating Procedures (SOPs), in Section 7 of this document, provide detailed step-by-step directions, contingency plans, sampling tips, and best practices for implementing this sampling procedure. To properly collect and process samples, field staff **must** follow the protocol and associated SOPs. Use NEON's problem reporting system to document and resolve any field issues associated with implementing this protocol.

The value of NEON data hinges on consistent implementation of this protocol across all NEON domains, for the duration of the project. It is therefore essential that field personnel carry out this protocol as outlined in this document. In the event that local conditions create uncertainty about carrying out these steps, it is critical that observers document the problem and enter it in NEON's problem tracking system.

Quality assurance is performed on data collected via these procedures according to the NEON Science Data Quality Plan (AD[06]).

# 4 SAMPLING SCHEDULE

## 4.1 Sampling Frequency and Timing

**Table 1**. Sampling frequency for Plant Phenology procedures on a per SOP per plot type basis.

| SOP | Plot Type | Plot Number | Bout Duration | Bouts Per Year | Bout Interval | Remarks |
|---|---|---|---|---|---|---|
| SOP B: marking the primary transect | Tower | 1-2 | 1 day | 1 x per site | Variable | Occurs 1x per plot per site. |
| | Distributed | NA | NA | NA | NA | Distributed and Gradient plots are not sampled for this protocol. |
| SOP C: Selecting individuals and patches | Tower | 1-2 | 1 day | 1 | 1 x | Occurs 1x per plot per phase if all species are perennial. Occurs every year or episodically if annual species monitored or management activities dictate. |
| SOP D: Collecting phenophase observations | Tower – Year round sampling | 1-2 | 2 hrs | ~ 50 | 1 w | |
| | Tower – Seasonal sampling | 1-2 | 2 hrs | ~ 50 | 2 d – 2 w | Frequency depends active phenophase. |
| | Tower – Hybrid | 1-2 | 2 hrs | ~ 50 | 2 d – 1 w | Year round sampling with adaptive frequency based on episodic periods of growth. |
| SOP E: Collecting annual data | Tower | 1-2 | 1 day | 1 | 1 y | |

All individuals/patches selected for phenology monitoring within a site will be monitored with the same frequency; the primary transect and the phenocam plot will be monitored on the same schedule unless the primary transect and phenocam plot are in different locations (i.e. not both near the NEON tower).

Sampling schedules will either be 1) year round, 2) seasonal, or 3) hybrid.

Year round sampling schedule. At sites with limited or no pronounced dormant season (e.g., tropical, southeast), or >1 growing season/year (e.g., desert southwest), observation bouts will occur throughout the entire year at a frequency of 1x/ week.

Seasonal sampling schedule. At sites with well-defined, discrete, growing seasons, the seasonal sampling frequency varies to capture rapid changes during phenological transition periods. The sampling season begins with at least one observation each year within 7 days prior to the onset of springtime activity (variably defined as breaking leaf buds, breaking needle buds, emerging needles, or initial growth; see column 2 in Table 2). Pre-season weekly sampling begins one to two weeks in advance of anticipated leaf/flower bud break, based on MODIS green up data or data from previous years' sampling at the site. Intensive sampling (3x/week in Phase I, 2x/week in Phase II) occurs in conjunction with the onset of springtime phenological activity and continues through the early spring development. Once >50% of leaf/canopy development has occurred sampling can be reduced to once a week until full canopy has developed. Post 95% canopy development, sampling is further reduced to once every other week until reproductive phenophases are complete. A second intensive stage (2x/week) begins with the first colored leaf or needle indicating seasonal senescence, and continues until all individuals show some sign of fall color change then reduces to once a week through the end of the season. It is not uncommon for sites with short growing season to skip mid-season low frequency sampling intervals because phenophase intensity triggers are not met.

Hybrid sampling schedule. Some sites, including arid or semiarid sites, driven by moisture rather than temperature, or sites where plants do not typically hit the seasonal frequency triggers, are particularly difficult to schedule in advance and do not progress in predictable fashion throughout the year. Such sites may be sampled according to a hybrid schedule. Sampling dates and frequency may be more episodic but sampling should have the same goal as the seasonal sampling schedule of increasing frequency during periods of rapid change, but are flexible to start and end sampling multiple times throughout the year. One example of a hybrid sampling schedule is starting with year round regular sampling (1x/week), increasing frequency during periods of growth, then dropping to <1x/week during dormant periods (see Appendix E for an example schedule from a semiarid site). The varied intensity is intended to strategically use sampling periods in order to monitor phases of rapid phenological change, while minimizing labor/disturbance associated with frequent measurements during times of less rapid change or inactivity and still targeting total number of bouts to 50 per year (Table 2). A hybrid sampling schedule requires greater flexibility to modify sampling schedule based on local conditions at the site.

Field ecologists are required to record phenological observations on all individuals, on both the primary transect and within the phenocam plot, each time monitoring is performed, unless the end-of-season phenophase/trigger has been reached for a particular individual (seasonal sampling schedule only), in which case, monitoring of that individual is not required for the remainder of the season.

Timing of monitoring bouts based on specified frequency is as follows:

- When sampling at 3x a week frequency, monitoring bouts should be separated by 1-2 days on which bouts are not scheduled. An ideal schedule for 3x/week sampling is Monday, Wednesday, Friday bouts.
- When sampling at 2x a week frequency, monitoring bouts should be separated by 2-3 days on which bouts are not scheduled. For example, if sampling 2x/ week, if first bout is on Monday, the next acceptable day to sample is Thursday or Friday.
- When sampling at 1x a week frequency monitoring bouts should be 6-9 days apart. Sampling on the same day each week during 1x/week frequency will achieve the appropriate interval.
- When sampling 1x every other week, monitoring bouts should be 10-18 days apart.
- Regardless of sampling frequency, bouts should not be conducted on consecutive days.

Sampling schedule is determined by Field Operations staff in coordination with Science, and is based on local conditions with consideration for the timing and annual patterns of plant growth at the site (**Error! Reference source not found.**).

At sites where the primary transect is not located in the Tower Airshed and is instead collocated with Distributed plots, it may not be practical to observe both the primary transect and individuals in the phenocam plot during the same field visit bout. In this scenario the schedule for each may be decoupled; conduct observation bouts on the primary transect as described above and make observations on the phenocam plot opportunistically when field ecologists are visiting the Tower or Tower Airshed for other activities (e.g. LAI measurements, or regular Tower maintenance).

#### 4.1.1 Priorities for scheduling observation bouts

6. Capture the entire growing season. – It is essential that within a given growing season, monitoring bouts begin *before* early season activity (breaking leaf buds, breaking needle buds, emerging needles, or initial growth) and continues until individuals/patches return to dormancy.
7. Increase observation frequency to capture leaf phenophase transitions. - High frequency bouts are targeted to capture transition dates and characterize rate of change for leaf development phenophases.
8. Capture timing of flower development. *Note: Flower buds that break before leaf buds do not trigger three times a week sampling frequency; in this situation, sampling frequency should be once a week until leaf bud break occurs.*

#### 4.1.2 Site specific modifications to prescribed sampling schedule

To keep phenology monitoring within logistical constraints, Field Operations staff should first select a sampling strategy that matches the site conditions (year round, seasonal or hybrid, see**Table 13**) then coordinate with Science to adjust schedule as needed to keep the total number of bouts to approximately 50 per year. Sites most at risk of exceeding the 50 bout target are those that have a seasonal sampling schedule and extended growing seasons or are observing species whose phenology do not align (i.e. leaf development occurs at different times in each species leading to extended periods

of increased frequency to capture spring transition). Whenever possible, observed phenology should be the driver of monitoring frequency, not absolute number of monitoring bouts, however the realities of resource limitations may, in some cases, require deviation from the frequency guidelines provided in this protocol.

The preferences for how to eliminate bouts if necessitated by logistics are as follows:

- Consider if year-round sampling is warranted (i.e. there is no clear dormant season)
- Eliminate mid-season bouts intended to capture open flower in order to prioritize capturing the full growing season
- Reduce 3x/week early season frequency to 2x/week

In Phase II, high frequency sampling drops from 3x/week to 2x/week to accommodate extended spring transitions for the increased number of species. Some sites switch from seasonal sampling to year round sampling in Phase II to accommodate an extended growing season resulting from the increased number of species.

**Table 2**. Rule sets for specific growth forms for phenology sampling at sites with a well-defined growing season (i.e. seasonal or hybrid schedules only)[1]

| Growth form | Monitor indicator individual for: | Sample 3x/week until all tagged individuals of a given species show[2, 3]: | Sample 1x/week until all tagged individuals of a given species show[3]: | Then[4]: | Then: | Sample 2x/week until all individuals show[5]: | Sample 1x/week until[3]: | Then: |
|---|---|---|---|---|---|---|---|---|
| **Cactus** | Breaking flower buds | NA | End sampling season when no more fresh flowers are present | NA | NA | NA | NA | NA |
| **Deciduous broadleaf** | Breaking leaf or flower buds[2] | >50% of canopy is full with leaves or three consecutive bouts of no change | 95% or more of canopy is full with leaves OR three consecutive bouts with no change | Commence every-other week monitoring for open flowers | Monitor indicator individuals for one or more colored leaves | One or more colored leaves | <5% of canopy full with green or colored leaves OR three consecutive bouts with no change | End sampling season |
| **Deciduous conifer** | Breaking needle buds | >50% of canopy is full with needles or three consecutive bouts of no change | 95% or more of canopy is full with needles OR three consecutive bouts with no change | Commence every-other week monitoring for open pollen cones | Monitor indicator individuals for one or more colored needles | One or more colored needles | <5% of canopy full with green or colored needles OR three consecutive bouts with no change | End sampling season |
| **Drought deciduous broadleaf** | Breaking leaf buds | Young leaves | No more young leaves | Commence every-other week monitoring for open flowers | Monitor indicator individuals for one or more colored leaves[6] | One or more colored leaves | <5% of canopy full with green or colored leaves OR three consecutive bouts with no change | End sampling season |

| Growth form | Monitor indicator individual for: | Sample 3x/week until all tagged individuals of a given species show[2, 3]: | Sample 1x/week until all tagged individuals of a given species show[3]: | Then[4]: | Then: | Sample 2x/week until all individuals show[5]: | Sample 1x/week until[3]: | Then: |
|---|---|---|---|---|---|---|---|---|
| **Evergreen Broadleaf** | Breaking leaf buds | Young leaves | No more young leaves | Commence every-other week monitoring for open flowers | End sampling season when no more fresh flowers are present | NA | NA | NA |
| **Evergreen Broadleaf – no leaf buds** | Young leaves | NA | No more young leaves | Commence every-other week monitoring for open flowers | End sampling season when no more fresh flowers are present | NA | NA | NA |
| **Evergreen broadleaf - no leaves** | Breaking flower buds | NA | End sampling season when no more fresh flowers are present | NA | NA | NA | NA | NA |
| **Evergreen conifer** | Breaking needle buds | Young needles | No more young needles | Commence every-other week monitoring for open pollen cones | End sampling season when no more fresh pollen cones are present | NA | NA | NA |
| **Evergreen conifer – no needles** | Pollen cone development | NA | End sampling season when no more fresh pollen cones are present | NA | NA | NA | NA | NA |
| **Evergreen forb** | Breaking leaf buds | Young leaves | No more young leaves | Commence every-other week monitoring for open flowers | End sampling season when no more fresh flowers are present | NA | NA | NA |

| Growth form | Monitor indicator individual for: | Sample 3x/week until all tagged individuals of a given species show[2, 3]: | Sample 1x/week until all tagged individuals of a given species show[3]: | Then[4]: | Then: | Sample 2x/week until all individuals show[5]: | Sample 1x/week until[3]: | Then: |
|---|---|---|---|---|---|---|---|---|
| **Forb** | Initial growth | One or more fully unfolded leaves | NA | Commence every-other week monitoring for flowering phenology | Monitor indicator individuals for evidence of senescence | NA | No more full sized leaves are present OR three consecutive bouts with no change | End sampling season |
| **Graminoid** | Initial growth | >50% of plant is green or three consecutive bouts of no change | >95% of plant is green OR three consecutive bouts with no change | Commence every-other week monitoring flowering phenology | Monitor indicator individuals for >5% Leaf senescence (i.e., percentage of plant that is green <95%) | <95% green leaves | <5% of plant is green OR three consecutive bouts with no change for ≥90% of individuals | End sampling season |
| **Pine** | Emerging needles or pollen cone development | Young needles | No young leaves | Commence every-other week monitoring for open cone | End sampling season when no more fresh pollen cones visible | NA | NA | NA |
| **Semi-evergreen broadleaf[7]** | Breaking leaf or flower buds[2] | Young leaves OR >50% of canopy is full with leaves OR three consecutive bouts of no change | No more young leaves OR 95% or more of canopy is full with leaves OR three consecutive bouts with no change | Commence every-other week monitoring for open flowers | Monitor indicator individuals for one or more colored leaves[5] | One or more colored leaves | <5% of canopy full with green or colored leaves OR three consecutive bouts with no change | End sampling season |

[1] This is an idealized sampling schedule and is generally applicable to temperate or boreal systems. Phenophase order may differ for some species or mid-season phenophases may be skipped completely at sites with short growing season if sampling reduction triggers are not met. Sites lacking a distinct growing season where growth occurs year-round or is episodic such that a growing season cannot be defined will be monitored on a weekly basis.

[2] If flowers/pollen release precede leaves in spring development, only increase sampling frequency to once a week until leaf bud break

[3] Sampling may end or frequency reduced if ≥90% of individuals have experienced 3 consecutive bouts of no change

[4] If flowering phenology precedes leaf/needle bud break and development skip the steps outlined in this column and decrease monitoring to watching indicator individuals for fall senescence or end monitoring for the season as specified in the following column.

[5] For sites with extended yet well-defined growing seasons, if increasing frequency just based on indicator individuals is likely to increase the total number of bouts to >50, the threshold for increasing frequency may be that 'once indicator individual displays trigger phenophase, commence 1x/week sampling until 10% of individuals of a given species on the transect transition, then increase to 2x/week sampling.

[6] Seasonal monitoring may end at this point if senescence does not occur.

[7] Semi-evergreen broadleaf growth form may be used for species in which life history varies with latitude. Growth Form assignment will be provided by Science, consistent with USA-NPN guidelines.

### 4.2 Criteria for Determining Onset and Cessation of Sampling

The date of onset, duration and date of cessation for phenology monitoring varies by site and is based on the expected phenology of plant species at the site (**Table 3**).

In order to estimate start of season for each individual monitored, the first 'yes' record for early season phenophases (initial growth, breaking buds, emerging needles) must be preceded by, at minimum, one 'no' record; therefore, sampling must begin at least seven days *prior to the onset of spring phenology*. Start of sampling will be determined by Field Operations personnel and will differ across the Observatory on a regional and site specific basis based on knowledge of the local flora and previous phenology data from the site. MODIS data in Appendix C**Error! Reference source not found.** provide the earliest recorded increase in NDVI; in the absence of data from previous sampling years, this date provides an estimate of the earliest day of the year when phenology monitoring may begin but should be augmented by observations made at the site (i.e., near the NEON tower) on individuals of the selected phenology species at the site, hereafter referred to as the 'indicator individuals.

The swelling of leaf buds and the separation of leaf bud scales will be monitored, throughout the dormant season, using the 'indicatordata' datasheet (RD[05]).Indicator individuals are monitored to help guide the start of seasonal sampling and to inform transition to fall monitoring frequency. There is no set frequency for monitoring indicator individuals, the only requirement is that indicator individuals must be capable of triggering monitoring of the primary transect such that a bout is completed *prior to phenophase transitions occurring on the transect* (i.e., one or more bouts of status='No' observations, for all individuals/patches, are recorded within 7 days of the first status='Yes'). One individual of each dominant species should be monitored opportunistically for phenological activity. Indicator individuals may be located near the NEON Tower or may be in a location demonstrating advanced phenology relative to individuals on the phenology transect; these individuals do not need to be tagged and data not recorded in the data collection mobile application but may be recorded on paper datasheets and maintained for internal tracking purposes. Regular phenology sampling begins when the indicator individuals display swelling leaf or flower buds and there is observable spreading of the leaf bud scales (if present). One strategy to address opportunistic monitoring for bud swell is to leverage regular tower maintenance visits; personnel responsible for maintaining the NEON tower would require cross-training on species identification and how to recognize swelling leaf or flower buds.

In temperate sites with defined growing seasons, sampling ends when all individuals reach the 'end sampling season' trigger (**Table 2**). Monitoring of graminoids and semi-deciduous growth forms that do not reach the < 5% live canopy trigger at the end of the growing season may end if ≥90% of individuals are monitored for three consecutive bouts with no observable change.

At sites with limited or no pronounced dormant season (e.g., tropical, southeast), or >1 growing season/year, sampling will take place year round. As such, there is no specified onset or cessation of sampling.

Onset and cessation of sampling at sites with variable or multiple periods of growth each year, sites with a hybrid sampling schedule, must be adaptable as timing will be determined by phenology and may not be limited to a pre-defined time of the year.

**Table 3**. Summary of onset and cessation criteria based on growing season.

| Growing season | Onset of sampling | Cessation of sampling | Special considerations |
|---|---|---|---|
| Well defined-Seasonal schedule | Prior to spring phenological activity, directed by MODIS NDVI data, observations of indicator individuals, or based on data from previous years at the site | All individuals reach the 'end sampling season' trigger is reached (Table 1) | Monitoring of graminoids and semi-deciduous growth forms that do not reach the < 5% live canopy trigger at the end of the growing season may end if ≥90% of individuals are monitored for three consecutive bouts with no observable change. |
| Year round schedule | No onset or cessation, observation bouts occur all year regardless of phenological activity. | | |
| Multiple or unpredictable periods of growth – Hybrid schedule | Observation bouts may occur episodically throughout the year based site specific drivers of phenological activity. | No specified 'end of season' trigger as growth periods may be episodic and occur multiple times in a given calendar year. | Bouts may be distributed as needed throughout the year, target total number of bouts is still 50 per calendar year |

### 4.3 Timing for Laboratory Processing and Analysis

This protocol produces no samples for laboratory analysis, so no timing details are provided.

### 4.4 Sampling Timing Contingencies

- If field conditions are unsafe, stop work, record location along the phenology loop and resume phenology measurements as soon as possible.
- If sampling must be completed on a different day, begin sampling again from the start point of the transect loop.

- If sampling must be delayed for several days such that 1 or more planned sampling bouts are missed, resume as soon as possible. Be especially mindful of missed phenophase transitions and determine sampling frequency based on the phenology occurring when monitoring resumes.

At many sites, disturbance is a major factor shaping plant communities. If there is a disturbance at a site that affects most or all of the phenology transect (e.g., fire that kills aboveground vegetation, unseasonal freeze event that kills developing leaf buds) and resets the phenology to pre-spring (dormant) status, record disturbance in the remarks field of the Phenophase Observations mobile application for the date and individuals on which the disturbance was observed then drop frequency down to low level, once a week or once every other week depending on severity and monitor for regeneration within the field season. Resume sampling frequency based on start of season guidelines (**Table 2**).

**Table 4**. Contingency decisions for Plant Phenology.

| Delay/ Situation | Action | Outcome for Data Products |
|---|---|---|
| 1 - 12 hours | Resume monitoring as soon as feasible from last sampled location along transect. | None |
| 12 hours – 2 days | Resume monitoring as soon as feasible from beginning of transect. | None |
| 2 days – 2 weeks | Resume monitoring as soon as feasible | Potential to miss phenophase transitions, increased uncertainty in estimate of transition dates |
| 2 weeks – 2 months | Resume monitoring as soon as feasible | Potential to miss multiple phenophase transitions, inability to estimate transition dates for missed phenophases |
| > 2 months | Suspend phenology monitoring for the year following discussion with Science | Estimation of transition dates for multiple phenophases for multiple species will not be possible |

### 4.5 Estimated Time

The time required to implement a protocol will vary depending on a number of factors, such as skill level, system diversity, environmental conditions, and distance between sample plots. The timeframe provided below is an estimate based on completion of a task by a skilled two-person team (i.e., not the time it takes at the beginning of the field season). Use this estimate as framework for assessing progress. If a task is taking significantly longer than the estimated time, a problem ticket should be

submitted. Please note that if sampling at particular locations requires significantly more time than expected, Science may propose to move these sampling locations.

**Table 5**. Estimated staff and labor hours required for implementation of Plant Phenology

| SOP | Estimated time | Suggested staff | Total person hours |
|---|---|---|---|
| *SOP C: Selecting, Marking and Mapping Individuals/patches – Initial Phase I/II establishment* | *8 h* | *2* | *16 h* |
| *SOP C: Selecting, Marking and Mapping Annual re-establishment* | *4 h* | *2* | *8 h* |
| *SOP D: Collecting Phenophase Observations* | *2 h* | *2* | *4 h* |
| *SOP E: Collecting Annual Structure Data* | *4 h* | *2* | *8 h* |

## 5 SAFETY

This document identifies procedure-specific safety hazards and associated safety requirements. It does not describe general safety practices or site-specific safety practices.

Personnel working at a NEON site must be compliant with safe field work practices as outlined in the Operations Field Safety and Security Plan (AD[02]) and EHS Safety Policy and Program Manual (AD[01]). Additional safety issues associated with this field procedure are outlined below. The Field Operations Manager and the Lead Field Technician have primary authority to stop work activities based on unsafe field conditions; however, all employees have the responsibility and right to stop their work in unsafe conditions.

### 5.1 Laser Rangefinder Safety

A laser rangefinder/hypsometer/compass instrument is used to map individuals selected for phenology monitoring, and to measure various stem structural attributes. Safety considerations for this instrument include:

- Avoid staring directly at the laser beam for prolonged periods. The rangefinder is classified as eye-safe to Class 1 limits, which means that virtually no hazard is associated with directly viewing the laser output under normal conditions. As with any laser device, however, reasonable precautions should be taken in its operation. It is recommended that you avoid staring into the transmit aperture while firing the laser.

- Never attempt to view the sun through the scope. Looking at the sun through the scope may permanently damage the eyes.

### 5.2 Cactus Safety

The potential for injury exists when working with cacti due to the prevalence of spines. As a simple precautionary measure, avoid making contact with cacti. Always wear personal protective equipment such as leather boots, long pants, long sleeves, and gloves, and remain cognizant of where you walk.

Most cactus-inflicted wounds should be treated like any other scratch or puncture, that is, cleaned then bandaged if necessary. Use a comb, tweezers, or adhesive to pick out spines that break off in the skin prior to treating the affected area.

Glochids that penetrate the skin may be difficult to extract because of their barbed shafts. To remove glochids, use tweezers or adhesives. Treat any remaining glochids as a wound, keep the area clean and covered to prevent dermatitis.

Segments of *Cylindropuntia* species break off easily and may become attached to footwear, clothing, or skin. To remove segments, use a comb or other solid object (i.e. Leatherman, rocks, etc.) to dislodge the segment. Symbiotic bacteria living on cactus spines may cause inflammation, which typically subsides without treatment within a few days.

# 6 PERSONNEL

## 6.1 Training Requirements

All technicians must complete required safety training as defined in the NEON Training Plan (AD[04]). Additionally, technicians must complete protocol-specific training for safety and implementation of this protocol as required in Field Operations Job Instruction Training Plan (AD[05]). Protocol training includes classroom and field instruction and activities. Assessment entails demonstrated understanding of procedures through written and observation-based evaluation.

## 6.2 Specialized Skills

Ability to identify regionally specific plants on sight or with a dichotomous key is required for the field ecologist who initially sets up the phenology loop and provides instruction and training to seasonal staff. Once individuals/patches to monitor have been selected and marked and a taxa-specific library of phenophase photos has been developed for each site, individuals without botany training can conduct surveys provided they are trained by a qualified trainer and that a botany lead is available to provide guidance and conduct periodic QA/QC checks in the field and of photos.

All staff conducting phenology observations must be able to recognize all applicable phenophases for species being monitored.

If no member of the field crew is able to identify individuals while they are dormant, contracts with a local botanist to identify and mark individuals for phenological sampling may be employed.

At least one field crew member is required to have hands-on training with the Trimble GPS receiver, TerraSync software, and GPS Pathfinder Office software.

# 7 STANDARD OPERATING PROCEDURES

## SOP Overview

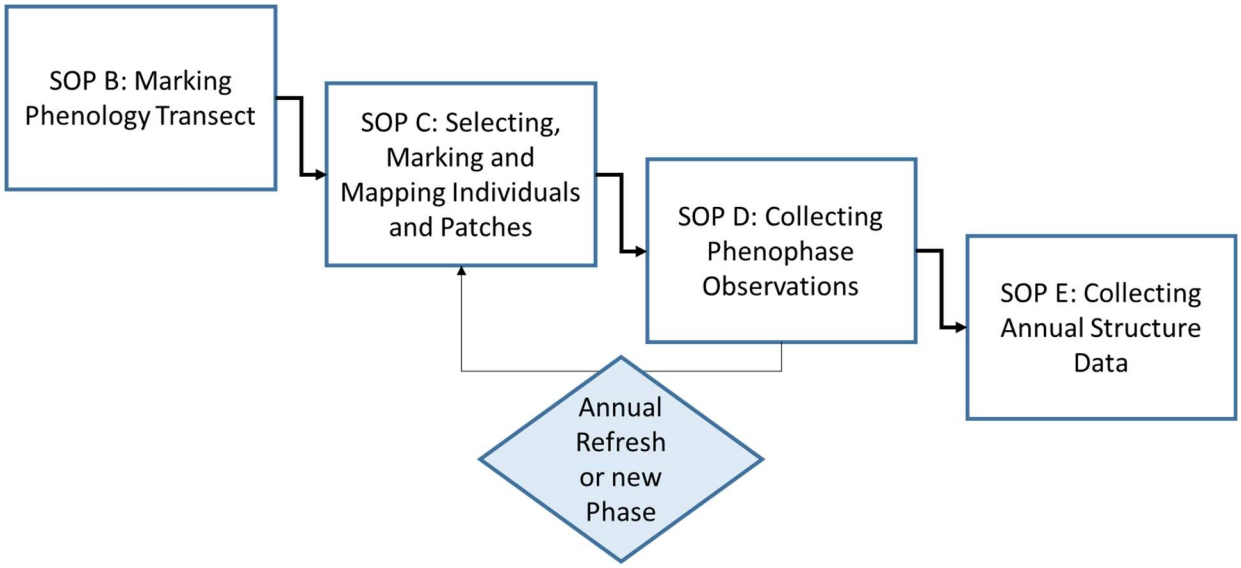



**Figure 2**. A high level workflow diagram that visually shows how the separate SOPs are sequentially connected.

SOP A: Preparing for sampling – Includes tasks to complete in the domain support facility prior to samplingSOP B: Marking phenology transect – Procedure for delineating and placing markers along phenology transect

SOP C: Selecting, Marking and Mapping Individuals and Patches – Procedure for selecting individuals/patches and mapping relative locations

SOP D: Collecting Phenophase Observations – Steps for conducting regular observation bouts

SOP E: Collecting Annual Structure Data – Measurements of size and health of individuals/patches

SOP F: Data Entry and Verification - Bout completion and QC follow up tasks completed at the domain support facility following field activities

## SOP A Preparing for Sampling

### A.1 Preparing for Data Capture

Mobile applications are the preferred mechanism for data entry. Mobile devices should be fully charged at the beginning of each field day, whenever possible.

However, given the potential for mobile devices to fail under field conditions, it is imperative that paper datasheets are always available to record data. Paper datasheets should be carried along with the mobile devices to sampling locations at all times.

Prior to each field season, review pre-selected species for each site (**Error! Reference source not found.**).

### A.2 Preparing for selecting individuals

Initial species selection is based on characterization surveys completed in advance of regular sampling at each NEON site. Characterization data are used to create a list of species present at the site, ranked by relative abundance. This list is used to select species for phenology observation, and will be available either in a mobile application or via a database stored on NEON's internal server. Phase I species (3 dominant species) will be monitored from initial establishment of the transect at a site until 3 years into the Operations phase of the Observatory; phase II species (n <=20 total) will then be added and the number of replicate individuals per species will be reduced (typically n=5, see AD[06] for additional detail).

1. If selecting individuals for the first time for either Phase I or Phase II sampling at a site, sync the 'Phenology DB' application on the mobile digital device that will be used in the field so the list of prioritized species is available:
    a. Refer to the National Phenology Network Species List in the Sampling Support Library (SSL) for growth form assignment of all species already monitored in the NPN network, or load this list to your mobile device for reference if needed
2. If mapping selected individuals within the phenocam plot, set up GPS receiver for collecting points. GPS collection will be a onetime event over the lifetime of the selected individual.
    a. Set up the Trimble GPS receiver following steps outlined in Appendix B in the Plot Establishment Protocol (RD[12])
    b. Import the "Phenocam_individuals.ddf" data dictionary following steps in A.4 (RD[12])
        i. The Phenocam data dictionary will be available in the N:\Science\GISData\FOPS\DataDictionaries folder
3. In order to provide field linkages with the phenocam on the tower the phenocam plot is always placed within the phenocam field of view regardless of the site boundary.
    a. Check Appendix F to see if a portion of the phenocam plot falls outside of the site boundary and whether a different workflow is required to ensure phenocam individuals are selected in the permitted area.

### A.3 Review species specific resources, gather necessary equipment

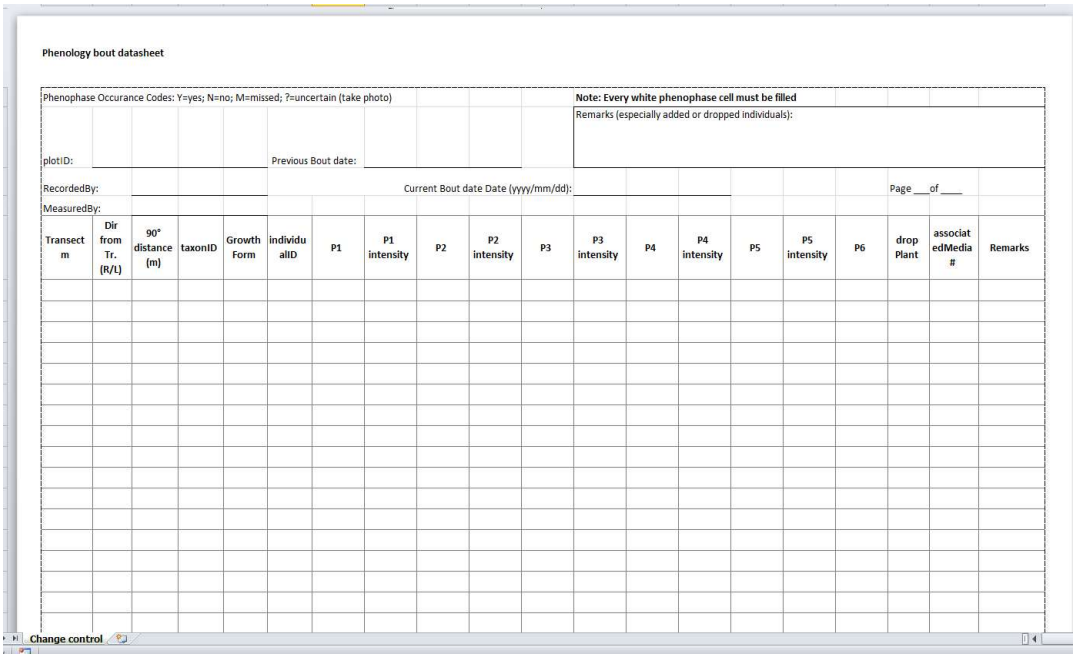
Prior to each data collection bout locate sampling equipment. If the site has species that will be monitored in 0.25 m x 0.25 m patches, and this is the first sampling bout or selection of individuals bout, you will need to construct a sampling quadrat (RD[09]). If the site has species that will be monitored in 1 m x 1 m patches, use the sampling frame from RD[08] for establishment and monitoring of patches of woody species. Familiarize yourself with the phenophase definitions (**Error! Reference source not found.**) and domain/species specific photos contained in internal reference materials. Bringing photos with you to the field is advised for all staff.

### A.4 Pre-populate Paper Datasheets

If a mobile digital device with a phenology app is not available for field data collection, pre-populate paper data sheets to streamline phenology observations. Pre-populate datasheets with individual location, tagID, species and growth form, and format data fields to constrain data entry based on the growth form of the individual/patch being observed. Datasheets should be organized sequentially according to location along transect, in the order that the transect will be sampled. This is only possible for sampling bouts that occur after the initial selection of individuals.

***Note:*** *Pre-populating datasheets is only an option if perindividual data entry has already occurred and a .csv of entered data is available for download.*

- Open the .xls datasheet for Phenology (RD[05])



Phenology bout datasheet

Phenophase Occurance Codes: Y=yes; N=no; M=missed; ?=uncertain (take photo)

Note: Every white phenophase cell must be filled

Remarks (especially added or dropped individuals):

plotID: Previous Bout date:

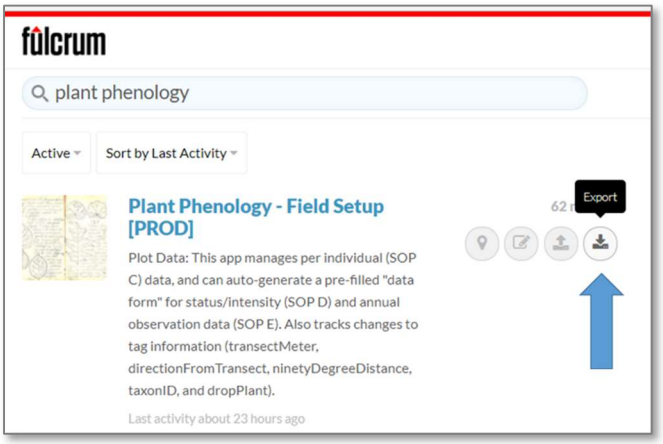
RecordedBy: Current Bout date Date (yyyy/mm/dd): Page ___of ___

MeasuredBy:

| Transect m | Dir from Tr. (R/L) | 90° distance (m) | taxonID | Growth Form | individualID | P1 | P1 intensity | P2 | P2 intensity | P3 | P3 intensity | P4 | P4 intensity | P5 | P5 intensity | P6 | drop Plant | associatedMedia # | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | | | | |

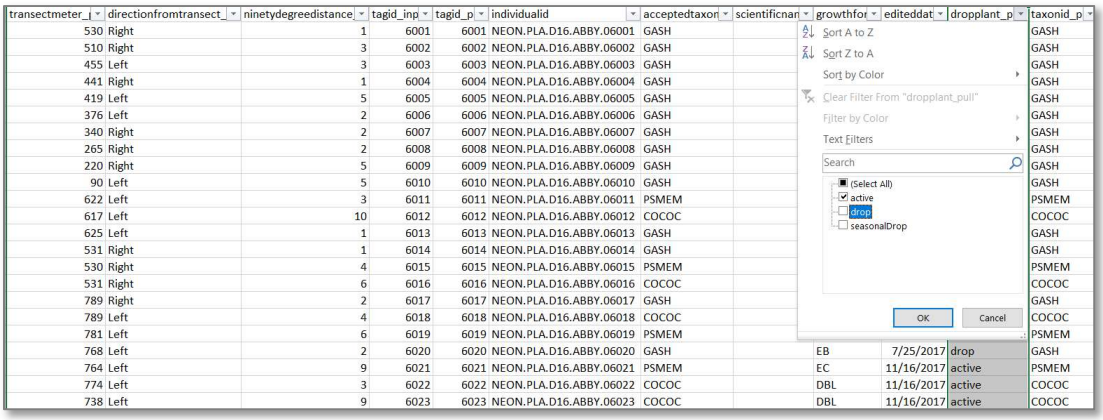
Change control

9. Download .csv of records for the target siteID, from the 'Plant Phenology - Field Setup [PROD]' using the download feature on the main page of the fulcrum desktop application.




10.

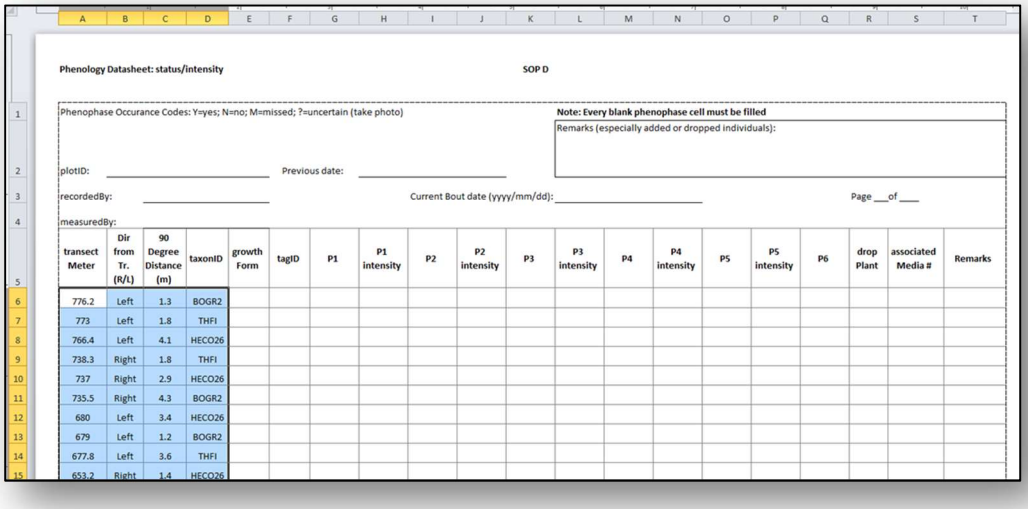
11. Open the file labeled 'plant_phenology_field_setup_prod_children_pertag.csv ' from the downloaded zip file. Filter records to **dropplant_pull** = 'active'




12. Copy fields:

- transectMeter
- directionFromTransect
- ninetyDegreeDistance
- Species Code (taxonID)
- tagID

13. Paste (values only) into corresponding fields in datasheet



Phenology Datasheet: status/intensity — SOP D

Phenophase Occurance Codes: Y=yes; N=no; M=missed; ?=uncertain (take photo)

Note: Every blank phenophase cell must be filled

Remarks (especially added or dropped individuals):

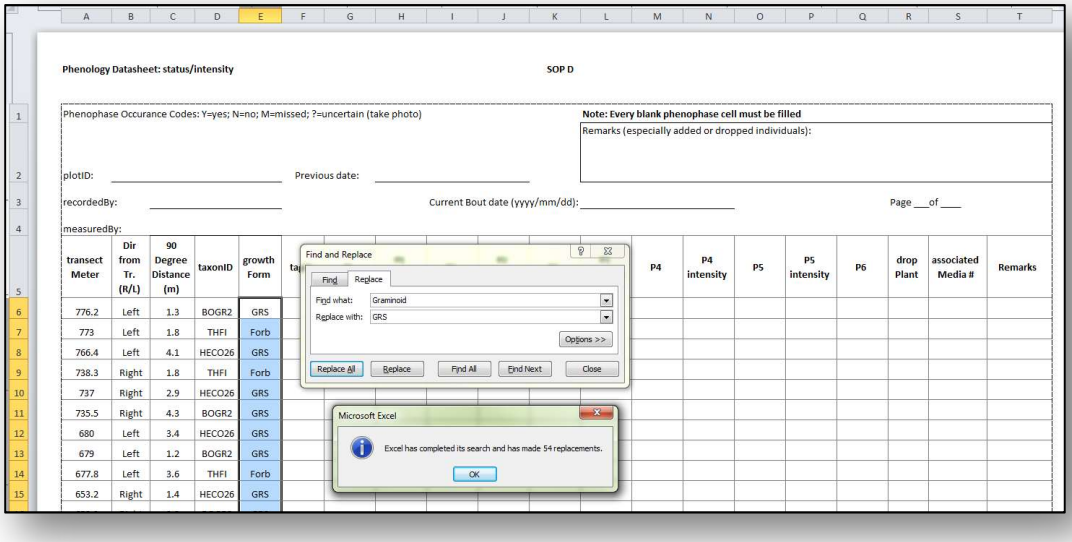
plotID: _____ Previous date: _____

recordedBy: _____ Current Bout date (yyyy/mm/dd): _____ Page ___of___

measuredBy:

| transect Meter | Dir from Tr. (R/L) | 90 Degree Distance (m) | taxonID | growth Form | tagID | P1 | P1 intensity | P2 | P2 intensity | P3 | P3 intensity | P4 | P4 intensity | P5 | P5 intensity | P6 | drop Plant | associated Media # | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 776.2 | Left | 1.3 | BOGR2 | | | | | | | | | | | | | | | | |
| 773 | Left | 1.8 | THFI | | | | | | | | | | | | | | | | |
| 766.4 | Left | 4.1 | HECO26 | | | | | | | | | | | | | | | | |
| 738.3 | Right | 1.8 | THFI | | | | | | | | | | | | | | | | |
| 737 | Right | 2.9 | HECO26 | | | | | | | | | | | | | | | | |
| 735.5 | Right | 4.3 | BOGR2 | | | | | | | | | | | | | | | | |
| 680 | Left | 3.4 | HECO26 | | | | | | | | | | | | | | | | |
| 679 | Left | 1.2 | BOGR2 | | | | | | | | | | | | | | | | |
| 677.8 | Left | 3.6 | THFI | | | | | | | | | | | | | | | | |
| 653.2 | Right | 1.4 | HECO26 | | | | | | | | | | | | | | | | |

14. Copy/paste (values only) **growthForm** into the datasheet. Use the find/replace (Ctrl + h) function to convert growth form names to code (optional).



Phenology Datasheet: status/intensity — SOP D

Phenophase Occurance Codes: Y=yes; N=no; M=missed; ?=uncertain (take photo)

Note: Every blank phenophase cell must be filled

Remarks (especially added or dropped individuals):

plotID: _____ Previous date: _____

recordedBy: _____ Current Bout date (yyyy/mm/dd): _____ Page ___of___

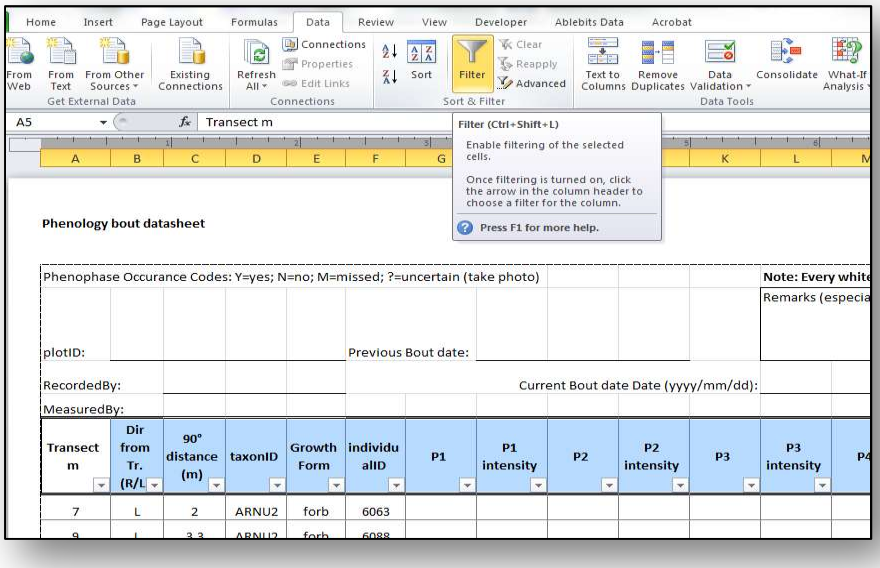
measuredBy:

| transect Meter | Dir from Tr. (R/L) | 90 Degree Distance (m) | taxonID | growth Form | P4 | P4 intensity | P5 | P5 intensity | P6 | drop Plant | associated Media # | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 776.2 | Left | 1.3 | BOGR2 | GRS | | | | | | | | |
| 773 | Left | 1.8 | THFI | Forb | | | | | | | | |
| 766.4 | Left | 4.1 | HECO26 | GRS | | | | | | | | |
| 738.3 | Right | 1.8 | THFI | Forb | | | | | | | | |
| 737 | Right | 2.9 | HECO26 | GRS | | | | | | | | |
| 735.5 | Right | 4.3 | BOGR2 | GRS | | | | | | | | |
| 680 | Left | 3.4 | HECO26 | GRS | | | | | | | | |
| 679 | Left | 1.2 | BOGR2 | GRS | | | | | | | | |
| 677.8 | Left | 3.6 | THFI | Forb | | | | | | | | |
| 653.2 | Right | 1.4 | HECO26 | GRS | | | | | | | | |

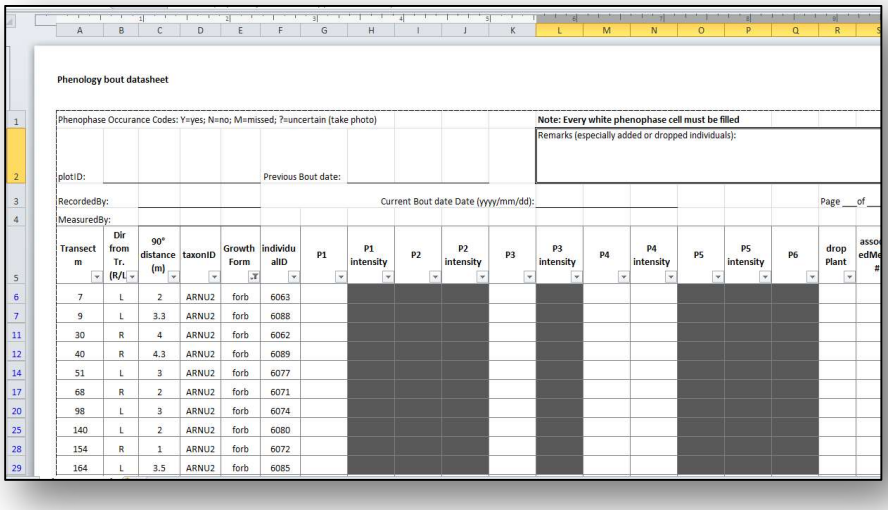


15. Double check that all columns are properly aligned and that the location information matches the individual ID

16. Add filters to the datasheet
    - Highlight the row containing field names
    - In the 'Data' tab click filter, arrows will appear next to field names

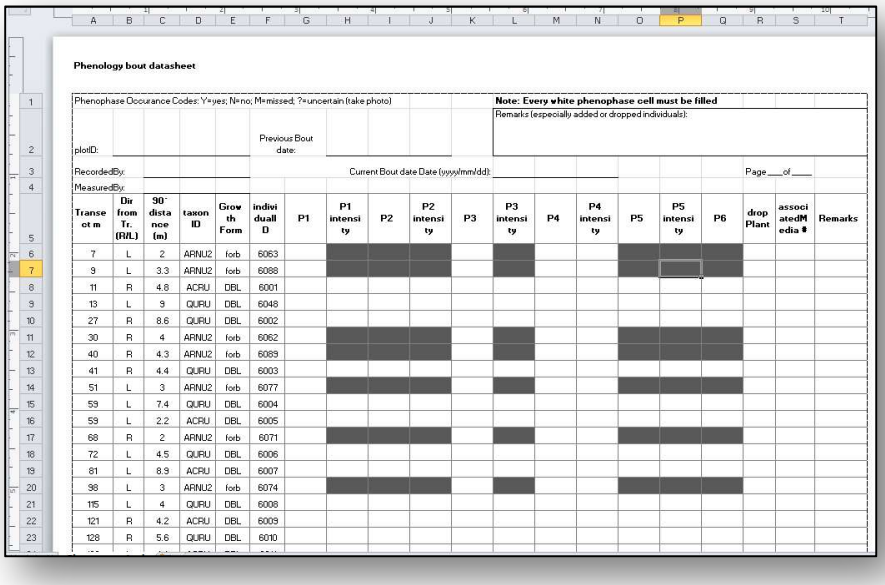



17. Filter by **growthForm**, select one **growthForm** at a time
18. Shade in cells for all phenophases which are not required for that **growthForm** (summary table available in Appendix A)




19. Repeat this process for all **growthForm**s

20. Un-filter **growthForm**s so that all are displayed



Phenology bout datasheet

Phenophase Occurance Codes: Y=yes; N=no; M=missed; ?=uncertain (take photo)

Note: Every white phenophase cell must be filled

Remarks (especially added or dropped individuals):

plotID: Previous Bout date:

RecordedBy: Current Bout date Date (yyyy/mm/dd): Page ___of___

MeasuredBy:

| Transect m | Dir from Tr. (R/L) | 90° distance (m) | taxon ID | Growth Form | individual ID | P1 | P1 intensity | P2 | P2 intensity | P3 | P3 intensity | P4 | P4 intensity | P5 | P5 intensity | P6 | drop Plant | associatedMedia # | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 | L | 2 | ARNU2 | forb | 6063 | | | | | | | | | | | | | | |
| 9 | L | 3.3 | ARNU2 | forb | 6088 | | | | | | | | | | | | | | |
| 11 | R | 4.8 | ACRU | DBL | 6001 | | | | | | | | | | | | | | |
| 13 | L | 9 | QURU | DBL | 6048 | | | | | | | | | | | | | | |
| 27 | R | 8.6 | QURU | DBL | 6002 | | | | | | | | | | | | | | |
| 30 | R | 4 | ARNU2 | forb | 6062 | | | | | | | | | | | | | | |
| 40 | R | 4.3 | ARNU2 | forb | 6089 | | | | | | | | | | | | | | |
| 41 | R | 4.4 | QURU | DBL | 6003 | | | | | | | | | | | | | | |
| 51 | L | 3 | ARNU2 | forb | 6077 | | | | | | | | | | | | | | |
| 59 | L | 7.4 | QURU | DBL | 6004 | | | | | | | | | | | | | | |
| 59 | L | 2.2 | ACRU | DBL | 6005 | | | | | | | | | | | | | | |
| 68 | R | 2 | ARNU2 | forb | 6071 | | | | | | | | | | | | | | |
| 72 | L | 4.5 | QURU | DBL | 6006 | | | | | | | | | | | | | | |
| 81 | L | 8.9 | ACRU | DBL | 6007 | | | | | | | | | | | | | | |
| 98 | L | 3 | ARNU2 | forb | 6074 | | | | | | | | | | | | | | |
| 115 | L | 4 | QURU | DBL | 6008 | | | | | | | | | | | | | | |
| 121 | R | 4.2 | ACRU | DBL | 6009 | | | | | | | | | | | | | | |
| 128 | R | 5.6 | QURU | DBL | 6010 | | | | | | | | | | | | | | |

21. Remove filters from field names
22. Sort by **transectMeter** so that individuals are organized as they occur sequentially along the transect
23. Save datasheet to local drive
24. Print datasheets
25. Update as necessary as individuals are added/dropped

## SOP B Marking Phenology Transect

### B.1 Establishing the transect

Phenology observations occur along an 800 meter loop transect within the tower airshed. Primary markers are placed at the SW and NE corners of the transect, secondary markers are placed every 100 meters along the transect. Plot establishment for plant phenology (RD[12]) must be completed prior to or concurrently with this procedure.

- **Navigate** to the permanent plot marker at the southwest corner; this is the plot origin (meter 0).
- Use GPS and plot markers to locate the 100 meter **secondary marker** in the clockwise direction (begin by walking north from the SW corner) along the transect.
- **Stretch a 100 meter tape** between each point. Use chaining pins or similar stake at each end to hold the tape in place.
- **Place a pin flag** (or other marker as appropriate for site specific conditions or site host preference) every ten (10) meters along the tape. If visibility is limited such that pin flags are not visible at 10 meter intervals, place flags at shorter distances. Over the course of the season a path will likely develop and extra pin flags may be removed if they are no longer necessary. Use pin flags that differ in color from those used to mark other tower plots to provide a visible, reproducible path to walk while monitoring phenophases.

**Note:** Due to topography of the transect or drift in the tape caused by vegetation and wind, the distance measured between permanent markers may not be exactly 100 meters. In this case, anchor first to one marker location, stretch the tape between the two points, divide the resulting number by 10 and use that value to guide incremental placement of pin flags within that stretch of transect. For example if the distance measured between point A and point B = 110 m, spacing between pin flags will be 11 m rather than 10 m. Because of the precision of point placement required during initial plot establishment, when there is disagreement between markers and tape, priority goes to the placement of markers and the difference is averaged across that stretch of the transect.

- **Write the transect distance/location information** (e.g., 10 m, 20 m…780 m 790 m) with a permanent marker on each pin flag numbered 0-790 in increments of 10 meters.
- While marking the transect, **replace** any faded, broken or missing plant cards, marking 0.25 m x 0.25 m patches to facilitate easy location of previously marked individuals/patches.
- Use flagging to mark an **access route** to the phenology sampling loop outside of the site-specific tower and soil array buffer area. Field staff must use the designated route when accessing the phenology loop to reduce trampling damage within the tower airshed.

- Select a **sampling start point**, this is the corner nearest to the transect access route and will be the location where sampling bouts will begin. This does not have to be the SW corner.

## SOP C Selecting, Marking, and Mapping Individuals and Patches

### C.1 Preparing for Data Capture

Mobile applications are the preferred mechanism for data entry.

Data for recording location information for new individuals are entered in the 'Plant Phenology - Field Setup [PROD]' fulcrum application. This application is used to auto-generate available individuals in the observation and annual applications.

Before going to the field:

- Double check that mobile devices are charged and synched
- Double check that GPS units are fully charged and have appropriate files loaded
- If selecting phenocam individuals:
    - Request phenocam IP addresses from the lead Tower Instrumentation Field Ecologist
    - Print historic phenocam images from a range of seasons for reference while in the field
    - Determine the season with the greatest visibility through existing vegetation during which species identification is also possible.
    - Determine whether Phase I species and identifiable individuals are present within the viewshed of the phenocam.
    - If the community composition of the phenocam plot differs from the primary transect, identify which species may be viable alternatives, submit a problem ticket Science.

Given the potential for mobile devices to fail under field conditions, it is imperative that paper datasheets are always available to record data. Paper datasheets should be carried along with the mobile devices to sampling locations at all times.

### C.2 Primary Transect – Selecting Individuals/patches

Selection of individuals for phenology monitoring occurs after annual establishment of the phenology transect (SOP B). Though transect establishment and plant selection (SOP C) may be completed on the same day, they should not be completed concurrently. To ensure data quality, complete SOP B in its entirety before moving on to SOP C. Use the 'Plant Phenology - Field Setup [PROD]' digital app or the 'Selection Datasheet' to record data from this SOP.

A list of species and the target number of individuals selected for phenology monitoring will be provided via the 'Phenology DB' mobile application for each phase of phenology monitoring. These lists are developed based on a quantitative survey of plant species and abundance within the Tower airshed. The lists provided by Science are ordered by priority for selection and will include extra 'contingency' species. Species must be considered in the order they are ranked and may only be skipped or rejected for the following reasons:

- **Skipped –** not qualified for inclusion in this protocol
    - The record is for a fern, fern ally, or non-vascular species

  - The record is not to species level resolution (i.e., genus or lower)
- **Rejected –** temporarily not selected for sampling
  - The species is not present on the transect in sufficient numbers for monitoring
  - The species is an overstory species and all required overstory species have already been selected
  - The species is an understory species and all required understory species have already been selected
  - There are 'special circumstances' (e.g., the most abundant species are all from the same genus), and a problem ticket has been submitted.

If a species is skipped or rejected, record **selectionStatus** = "skipped", "rejected Phase I", or "rejected Phase II" and record the reason for not selecting the individual in the **Reason Plant Not Selected** field in the application, then consider the next ranked species on the list. All species rejected for Phase I sampling will be reconsidered for Phase II species selection

Phase II species are selected to include:

- the three dominant species from Phase I
- any species present already targeted by an existing phenology monitoring network (USA-NPN or Project BudBurst) and
- selection from remaining species, ordered by relative abundance. If during initial selection, a target species is not present on the transect for monitoring, move to the next species on the list.

State and Federally recognized Threatened and Endangered (T&E) species will not be selected for phenology monitoring as locality information about these species cannot be made publicly available. T&E species will be stripped from the list of species considered for phenology monitoring, however if any are unintentionally included on the prioritized list of species, these should automatically be skipped, regardless of their presence/abundance on the transect. Record the rationale for skipping as 'The record is too low taxon resolution (i.e., genus or lower)', these records will fuzzed before being published.

Ferns, fern allies and non-vascular species will also be removed from consideration as distinct phenophases have not been defined for these growth forms.

With the identified priority species in mind:

1. Walk the entire phenology loop to **observe the vegetation patterns** along the transect. This must be done by a field ecologist familiar with local flora. Make notes in the field notebook about how the species chosen for phenology monitoring are spaced (i.e., where there are clusters of individuals and where there are gaps) along the transect.
2. Walk the phenology loop transect a second time and select individuals to monitor following the generalized criteria for selection:

- **Health Criteria – Choose individuals/patches that:**
  - Phase I: Represent the average health for that species at the site

- Phase II: Appear healthy enough to be expected to survive for the foreseeable future
- Appear to be healthy, undamaged, and free of pests and disease (except in cases where the majority of individuals of that species at a site are affected by the disease).
- If diseased, pick individuals that are representative of the disease status of the majority of the population.

- **Size Criteria:**
  - Choose plants that represent a range of size classes.
  - For species monitored in patches, select the densest patches available along the transect.
  - Include a diversity of sizes if more than a single individual is available within the target zone.
  - Select individuals that are mature enough they are likely to survive, i.e., do not select seedlings or, if the management at the site includes prescribed burning, do not select individuals not likely to survive a typical burn.
  - For woody species that occur in continuous thickets such that it is not practical to select a single stem or distinct group to observe, establish 1 m x 1 m patch observation points.

- **Location Criteria:**
  - Choose individuals that are visible from the transect that may be observed without leaving the transect (consider visibility at peak green)
  - Target individuals that are
    - Between 1 and 10 m from the transect
    - More than 10 m from roads or buildings
  - Prioritize individuals for monitoring that are included in productivity sampling, if feasible.
  - Only select individuals that may be monitored from the transect and without excessive trampling of the productivity plots.
  - Reduce total sampling time (i.e., stops along the loop) by selecting collocated groups of individuals of different species.
  - Sample individuals of same species from alternating sides of the phenology loop at alternating sample points.
- **Distribution Criteria:**
  - Individuals of a single species should be more or less evenly distributed around the phenology loop.
  - There should be about 24 meters between the thirty, evenly spaced, individuals/patches of a single species for Phase I monitoring.
  - If it is not possible to find individuals that are evenly spaced around the transect, it is acceptable to select groups of more closely spaced individuals.

- **Annual and Biennial Criteria:**
  - For annuals, select a 0.25 m x 0.25 m patch (rather than an individual).
    - Avoid locations where selected patch is likely to be trampled accessing other phenology individuals or by field staff implementing other sampling protocols.

- 1 m x 1 m patch size should only be used for perennial, woody, species, do not select this patchSize for herbaceous species.

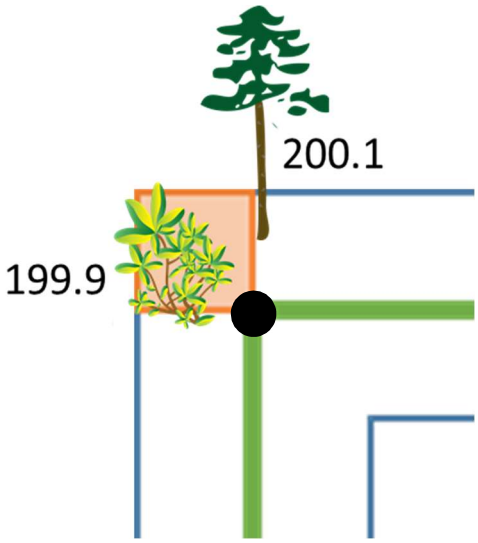
- For biennials, avoid choosing the first or the last seedling to emerge in the spring since they may not be representative of the larger population at the site.
- If at all possible, avoid using patches to observe perennial species, consistent assessment of phenophase intensity is more difficult on patches than on individuals.

### C.3 Primary Transect - Mapping location of selected individuals/patches

Coordinates for each individual/patch will be calculated from the relative position along the transect, utilizing the permanent markers.

1. Measure and record (RD[05]- perindividual):
   - **transectMeter** – the location along the transect (0-**799** m) at which the individual is perpendicular; meter 0=SW corner, 200=NW, 400=NE, 600=SE. Use the permanent markers or labeled flags and tape**,** or the laser rangefinder **in HD mode** (preferred method) to determine the transect meter. The tolerance for transectMeter is +/- 2m along the transect to account for topography and distance from the nearest GPS point that may make greater precision difficult at some locations.

***Note:*** *if transectMeter = 0, 200, 400, or 600 AND directionFromTransect = Left, that is, if the individual/patch is to the outside of one of the transect corners, a decimal point must be included to indicate which side of the corner the individual/patch is measured from (e.g., 199.9/L ok; 200.01/L ok; 200/L not ok). If directionFromTransect = Right, transectMeter must ≥ 1 m from a corner (e.g., 199 or 201, not 199.1-200.9) or the location will violate the minimum 1 meter from transect on the adjacent side.*



- **directionFromTransect -** Direction (right or left) of individual from transect, when transect is walked in a clockwise direction
- **ninetyDegreeDistance -** Perpendicular distance from transect to the tagged corner of the selected patch (in meters). Use a laser rangefinder (15 cm accuracy) in HD mode or tape measure. Acceptable tolerance for perpendicular distance is +/- 1 m provided the minimum distance of 1 meter from the transect is met. It is anticipated, however, that at most locations +/- 30 cm precision is attainable. *Note: the minimum distance from trail is intended to minimize likelihood of trampling, light gaps or other human mediated potential impacts to observed phenology, ninetyDegreeDistances of <1 m from the transect are permissible if the conditions dictate, after consultation with Science.*
    - The maximum ninetyDegreeDistance is 10 meters from the transect. If there is strong rationale for selecting individuals >10 m away, submit a problem ticket to discuss with Science

2. Mark according to guidelines in C.6.

### C.4 Phenocam plot - Selecting individuals

For sites where the primary phenology transect is not located directly north of the NEON tower, a secondary, phenocam plot is established (**Figure 1**). The intent is to enable *in situ* observations of individuals whose phenology is also being captured by the tower-mounted phenocam. Doing so is essential to enabling scaling of phenology data from the individual to the landscape and, ultimately, the continent. Individuals cannot be selected within the phenocam plot until the phenocam has been mounted and images are available. A maximum of 3 species will be selected within the phenocam plot; typically, these will be the Phase I species.

The ideal season for selecting phenocam individuals is likely site specific. Individuals in herbaceous communities may best selected during the growing season whereas the dormant season may be ideal for selecting individuals at sites dominated by deciduous trees.

If the phenocam plot is located at a distance too far from the NEON tower to identify the southern border or selected individuals in phenocam images, submit a problem ticket to Science. Delineating plot boundaries and selecting individuals from within the plot that are also within view of the phenocam requires coordination between team members in the field, and team members located in the instrument hut with access to live feed from the phenocam.

**At the hut:**

1. Plug in laptop using Ethernet cable or connect to tower wireless network
2. Navigate to the IP address associated with the phenocam tower top phenocam
3. Confirm live image is streaming
4. Compare current image to prints historical phenocam images to assess canopy visibility

5. Using both live feed and historical images, guide crew members in the field to an acceptable individual
6. Once selected either mark individuals on print out of phenocam image or take a screenshot of the live feed and mark the location of the selected individuals for the phenology reference manual and training materials (**Error! Reference source not found.**).

**In the field:**

1. Use the Trimble to navigate to the southern boundary of the phenocam plot
2. Wave brightly colored objects (could be safety vest, or piece of fabric, or Mylar balloon, chose any item of sufficient size and contrast to be easily seen in the camera image)
3. Use hand held radio to communicate with crew member located in the instrument hut and confirm visibility
4. Follow guidance from the hut to navigate to suitable individual that is visible in the phenocam image in multiple seasons.
5. Once an individual has been selected:
    a. confirm on Trimble that the location is within the phenocam plot
    b. confirm the individual is a target species
6. Mark according to guidelines in C.6.
7. Flag access to path to selected individuals

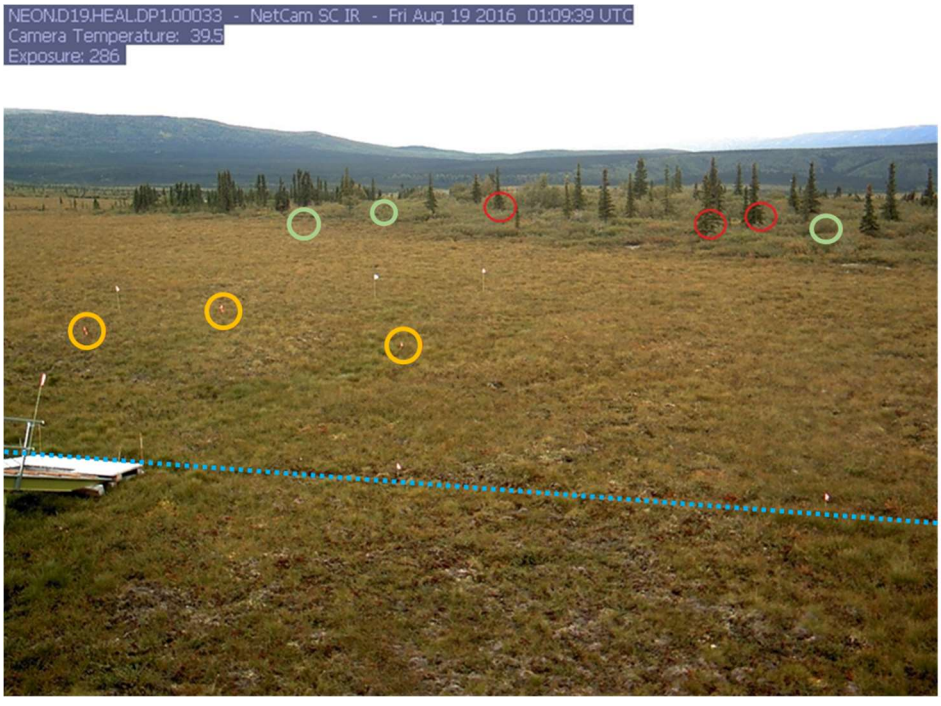



**Figure 3**. Phenocam image from D19-HEAL with marked individuals. Each color indicates a different Phase I species. Blue dashed line indicates southern boundary of the phenocam plot.

### C.5 Phenocam Plot - Mapping location of selected individuals/patches

The phenocam plot is a 200 m x 200 m plot within which individuals are selected. In an area with these dimensions, it is not practical to calculate absolute position from a series of relative position measurements, as is done on the primary transect. Instead, UTM Coordinates will be recorded directly for each individual/patch. This procedures requires data to be recorded on both the Trimble GPS unit and within the "Plant Phenology - Field Setup [PROD]" mobile application.

1. Navigate to the selected individual/patch
2. Make sure you do not have an existing data file open.
    a. To close an existing data file go to the **MDD** (Main Drop Down menu icon in GPS receiver) **> Data** and click **Close.**
3. Create a new data file.
    a. Go to **MDD > Data**, and then go to the **SDD (**Sub Drop Down directly below the MDD) and select **New.**
    b. Use the default settings: **File type** (Rover) and **Location** (Default); Click on the **File Name** field.
4. Enter the file name using the naming convention below.
    a. Filename begins with the letter D, followed by the two-digit number for the domain, followed by an underscore: e.g. **D01_**
    b. Add the four letter site ID followed by an underscore: e.g. D01_**HARV_**
    c. Add the tag ID (1-5 digits) for the phenocam individual you are collecting GPS data for followed by an underscore: e.g. D01_HARV_**1234_**
    d. Add "phe" followed by an underscore: e.g D01_HARV_1234_**phe_**
    e. To indicate the file contains GPS data add "GPS": e.g. D01_HARV_1234_ phe_**GPS**
5. In **Dictionary Name** choose the "Phenocam_individual" data dictionary
    a. Note- if you did not import the data dictionary before heading into the field choose the generic dictionary and enter the metadata into the comments file.
    b. Click **Create.**
    **c.** In the screen that pops up:
        **i.** Antennae height should be **1.000 m.**
        ii. Select Type as **GeoXH XXXX internal** (whichever GeoXH unit you are using) and click **OK.**
6. Open the "Phenocam_individual" feature in the Data screen.
7. There are three metadata fields in the data dictionary.
    a. **tagID:** 1-5 digits assigned to each individual phenocam individual.
        i. default is 1.
        ii. tagID is duplicated in the datafile name.
    **b.** **taxonID:** Code for the plant's identification.
    c. **comments:** Not a required field, available for any pertinent information.

**Collect GPS coordinates.**

1. Due to less restrictive accuracy requirements, the external antenna used during plot establishment is not needed to collect the spatial data for the phenocam individuals. However, to ensure best possible logging go to **MDD>Status>Skyplot** and make sure your values are:
    - Position Dilution of Precision (PDOP) is ≤ 6.
    - The Signal to Noise Ratio (SNR) should be ≥ 4.
    - Number of satellites used ≥ 4.

    a. Navigate back to the data collection screen by **MDD>Data.**

2. Determine your logging position.

    b. The stature of the plant you are collecting GPS data for will determine where you hold the Trimble unit when you start logging.
        i. If possible, hold the Trimble directly over the plant.
        ii. If the plant is too tall hold the Trimble next to the plant.

3. Start logging positions by clicking Log. Depending on the canopy cover choose the appropriate action:

    c. **Open field or minimal canopy cover:** record GPS data for at least 120 logs using the accuracy-based logging feature.
        i. If you are not able to log a point within the first minute, disable logging feature (see instructions below) and collect the 120 logs regardless of accuracy.

    d. **Semi-open and closed canopy:** record GPS data for at least 300 logs using the accuracy-based logging feature.
        i. If you are not able to log a point within the first minute, disable the logging feature (see instructions below) and collect the 300 logs regardless of accuracy.

4. When holding the Trimble during GPS point collection use the following best practices:
    - Make sure the barometric holes on the underside of the Trimble are not obstructed.
    - Minimize any movement of the Trimble.
    - Hold the Trimble out away from your body.
    - Accuracy is best if the Trimble is oriented toward the South

5. When you have finished collecting the minimum number of logs hit **Done** and close the data file.

6. Repeat the data file and GPS collection steps above on the remaining phenocam individuals.

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**Trimble Troubleshooting and Tricks**

- To find the "_" when creating the datafile name hit the **CAP** symbol on the keypad.
- Disable Logging Feature

- Go to MDD > Setup
- Click on Logging Settings
- Under Logging Settings click on the wrench to the right of the screen.
- Scroll down and in the Use Accuracy-based Logging click **No.**
- Click **Done** for the two following windows .
- To go back to the data collection go to MDD>Data + SDD>Existing File.

- If you are not able to log:
  - Make sure the receiver is active by going to the **MDD>Setup**; if the satellite icon is not visible: click on the **GNSS** box which should be in upper right side of the screen.
- For more troubleshooting see Appendix H in the Plot Establishment Protocol (RD[12]).

7. Record tag data in the "Plant Phenology – Field Setup [PROD]" mobile application:

- Create new field setup record
- Select:
  - **siteID**
  - **plotID** (phenocam plot)
  - **Enter per individual information**
    - **Add New tag?** Yes
    - **gpsDatafile** – The name assigned to the Trimble point
    - **logCount** – the number of logs collected
    - **tagID**
    - **taxonID**
    - **growthForm** – Refer to the National Phenology Network Species List in the SSL for growth form assignment of all species already monitored in the NPN network, or consult with Science if this is not known in advance
    - **dropPlant** – Active
  - Save record

8. Upon return to the DSF, upload GPS files to N:\Science\GISData\FOPS\PhenoCamPoints and notify Science that files are ready for post processing
9. Sync tablet when internet connection is available
10. Verify that new records have been pushed to the "Phenology – Per Individual INGEST [PROD]" application.

### C.6 Marking selected individuals/patches

Blue aluminum plant tags with unique numbers 6000-8000, are designated for phenology sampling; plant cards or flagging may be used to increase visibility (and). Tags will be placed according to the specifications provided in

**Table 6**, consistent with guidelines in the vegetation structure protocol (RD[07]).

**Figure 4**. Examples of recommended phenology markers. Photo credit: National phenology network (left), Ben Meadows (center), Forestry Suppliers (right)

1. Record:
    - **tagID –** 1-5 digit number, unique ID by site.
    - **taxonID –** USDA species code (domain specific lists available on Field Operations, TOS page on the NEON intranet)
    - **identificationQualifier –** if species identification is uncertain (i.e., if selection of individuals occurs prior to development of diagnostic morphological features) enter the assumed genus and species and apply an identification qualifier code to note the uncertainty and follow up at a later date
        - once positive ID is possible, these records will need to be updated (see SOP F)
    - **Remarks –** record the camera assigned file code for photos, if photos are taken

**Table 6**. Methods for marking individuals for phenology observations.

| Plant Type | Marking Method |
|---|---|
| Trees | Nail or otherwise attach tag to trunk at height of 1.4 m using site appropriate methods |
| Shrubs | Attach tag to a prominent branch or main stem with 20 gauge wire. Mark individual with florescent flagging (if permitted by site host) to aid in finding plant.<br><br>Small shrubs which cannot easily be tagged according to guidelines in the vegetation structure protocol (e.g., Gutierrezia sp.) may be marked with a tagged stake, similar to grasses and forbs. |
| Perennial bunchgrasses and forbs | Attach blue tag and plant card (w/ species code and tagID) to a tag stake. Place stake in the ground at the base of the selected individual. |
| Clonal species (e.g., aspen, staghorn sumac, rhizomatous perennials) | Attach tag to individual ramets from different clones. |
| Individual already marked for productivity sampling (RD[07]) | Punch productivity ID number into a blank blue tag.<br>Replace existing tag with blue tag. |
| Spreading perennial forbs and grasses | Mark corners, attach blue tag and plant card (w/ species code and Unique ID) to a tag stake. Place stake in the ground in the lower patch corner on the transect side of the patch. |
| Annual or biennial | Attach blue tag and plant card (w/ species code and Unique ID) to a tag stake. Place stake in the ground in the lower patch corner on the transect side of the patch. |
| Low growing woody species growing in continuous patches | Monument 1 m x 1 m patch corners with fiberglass posts tall enough to extend above vegetation. Attach flagging and tagID to lower patch corner, on the transect side of the patch. |

***Note**: It is important to ensure that the method of marking chosen does not change the growing conditions of the plant or injure the plant in any way. Shrubs* - Wrap wire loosely to avoid damaging stem as the plant grows. One effective method is to "coil" bailing wire around a pencil or other circular tool then wrap the coiled wire around the stem to enable stretching as the stem diameter increases over time (Figure 5). *Trees - When nailing tags to trees,* leave room for future tree growth (see RD[07] for details). The nail should be deep enough that it cannot easily be removed, but not flush to the bark.

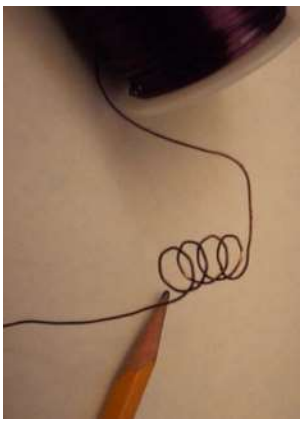


**Figure 5**. Bailing wire coiled around a pencil

**Table 7**. Identification qualifier codes (idQ) to designate species with uncertain identification

| idqCode | Identification Qualifier Description* |
|---|---|
| CS | cf. species |
| AS | aff. species |
| CG | cf. genus |
| AG | aff. genus |
| CF | cf. family |
| AF | aff. family |

* cf, roughly equals "not sure"; aff. Roughly equals "similar to, but is not"

**Steps for marking patches**

For small plants and lower growing woody plants that grow in patches of individual stems, it can be difficult to single out a few individuals to observe over time. Instead **set up a 0.25 m x 0.25 m** or **1 m x 1 m patch** and report on the phenophases for target species within the patch. This method works well for mat-forming grasses, clonal species that tend to grow as a groundcover, and very small forbs that tend to grow in clumps of individuals.

- **Lay out a 0.25 m x 0.25 m quadrat or 1 m x 1 m sampling frame** over the densest or most central portion of a group of plants.
- **Mark all four corners** of the square with non-oxidizing metal tag stakes, PVC, fiberglass, or wooden stakes so that the plot frame may be placed in the same location on subsequent monitoring bouts.

***Note:*** *When selecting stakes to mark patches, consider the impact stakes may have on the plants within the patch; avoid placing a broad stake next to a small plant that would shade it or cause root damage. For woody species, select a stake tall enough to extend above the average height of patch.*

- Attach a blue tag to the lower corner of the transect-side of the patch. Though, in the case of annuals or biennials, they will only be used for one or two years, annuals do need to have a permanent aluminum tag used to mark them. This helps ensure that duplicate tagIDs are not assigned to multiple individuals.
- Place a brightly colored plastic plant card in a tag stake in the same corner of the quadrat as the ID tag, write the species and tagID on the card. In the event of disturbance caused by wildlife drawn to brightly colored cards, discontinue use of plant cards and rely instead on location information (transect meter, direction and distance) to relocate and monitor patches.
- Annuals occasionally live more than a single season. In order to capture this if it occurs, do not remove plant ID cards (where allowed) until the following year.
- Primary Transect - Measure and record:
  - **tagID** -unique number from pre-stamped blue tag
  - **transectMeter** – Distance (in meters) of individual from beginning of transect, when transect is walked in clockwise direction
  - **directionFromTransect -** Direction (right or left) of individual from transect, when transect is walked in a clockwise direction
  - **ninetyDegreeDistance -** Perpendicular distance from transect to the tagged corner of the selected patch (in meters)

**Flag individuals**. Small metal tags can be obscured by vegetation making individuals difficult to locate from afar. Add florescent pin flags and/or flagging tape near marked individuals to aid observers in finding the plant (where permitted by site hosts). Pin flags and flagging do occasionally get eaten or lost, thus pin flags must not be the ONLY method of identification and marking.

**Figure 6**. Examples of flagging to increase visibility (photo credit: left, K. Jones; right, R. Hufft

## SOP D Collecting Phenophase Observations

### D.1 Preparing for Data Capture

Mobile applications are the preferred mechanism for data entry. Mobile devices should be fully charged and synched at the beginning of each field day.

Location and taxon information in the 'Plant Phenology – Field Setup [PROD]' application are used to pre-populate empty bout records for a specific observation date in the 'Plant Phenology-Phenophase Observations [PROD]' fulcrum application where phenophase status and intensity data are recorded. Upon completion of data collection and QC, each bout must be finalized and pushed to the 'Phenology – Observations INGEST [PROD]' application before it can be ingested to the NEON database

However, given the potential for mobile devices to fail under field conditions, it is imperative that paper datasheets are always available to record data. Paper datasheets should be carried along with the mobile devices to sampling locations at all times.

### D.2 Observing phenophases

Regular data collection, i.e. observation of phenological development, will occur throughout the growing season. Use the Plant Phenology mobile app, or formatted, pre-populated (if available) 'status/intensity' paper datasheets (RD[05]) to record data. You may bring copies of the data from most recently completed bout into the field as a reference for the current bout. Both the primary transect and individuals within the phenocam plot will be observed during every phenology bout.

- Locate the sampling start point of the plant phenology transect
- Enter metadata (e.g., **fieldcollectiondate**, **recordedBy**, **measuredBy** etc.)

***Note:*** *if roles switch over the course of the transect, indicate in the notes who had which role for each record, so that this will be captured when data are entered*

1. Collect phenophase data from the plant phenology transect
    - Traverse loop in a clockwise direction, or according to the established trail to phenocam individuals
    - Stop at each individual/patch listed on the datasheet.

***Note:*** *If it is not possible to assess the entire individual from the mapped transect location, it is acceptable to move along the transect to get a different view or make observations with only a partial view. Leaving the transect to make phenophase observations should only occur in rare instances and in consultation with the lead botanist. Considerations include site impacts, time, and data quality.*

- Collect data from each individual/patch along the loop.

- If the sampling start point is not the SW corner, order the datasheet to begin at the alternate corner. For example, if the NE corner is nearest the access route, begin sampling at meter 400, and still walk in a clockwise direction.

2. At each individual/patch, record the following data (Location, tagID, taxonID and growthForm – should be prepopulated).

   - **date** – YYYYMMDD
   - **phenophaseStatus -** Y/N/?/M/X for each phenophase required for that growth form (see **Error! Reference source not found.** for full descriptions of phenophases). Check for **every** required phenophase for every individual/patch during each sampling bout **Error! Reference source not found.**. *Note – due to space constraints, paper datasheets utilize coded values for phenophases. A key to codes is available in the footer of the datasheet.*
     - Yes (Y) – if phenophase *is* occurring
     - No (N) – if phenophase *is not* occurring
     - Uncertain (?) – if not certain whether the phenophase was occurring
       - Take a digital photo of individual to document phenophase, record photo file # on datasheet.
       - Review with local expert to identify phenophase and record per data handling procedure. Update the datasheet and data entered via mobile app to reflect new information.
       - This status may be used if a direct observation is temporarily not possible (e.g., the individual/patch is covered by snow or water but the growing season is still ongoing)
     - Missed Phase (M) – if a phase occurred between sampling bouts in the current growing season such that the previous bout recorded status=N and the current status=N BUT you have reason to believe that the phenophase occurred between the two bouts (such as dried flowers on the ground below the plant).
       - Do NOT record status=M if a phenophase occurred prior to initiating monitoring bouts for the year
       - Intensity values for missed phenophases are not recorded.
       - Do not use missed for skipped plants, not observed during a given bout
     - Unnecessary (X) – If data are not being recorded on a formatted, pre-populated, datasheet (SOP A.1) or mobile app, record 'X' if a particular phenophase is not required for the growth form of the individual to verify that nothing was skipped along the way

3. Select an appropriate phenophase **intensity range** (**Table 8**) for each phenophase for which 'Yes' is selected. Growth-form specific phenophases and their descriptions are listed in Appendix A).

**Table 8**. Intensity ranges.

| Intensity category | Intensity bins | | | | | |
|---|---|---|---|---|---|---|
| # (count) | < 3 | 3-10 | 11-100 | 101-1,000 | 1,001-10,000 | > 10,000 |
| % canopy, flower | < 5 | 5-24 | 25-49 | 50-74 | 75-94 | ≥ 95 |
| % leaf size | | < 24 | 25-49 | 50-74 | 75-94 | ≥ 95 |

4. Take a photograph of at least 3 examples of that phenophase*intensity combination on the first encounter in each species. Frame the shot so the image may be used to:
    - Build site-specific training materials and a reference collection
    - Calibrate observer assessment of status and intensity for all species/phenophase combinations

### D.3 Replacing lost, dead, or diseased plants

If an individual is lost or killed mid-season, a new individual may be selected from another location along the transect; if no suitable replacement is available, make a note for the individual metadata. Each new individual must receive a new tag with a new unique number; do not re-use tags from individuals that have been dropped from monitoring. If a tagged plant listed on the datasheet cannot be located, dies (perennials only) or has experienced an unrepresentative change in health:

- Assign a new tagID to an individual or patch in a location near where the original was located. Record the new location and identification information in the 'perindividual' datasheet or from within the Observations mobile app without having to open the Field Setup app.
- If a long lived species that was healthy becomes diseased or experiences >50% mortality, replace unless the shift in health status is common (representative) among that species at the site (e.g., pest infestation or widespread disease).
- Record dropped plants as either 'Dropped' (dropped permanently) for one of the reasons listed above (specify the reason in the notes field), or 'Seasonal drop' dropped for the season if the individual reached the 'end seasonal sampling' trigger. Season drops may only be utilized at sites on a seasonal sampling schedule.
    - The 'Seasonally dropped' option is not mandatory and is primarily utilized to manage data collection and track progress towards the end of sampling for the growing season rather than generation of a specific data product. Selecting 'seasonally dropped' does not create a new data record, phenophaseStatus observations must still be reported for the date an individual/patch is seasonally dropped. If new growth occurs (more common in annuals than perennials) after an individual/patch has been dropped for the season, monitoring the individual may be restarted by setting dropStatus to active on the 'Field Setup' mobile app. If using

paper datasheets, record data as usual, note date that observation resumed in the remarks field.

- If there is evidence elsewhere at the site or along the phenology transect of new growth in a species that has already been 'seasonally dropped' re-check marked individual and resume monitoring if necessary.
- Returning a seasonally dropped individual to active status within a given calendar year has no scientific impact on data quality. An individual may transition between seasonally dropped and active as many times as necessary based on the phenology of the individual.
- At sites where species may have multiple periods of growth, it is recommended that the 'seasonally dropped' option not be used as this can cause confusion. Simply record all phenophase status = No for dormant individuals throughout the sampling season.

Annuals that die do not need to be replaced within a given growing season, the same patch will be observed the following year. For annuals that die:

- Record 0% green leaf.
- Record phenophaseStatus = 'no' for all applicable phenophases
- If sampling is seasonal or hybrid, end phenology monitoring for that individual/patch for the season.

## SOP E Collecting Annual Structure Data

### E.1 Preparing for Data Capture

Mobile applications are the preferred mechanism for data entry. Mobile devices should be fully charged at the beginning of each field day, whenever possible.

Data for this SOP are recorded in the 'Plant Phenology - Annual Measurements [PROD]' Fulcrum application.

However, given the potential for mobile devices to fail under field conditions, it is imperative that paper datasheets are always available to record data. Paper datasheets should be carried along with the mobile devices to sampling locations at all times.

### E.2 Annual Data

Once each year, record size and location information for each individual/patch selected for phenology monitoring, on both the primary transect and within the phenocam plot. Record these data at peak season for herbaceous plants and forbs, and at the same time of the year (+/- 2 weeks) annually for woody species. If, for example, a site has both a grass and tree as selected phenology species, annual measurements of the grass may be best collected in July whereas the ideal time to collect annual measurements on the tree may be October; there is no requirement that annual measurements be made on all species at the same time. Record these data during a routine data collection bout. Use the annual data mobile app or 'perindividual_peryear' datasheet to record data for this SOP.

For each individual, record the following data, using the 'perindividual_peryear' datasheets:

- **Location Information** (may be pre-populated in mobile app or on a datasheet)
    - transectMeter (0-799m)
    - directionFromTransect (R/L)
    - tagID (tag#)
- **taxonID** (may be pre-populated) use United States Department of Agriculture Natural Resources Conservation Services (USDA-NRCS) PLANTS species codes
- **patchOrIndividual** (may be pre-populated)
- **patchSize**
    - 0.25 m x 0.25 m for herbaceous species
    - 1 m x 1 m for woody species
- **canopyPosition** Consistent with categories used in vegetation structure - Table 9
- Record biomass/productivity measurements consistent with NEON vegetation structure protocols (Table 9, RD[07]) with the following exceptions:
    - Use the laser rangefinder (15 cm accuracy) for canopy diameter and height measurements where appropriate.
    - The phenology ingest is only designed to handle 1 stem diameter / tagID. If the selected individual has multiple boles and would qualify for >1 diameter measurement according to

the vegetation structure protocol, select just the largest stem to measure for this protocol. The largest stem should be the one onto which the tag is affixed but may be additionally marked with a lumber crayon or flagging (if permitted by site host) to facilitate re-measurement in subsequent years.

- No stem diameter is required for individuals with all stems <1cm diameter. In this instance, record average height and canopy dimensions only. Include remark "all stems < 1 cm diameter".
- Vegetation that would be measured according to shrubgroup growth form in the vegetation structure protocol do not require diameter measurements. Record average height and canopy dimensions as the square root of the estimated canopy area.

- **plantStatus:** The physical status of the individual (**Table 10**). Options are the subset of live choices provided in the vegetation structure protocol.
- **diseaseType** – if known (e.g. cankers, heart rot, root rot, blight, tar spot, anthracnose, powdery mildew…)

**Table 9**. Canopy Position classes

| Class | Description |
|---|---|
| Open Grown | Full sun, not touching other plants - crowns that received full light from above and from all sides throughout most of its life, particularly during its early developmental period. |
| Full sun | Crowns extending above the general level of the canopy and receiving full light from above and partly from the sides. These individuals are taller than the average in the stand and their crowns are well developed, but they could be somewhat crowded on the sides. Also, individuals whose crowns have received full light from above and from all sides during early development and most of their life. Their crown form or shape appears to be free of influence from neighboring plants. |
| Partially shaded | Individuals with crowns at the general level of the crown canopy. Crowns receive full light from above but little direct sunlight penetrates their sides. Usually they have medium-sized crowns and are somewhat crowded from the sides. In stagnated stands, co-dominant trees have small-sized crowns and are crowded on the sides. |
| Mostly shaded | Individuals that are shorter than dominants and co-dominants, but their crowns extend into the canopy of co-dominant and dominant trees. They receive little direct light from above and none from the sides. As a result, intermediate trees usually have small crowns and are very crowded from the sides. |
| Full shade | Individuals with crowns entirely below the general level of the crown canopy that receive no direct sunlight either from above or the sides. |

(Modified from Forest Inventory Analysis protocols (USDA, Forest Service 2011))

**Table 10**. plantStatus classes, only a subset of codes used for vegetation structure are relevant to phenology individuals.

| Class | Description |
|---|---|
| Live | Any live Apparent Individual (new, re-measured or ingrowth) that is of typical healthy status for the ecosystem in question; that is, if trace amounts of insect damage to foliage are typical on the majority of individuals, use this code rather than code 4 below. |
| Live, insect damaged | Note 'crown' or 'bole' damage in **remarks**, and indicate type of insect causing damage if possible (e.g., Mountain Pine Beetle, Gypsy Moth, etc.) |
| Live, disease damaged | Note 'crown' or 'bole' damage in **remarks**, and indicate type of disease causing damage if possible (e.g., Blister Rust, rot, canker, other (specify), unknown. |
| Live, physically damaged | Note 'crown' or 'bole' damage in **remarks**, and indicate type of physical damage if possible (e.g., broken stem, bole scar, girdling, snow/ice damage, crushed, lightning, crown scorch, bole scorch) |
| Live, other damage | Note 'crown' or 'bole' damage in **remarks**, and note cause if possible. |
| Live, broken bole | Tree with broken spike top, tree with broken main bole and ascending leaders, tree broken and dead at top but live below |

**Table 11**. Biomass and productivity measurements

| Vegetation Structure[1] | Measurements | Tools to Measure |
|---|---|---|
| Individuals | • stemDiameter (cm) – woody species only<br>• maxCanopyDiameter: max. diameter (m)<br>• ninetyCanopyDiameter: Perpendicular to max. diameter (m)<br>• Height (m)<br>• Average adult leaf length* (Deciduous broadleaf only) (cm) | • Diameter tape<br>• Laser rangefinder<br>• Ruler<br>• Calipers for ddh |
| Patches | • Cover Percent<br>• Average height (m) | • 0.25 m x 0.25 m calibrated quadrat<br>• 1 m x 1 m calibrated sampling frame<br>• Ruler or short tape |

[1] Annual datasheets and data ingest interfaces do not accommodate shrub group data. If a shrub group has been selected enter the square root of the canopy area in each of the canopyDiameter fields, calculate the average height to record only a single height measurement, use the remarks to record % dead

***** Leaf length is optional and intended as guidance for estimating Increasing Leaf Size intensity in future years. This field is not used for data product generation. Use these values in the internally developed site specific reference materials

***Note:*** *If annual data collection occurs after an herbaceous individual has already senesced such that size and health cannot be assessed, do not record '0' for any size measurements. Instead, delete the individual child record from the bout parent and work with the lead botanist to schedule an earlier annual bout the following year to catch these individuals at peak biomass.*

**** Tips for measuring patches**:

- Each frame should be calibrated, incrementally marked along the edges, to make cover estimates easier
- Estimate percent cover according to guidelines provided in (RD[08]). Only estimate cover on plants, or portions of plants with stems occurring within the quadrat frame.
- Visually group individuals together into a percent cover. Fine tune that estimate by subtracting out any spaces or gaps.
- Cover should be recorded as the total aerial coverage of the target species. Estimates should not exceed 100% for the target species.

### E.3 Tissue samples for archive

Leaf tissue and voucher specimens will be collected from each species selected for phenology monitoring at NEON sites. Whenever possible, without impacting growth, samples should be taken directly from the individual/patch being monitored. Guidelines for specimen collection and preparation are outlined in the Plant Voucher Specimen Preparation SOP (RD[11]). Tissue collection and preparation for chemical analyses are described in the Plant Diversity Protocol (RD[08]).

## SOP F Data Entry and Verification

The importance of thorough, accurate data transcription cannot be overstated; the value of the efforts in the field is only manifested once the data are properly entered for delivery to NEON's end users.

Mobile applications are the preferred mechanism for data entry. Data should be entered into the protocol/SOP-specific application as they are being collected, whenever possible, to minimize data transcription and improve data quality. Mobile devices should be synced at the end of each field day, where possible; alternatively, devices should be synced immediately upon return to the Domain Support Facility. Additional details for the phenology observation mobile applications (Field Setup, Phenophase Observations, Annual data) are available in the 'Manual for Fulcrum Application: TOS Plant Phenology [PROD] –All SOPs' document in the Sampling Support Library (SSL).

However, given the potential for mobile devices to fail under field conditions, it is imperative that paper datasheets are always available to record data. Paper datasheets should be carried along with the mobile devices to sampling locations at all times. As a best practice, field data collected on paper datasheets should be digitally transcribed within 7 days of collection or the end of a sampling bout (where applicable). However, given logistical constraints, the maximum timeline for entering data is within 14 days of collection or the end of a sampling bout (where applicable). See RD[04] for complete instructions regarding manual data transcription.

Protocol-specific instructions and the associated data ingest workbook for entering plant phenology data can be found on the NEON intranet Field Operations TOS site. Be sure to enter data for all active individuals/patches within a bout unless the bout is ended prematurely due to unforeseen circumstances. If an entire bout is missed, no data need to be entered.

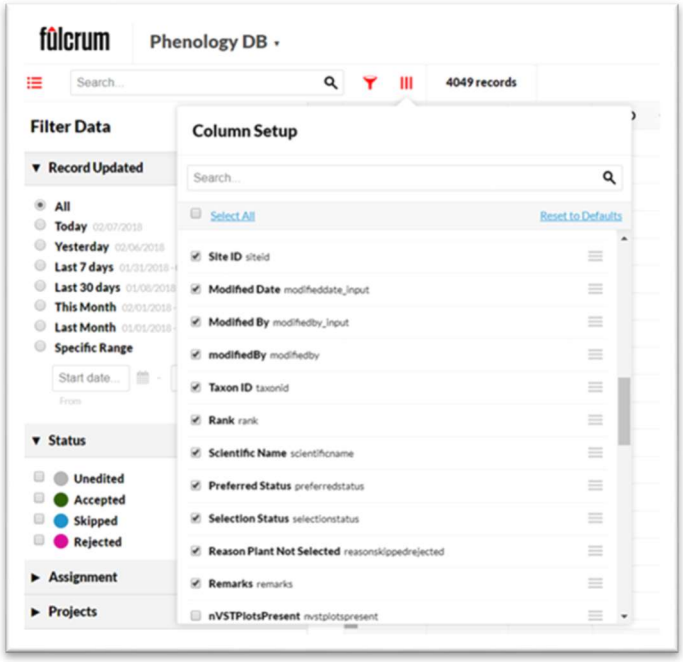
### F.1 Transferring phenocam individual GPS data

1. See section E.1 in the Plot Establishment Protocol (RD[12]) for GPS Pathfinder Office steps.
2. Transfer the data to the intranet location specified by Science, N:\Science\GISData\FOPS\PhenoCamPoints
3. Alert Science staff that data has been transferred through either a problem ticket or by email.

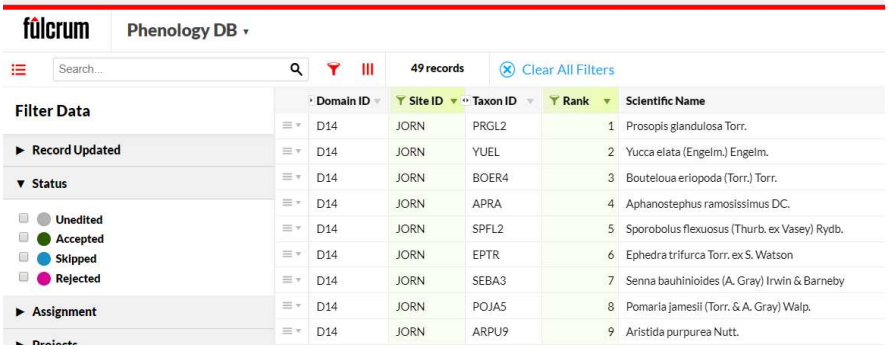
Science staff will post process the data and add the spatial data to the Fulcrum Web UI.

### F.2 Updating phenology database with selected species

1. Document species selection in the 'Phenology DB' mobile application
2. In the view data screen of the application, filter visible fields to just those you will need for species selection.




3. Filter to **Site ID** of interest and order by **Rank**
   a. Select Edit from the dropdown menu to the right of the first species in the list.




   b. Choose **selectionStatus** from the drop down menu
      1) for any choice other than “accepted – Phase I”, or “accepted – Phase II” you must enter a rationale for why that species was not selected:
         a) If **selectionStatus** = ‘skipped’, record **Reason Plant Not Selected** as:
            - Fern, fern ally, or other non-vascular species
            - TaxonID too low resolution, genus or lower
         b) If selectionStatus = ‘rejected Phase I’ or ‘rejected Phase II’, record **Reason Plant Not Selected** as:
            - overstory species and all required overstory species have already been selected

- - understory species and all required understory species have already been selected
- - Other [remarks required]

c) Select ✓ to save the record

### F.3 Entering and uploading observation data

1. Download photos. Phenology photos will primarily be used to develop site specific reference materials and for training purposes. Organizing and maintaining the phenology image library at each Domain is a Field Operations task.
    - Confirm uncertain phenophases (i.e., phenophaseStatus = ?) with local expert. Update datasheets and note that data were post-corrected in the lab.
    - Verify phenophase/intensity for any data collected by inexperienced staff (i.e., first 3 bouts). All photos must be reviewed and approved by the lead botany field ecologist before being included in phenology reference library.
    - Place all photos from a given year in a single folder labeled by date.
    5. suggested file structure: ~/Site/yyyy
    - Append taxonID_phenophaseName (use camelCase) to the camera-assigned file name to enable searching and maintain link to data.
    - Ex: D16_1692_TSHE_breakingNeedleBud
2. Review data for obvious errors and logical inconsistencies. Use the 'Phenology QA/QC Checklist' available on the SSL and the Phenology QC Shiny App to guide data review.
3. Export finalized Observation records from the 'Phenology - Observations INGEST [PROD]' Fulcrum application based on the date records were finalized. Use fulcrum_id (or _record_id) from the 'phenology_observations_ingest_prod.csv' file to subset records for the current bout in the 'phenology_observations_ingest_prod_child_statusintensity.csv', based on fulcrum_parent_id. Sort and print the csv to take to the field during the subsequent bout.

**Note:** *Do not finalize 'Plant Phenology-Phenophase Observations [PROD]' records until QC is complete, if subsequent bouts are used to double check validity of observations, wait until the subsequent bout is complete before finalizing. Once pushed to 'Phenology - Observations INGEST [PROD]' records will be ingested and locked immediately. Edits will only be possible if the record fails ingest validation.*

4. If data were recorded on paper data sheets, scan and print a copy of original data sheets from current bout to bring into the field on the next monitoring bout. Clearly label these sheets as copies to avoid confusion. Transcribe data into phenology Fulcrum desktop application in accordance with data entry and data QA/QC protocols (RD[04]).

IMPORTANT – double check that data are entered for plotID on which data were collected. PlotID **cannot be updated** if recorded incorrectly.

- Training materials for entering phenology data into the mobile applications are available on the  S. Any staff entering data in the mobile or desktop application must review these materials and must enter practice data on the training, [CERT] applications before entering actual bout data on [PROD].
- Sync tablets
- Verify on desktop application that sync was successful

### F.4 Addressing errors in field collected data

If errors are discovered or information must be updated (e.g., phenophase status = 'uncertain' has been resolved based on photos). Records must be updated.

**Perindividual – Field Setup**

If the original taxonID assignment was uncertain or an individual is discovered to have been mis-identified, update information in perindividual record. If, for example, the originally assigned **identificationQualifier** changes due to the emergence of diagnostic features during the growing season, update the **taxonID** and **idqCode** to reflect the new status. The same is true for perindividual location information (**transectMeter**, **directionFromTransect, ninetyDegreeDistance**) that must be updated. If a selected individual was incorrectly identified, update the perindividual **taxonID** to the correct species, drop the plant and select a new individual of the correct, target, species.

To update a perindividual record already ingested to the NEON database:

1. Sign in to the data entry application for the plot/date combination on which necessary changes to perindividual data were noted
2. Edit the perindividual data for the selected tagID.

***Note:*** *this will create a duplicate record that, ultimately, will be visible on the NEON data portal. Users will then be advised that the most recently created record contains the most up to date information. It is very important to QC entered data to the extent possible, when the data are first entered to avoid creating duplicate records on the data portal*

3. **plotID** fields CANNOT be updated. This field is a primary key for individuals within the NEON sample management system. If errors are found in this field, the **tagID** associated with the incorrect record must be permanently dropped and a new **tagID** assigned.

Updating phenophase observations or annual data already ingested to the NEON database:

1. If errors are discovered in any phenology applications:
    a. If data have already been ingested, request L0 update through Magpie: OS Data Viewer
    b. If data have not yet been ingested,
        i. a fulcrum user with edit access to the INGEST application may edit data

### F.5 Equipment Maintenance, Cleaning and Storage

- Double check that all photos have been downloaded then delete photos from camera.
- Charge camera, laser rangefinder, and mobile data recorder batteries.
- Charge GPS unit.

**SOP G Sample Shipment**

Samples are gathered for archive during annual data collection, details of sample collection, preparation and shipping are contained in RD[08] .

## 8 REFERENCES

Denny, E. G., K. L. Gerst, A. J. Miller-Rushing, G. L. Tierney, T. M. Crimmins, C. A. Enquist, P. Guertin, A. H. Rosemartin, M. D. Schwartz, and K. A. Thomas. 2014. Standardized phenology monitoring methods to track plant and animal activity for science and resource management applications. International Journal of Biometeorology:1–11.

K. Didan. 2015. MOD13Q1 MODIS/Terra Vegetation Indices 16-Day L3 Global 250m SIN Grid V006. NASA EOSDIS Land Processes DAAC. https://doi.org/10.5067/MODIS/MOD13Q1.006

National Phenology Network. "Nature's Notebook." https://www.usanpn.org/natures_notebook.

USDA, Forest Service. 2011. Forest Inventory and Analysis Nation Core Field Guide. Volume I: Field Data Collection Procedures for Phase 2 Plots. Version 5.1

# APPENDIX A QUICK REFERENCES

## A.1 Summary of Phenophases and Intensity Measurements

This table summarizes which phenophases to observe based on the assigned growth form and whether intensity should be recorded as an absolute number (#) or a percentage of the individual /patch on which the phenophase is occurring. There may be multiple phenophases on an individual during a single bout. There may be multiple episodes of a phenophase within a season.

**Phenophase Intensity Class Categories**

| Intensity category | Intensity bins | | | | | |
|---|---|---|---|---|---|---|
| # (count) | < 3 | 3-10 | 11-100 | 101-1,000 | 1,001-10,000 | > 10,000 |
| % leaves, flower, color | < 5 | 5-24 | 25-49 | 50-74 | 75-94 | ≥ 95 |
| % Increasing leaf size | | < 24 | 25-49 | 50-74 | 75-94 | ≥ 95 |

**Phenophases by Growth Form**

| Growth Form | Breaking buds / Emerging Needles/ Initial Growth | intensity | Increasing Leaf Size/ Young Leaves/ Young Needles | intensity | Leaves/ Needles | intensity | Open Flowers / Pollen Cones | intensity | Colored Leaves/ Needles | intensity | Falling leaves/ Needles | intensity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cactus | - | - | - | - | - | - | ✓ | % | - | - | - | - |
| Deciduous broadleaf (DBL) | ✓ | # | ✓ | % | ✓ | % | ✓ | % | ✓ | % | ✓ | - |
| Deciduous Conifer (DC) | ✓ | # | - | - | ✓ | % | ✓ | % | ✓ | % | ✓ | - |
| Drought deciduous broadleaf (DDB) | - | - | ✓ | # | ✓ | % | ✓ | % | ✓ | % | ✓ | - |
| Evergreen broadleaf (EBL) | ✓ | # | ✓ | # | - | - | ✓ | % | - | - | - | - |
| Evergreen broadleaf – no leaf buds (EB-NLB) | - | - | ✓ | # | - | - | ✓ | % | - | - | - | - |
| Evergreen broadleaf – no leaves (EBL-NL) | - | - | - | - | - | - | ✓ | % | - | - | - | - |
| Evergreen Conifer (EC) | ✓ | # | ✓ | # | - | - | ✓ | % | - | - | - | - |
| Evergreen Conifer – no needles (EC – NN) | - | - | - | - | - | - | ✓ | % | - | - | - | - |
| Evergreen Forb (EF) | - | - | ✓ | - | - | - | ✓ | % | - | - | - | - |
| Forb | ✓ | - | - | - | ✓ | - | ✓ | % | - | - | - | - |
| Graminoid (GRS) | ✓ | - | - | - | ✓ | % | ✓ | % | - | - | - | - |
| Pine | ✓ | # | ✓ | # | - | - | ✓ | % | - | - | - | - |
| Semi-evergreen broadleaf (SEB) | ✓ | # | ✓✓* | #/% | ✓ | % | ✓ | % | ✓ | % | ✓ | - |

* both young leaves and increasing leaf size are assessed for semi-evergreen broadleaf individuals

## A.2 Generalized Phenology Workflow

**STEP 1** – Delineate phenology loop or phenocam plot in tower airshed.

**STEP 2** – Select individuals and patches to monitor.

**STEP 3** – Map location of selected individuals and patches.

**STEP 4** – Mark individuals and patches with unique tagIDs.

**STEP 5** – Collect phenophase data, including photographs.

**STEP 6** – Select replacement individuals as needed (repeat steps 2-4 for new plants).

**STEP 7** – Download photographs and indicate phenophase for internal references and training.

**STEP 8** – Collect location, size, and health status data on all monitored plants (annually).

## A.3 Phenophase Observation QA checklist

**Before leaving DSF**

- Make sure tablet and GPS are fully charged
- Create blank observation bout record from Field Setup application
- Synch mobile device and verify records are available on mobile device
- Print or populate Fulcrum records with previous bout data
- Review and pack internal reference materials with species and phenophase specific information

**While in the field**

- Approach transect/plot using designated route
- Check that tags are organized on the mobile application by transectMeter
- Start transect at the designated start transectMeter
- If working with a partner, designate one recorder and one observer
- Triple check record date before recording any observations
- Walk in clockwise direction

- Stop at designated transectMeter or viewpoints to observe individuals/patches
- Do not leave the transect to make observations unless instructed to do so by the Flora lead
- Use binoculars or spotting scope to see tall trees
- Use call-response for each individual and phenophase using full names, questions and intensities to minimize confusion. For example:
    - Recorder: “tagID = 1234, left side”
    - Observer: “tagID – 1234, [taxonID]”
    - Recorder: “Breaking leaf buds” **Say full phenophase name, do not use codes**
    - Observer: “No”
    - Recorder: “Increasing leaf size?”
    - Observer: “No”
    - Recorder: “Leaves”
    - Observer “Yes”
    - Recorder: “What percentage of the potential canopy space is full with leaves?” **Say full phenophase intensity question.**
    - Observer: “Greater than 95 percent” **Say full intensity category, do not use codes.**
    - …
- Refer to previous bout and reference materials as needed throughout the bout
- **SAVE OFTEN!** An unexpected tablet shut down could result in loss of all data up to the last save
- Take pictures and notes about any phenophase status or intensity you are not confident about.

**Post bout actions - DSF**

- Sync tablet
- Review any status = uncertain with Flora lead
- Flora lead will finalize bout and push records to the Phenology – Observations [PROD] application
- Generate record for next scheduled bout

## A.4 Phenophase Definitions

| Early season growth | | | |
|---|---|---|---|
| **Phenophase Title** | **Applicable Growth Forms** | **Status Description** | **Intensity Question** |
| Breaking leaf buds | DBL<br>EBL<br>SEB | One or more breaking leaf buds are visible on the plant. A leaf bud is considered "breaking" once a green leaf tip is visible at the end of the bud, but before the first leaf from the bud has unfolded to expose the leaf stalk (petiole) or leaf base. | How many buds are breaking? |
| Breaking needle buds | DC<br>EC | One or more breaking needle buds are visible on the plant. A needle bud is considered "breaking" once a green needle tip is visible at the end of the bud, but before the first needle from the bud has unfolded and spread away at an angle from the developing stem, or from other needles in a bundle. | How many buds are breaking? |
| Emerging needles | Pine | One or more emerging needles or needle bundles (fascicles) are visible on the plant. A needle or needle bundle is considered "emerging" once the green tip is visible along the newly developing stem (candle), but before the needles have begun to unfold and spread away at an angle from others in the bundle. | How many needle bundles are emerging? |
| Initial growth | Forb<br>GRS | New growth of the plant is visible after a period of no growth (winter or drought), either from above-ground buds with green tips, new green or white shoots breaking through the soil surface, or re-greening of dried stems or leaves. Growth is considered "initial" on each bud or shoot until the first leaf has fully unfolded. For seedlings, "initial" growth includes the presence of the one or two small, round or elongated leaves (cotyledons) before the first true leaf has unfolded or has fully re-greened. | NA |

Initial Growth - GRS

Breaking needle buds - EC, DC

Breaking leaf bud - DBL, EBL, SEB

Emerging needles - Pine

| Early Development | | | |
|---|---|---|---|
| **Phenophase Title** | **Applicable Growth Forms** | **Status Description** | **Intensity Question** |
| Increasing Leaf size | DBL<br>SEB | A majority of leaves on the plant have not yet reached their full size and are still growing larger. Do not include new leaves that continue to emerge at the ends of elongating stems throughout the growing season. | What percentage of full size are most leaves? |
| Young Leaves | EBL<br>EBL-NLB<br>DDB<br>EF<br>SEB | One or more young, unfolded leaves are visible on the plant. A leaf is considered "young" and "unfolded" once its entire length has emerged from the breaking bud, stem node or growing stem tip, so that the leaf stalk (petiole) or leaf base is visible at its point of attachment to the stem, but before the leaf has reached full size or turned the darker green color or tougher texture of mature leaves on the plant. Do not include fully dried or dead leaves. | How many young leaves are present? |
| Young needles* | EC<br>Pine | One or more young, unfolded needles are visible on the plant. A needle is considered "young" and "unfolded" once it has spread away from the developing stem enough that its point of attachment to the stem is visible, or has spread from other **needles** in the bundle (and is no longer pressed flat against them), but before it has reached full size or turned the darker green color or tougher texture of mature needles on the plant. | How many young needles (EC) or young needle bundles (fascicles, Pine) are present? |

**A Note about Needles**

Needles, depending on species, may be solitary (e.g. *Picea sp., Abies sp., or Pseudotsuga sp.*), clustered together on short shoots (e.g. *Larix sp.*), or bundled in fascicles (e.g. *Pinus sp.)*. Fascicled needles are clustered tightly at the base with a small sheath surrounding the base—although that sheath can be deciduous in some species.

Increasing leaf size – DBL, SEB

Young leaves – EBL, DDB, EF, SEB

Young needles – EC, Pine

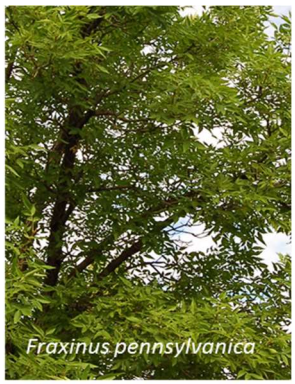
| Growing season duration | | | |
|---|---|---|---|
| **Phenophase Title** | **Applicable Growth Forms** | **Status Description** | **Intensity Question** |
| Leaves | DBL<br>DDB<br>SEB | One or more live, unfolded leaves are visible on the plant. A leaf is considered "unfolded" once its entire length has emerged from the breaking bud, stem node or growing stem tip, so that the leaf stalk (petiole) or leaf base is visible at its point of attachment to the stem. Do not include fully dried or dead leaves. | What percentage of the potential canopy space is full with leaves? Ignore dead branches in the estimate. |
| Leaves | Forb<br>GRS | One or more live, fully unfolded leaves are visible on the plant. For seedlings, consider only true leaves and do not count the one or two small, round or elongated leaves (cotyledons) that are found on the stem almost immediately after the seedling germinates. Do not include fully dried or dead leaves.<br><br>No intensity reported for forbs. | GRS - What percentage of the plant is green? Or, for patches, what percentage of the current years' growth of the target species within the patch is green? |
| Needles | DC | One or more live, unfolded needles are visible on the plant. A needle is considered "unfolded" once it begins to spread away at an angle from the developing stem enough that its point of attachment to the stem is visible, or from other needles in a bundle so that it is no longer pressed flat against them. Do not include fully dried or dead needles. | What percentage of the potential canopy space is full with needles? Ignore dead branches in the estimate. |

**Assessing intensity class for grasses, sedges, and rushes**

For annual grasses measured as patches, report *% green of the target species within the selected patch*, rather than % of patch that is green. For grass, sedge and rush species (GRS) where new growth is from new stems, the plant will probably be 100% green until it begins to turn brown in the late summer or fall. For species where existing stems can turn brown and then re-green, the intensity for the **leaves** may start low at the beginning of the growing season, become higher in the middle of the growing season, and then decline again as the plant turns brown again. In dryland environments where conditions are extreme, it can be particularly difficult to judge what portion of a grass plant is truly dead and what portion has the potential to re-green. If this is the case refer to the reference photobook for phenophase for that species. Take a picture for future reference and discuss with the lead botany field ecologist.

Needles - DC

Leaves – GRS, Forb



Leaves – DBL, DDB, SEB

| Reproductive phenophases | | | |
|---|---|---|---|
| **Phenophase Title** | **Applicable Growth Forms** | **Status Description** | **Intensity Question** |
| Open flowers | DBL<br>EBL<br>EBL-NLB<br>EBL-NL<br>Forb<br>GRS<br>Cactus<br>DDB<br>EF<br>SEB | One or more open, fresh flowers are visible on the plant. Flowers are considered "open" when the reproductive parts (male stamens or female pistils) are visible between or within unfolded or open flower parts (petals, floral tubes or sepals). Do not include wilted or dried flowers.<br><br>Tip: for perfect or female flower look for wilted style/stigma or swollen ovary to indicate the phenophase is complete. | What percentage of all fresh flowers (buds plus unopened plus open) on the plant are open? For species in which individual flowers are clustered in flower heads, spikes or catkins (inflorescences), estimate the percentage of all individual flowers that are open. |
| Open pollen cones | DC<br>EC<br>Pine | One or more open, fresh, male pollen cones (strobili) are visible on the plant. Cones are considered "open" when the scales have spread apart to release pollen. Do not include wilted or dried cones that have already released all of their pollen | What percentage of all fresh pollen cones (unopened plus open) on the plant are open? (do not include wilted or dried cones that have already released all of their pollen in this calculation) |

**Assessing intensity class for Inflorescences**

When estimating intensity class for **Open Flowers** on plants with inflorescences (including grasses), the percentage of individual flowers open on a single inflorescence (flower heads, spikes or catkins), will often be the same for all inflorescences on the plant. If this is the case, you can choose a single inflorescence, estimate the percentage of open flowers on it, and use that value to represent the entire plant. For larger plants, it is generally a good idea to check a few inflorescences (for example, one towards the bottom of the plant, one in the middle and one towards the top), and average the percentage of open flowers on each of these inflorescences to represent the entire plant.

Open flowers – DBL, EBL, Forb, GRS, Cactus, DDB, EF, SEB

Open pollen cones – EC, DC, Pine

| Senescence | | | |
|---|---|---|---|
| **Phenophase Title** | **Applicable Growth Forms** | **Status Description** | **Intensity Question** |
| Colored leaves | DBL<br>DDB<br>SEB | One or more leaves show some of their typical late-season or drought-induced color. Do not include small spots of color due to minor leaf damage, or dieback on branches that have broken. Do not include fully dried or dead leaves that remain on the plant. | What percentage of the potential canopy space is full with non-green leaf color? Ignore dead branches in your estimate. |
| Colored needles | DC | One or more needles show some of their typical late-season or drought-induced color. Do not include small spots of color due to minor needle damage, or dieback on branches that have broken. Do not include fully dried or dead needles that remain on the plant. | What percentage of the potential canopy space is full with non-green needle color? Ignore dead branches in your estimate. |

**Assessing leaf color change on diseased leaves**

Leaf discoloration is a common symptom of pathogen infection. If an individual selected for phenology monitoring is diseased, assess the colored leaves / colored needles phenophase on the uninfected portions of the leaves. The disease status will be captured during the annual measurements.

For example: assuming all leaves are still on an individual with 10 leaves and each of these leaves are 50% diseased (5 total leaf area diseased) and of the non-diseased portion, 60% is colored (3 total leaf area colored), intensity is 60%, not 30%.

Colored leaves - DBL, DDB, DEB

Colored leaves - DBL, DDB, DEB

| Return to dormancy | | | |
|---|---|---|---|
| **Phenophase Title** | **Applicable Growth Forms** | **Status Description** | **Intensity Question** |
| Falling leaves | DBL<br>DDB<br>SEB | One or more leaves with typical late-season color, or yellow or brown due to other stresses, are falling or have recently fallen from the plant. Do not include fully dried or dead leaves that remain on the plant for many days before falling. | NA |
| Falling needles | DC | One or more needles are falling or have recently fallen from the plant. | NA |

Falling leaves – DBL, DDB, SEB
Falling needles – DC (not shown here)

**** SEE SCENARIO ON NEXT PAGE FOR AN EXAMPLE OF LEAVES, COLORED LEAVES AND FALLING LEAVES STATUS AND INTENSITY ASSESSMENT****

**Estimating percent canopy with colored leaves/needles (P5)**

To estimate the percentage of the canopy that is full with **colored leaves/needles**, consider the proportion of colored leaves and needles that are left on the plant relative to the fully leafed out canopy.

For instance, if the plant canopy is 100% full with leaves but about half of them are green and half are colored, you would report that 100% of the canopy is full with leaves, and 50% of the canopy is full with colored leaves. (Scenario A)

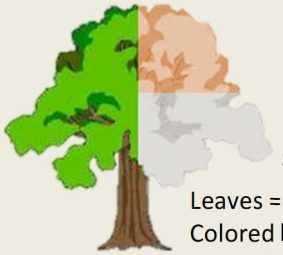
If it is windy the next day, and half of the colored leaves fall off (but none of the green leaves fall off), you would now report that 75% of the canopy is full with leaves and 25% of the canopy is full with colored leaves. (Scenario B)

As the days go on, more of the leaves change color and some fall off, and you might eventually find that only half of the leaves remain on the plant and there is no green left in them. At this point you would report that 50% of the canopy is full with leaves and 50% of the canopy is full with colored leaves. (Scenario C)

Note that the percentage of the canopy full with leaves or needles (green plus colored) should steadily decline from 100% to 0% as leaves or needles fall off. However, the percentage of the canopy full with colored leaves or needles may go up and down during this time of leaf/needle fall.

**Scenario A**

Leaves = 100% leaves on (≥95%)
Colored leaves = 50% (50-74%)
Falling leaves = no



**Scenario B**

Leaves = 75% leaves on (75-94%)
Colored leaves = 25% colored (25-49%)
Falling leaves = yes

**Scenario C**

Leaves = 50% leaves on (50-74%)
Colored leaves = 50% colored (50-74%)
Falling leaves = yes

**HELPFUL INFORMATION FOR INTENSITY ESTIMATION**

- **Multiple phenophases** may be reported for an individual in a single bout. Evaluate each phenophase independently from the others. For example, for **Breaking buds/ emerging needles / initial growth phenophase**, each leaf bud, needle bud, or shoot should be judged separately. As long as some buds or shoots on the plant are still breaking or initiating growth and have not yet produced an unfolded leaf or needle, you are seeing 'Breaking leaf/needle buds', 'Emerging needles', or 'Initial growth'. For plants that have more than one bud or shoot, in most cases you will still be seeing 'Breaking leaf/needle buds', 'Emerging needles', or 'Initial growth' in some buds or shoots for many days after you first begin seeing 'Leaves/Needles' or 'Young leaves/needles' from other buds or shoots. It is also possible to see multiple episodes of leaf/needle bud break or initial growth within a season. This might occur after a period of frost, drought, or after a plant is defoliated by insects. However, once ALL the active leaf/needle buds or shoots on the plant have at least one unfolded leaf/needle, you should be reporting that you no longer see 'Breaking leaf/needle buds', 'Emerging needles', or 'Initial growth'.

- For grass, sedge and rush species where new growth is from new stems, the plant will probably be 100% green until it begins to turn brown in the late summer or fall. For species where existing stems can turn brown and then re-green, the percentage may start low at the beginning of the growing season, become higher in the middle of the growing season, and then decline again as the plant turns brown again. In dryland environments where conditions are extreme, it can be particularly difficult to judge what portion of a grass plant is truly dead and what portion has the potential to re-green. If this is the case for your plant, you may want to ignore this intensity question and just report on whether or not you see green leaves. (https://www.usanpn.org/nn/faq#percent_green)

- If unsure about the intensity class for the increasing leaf size phenophase for deciduous broad leaf species (DBL), refer to the annual data from the previous year to see the length of an adult leaf for that species. In the first year of operations this will have to be an educated guess since the data will not yet be available for a quantitative assessment. This measurement is included in order to track the length of the "green-up" period, the amount of time it takes leaves to reach full size, an important aspect of a plant's response to climate change.

- Continue to report seeing 'Leaves/Needles' as long as fresh green or colored leaves/needles remain on the plant. Do not include dried, dead leaves or dead, brown needles that remain on the plant, such as occurs with some species throughout the dormant season (e.g., winter or dry season)..

- There are no intensity options for Falling Leaves because the percentage of leaves or needles that have fallen from a deciduous plant can be calculated from the percentage of leaves or needles that remains on the plant. This is already captured in the value you reported for percentage of the canopy is full with leaves/needles for the 'Leaves/needles' phenophase.

**APPENDIX B REMINDERS**

# Phenology Sampling

## Selecting plants: Be sure to…

- ☑ Select representative plants (in terms of age and health).
- ☑ Wrap wire loosely (if used to attach ID tag).
- ☑ Space selected individuals evenly around the loop.
- ☑ Give preference to plants that are close to the loop over those that are farther away.

## Walking the loop

- ☑ Use designated route for accessing loop.
- ☑ Stay out of restricted area.
- ☑ Avoid walking on/trampling plant productivity plots.
- ☑ Stay on the loop as much as possible.
- ☑ Look for all phenophases and assess intensity.
- ☑ Record photo file number on Data Sheet.

## Photography tips

- ☑ Flash: Turn off for close-up shots.
- ☑ Macro mode: Use for close-ups.
- ☑ Framing: Position camera so subject fills the frame.
- ☑ Focus: Check this! Brace yourself to reduce movement.
- ☑ Purpose: Keep this in mind.

A middle-distance shot shows intensity.

A close-up captures each flower.

## APPENDIX C ESTIMATED DATES FOR ONSET AND CESSATION OF SAMPLING

The dates in the table below are estimated from satellite MODIS-EVI phenology data averaged from 2005-2014 (Didan 2015). Dates presented here are only a guide, and are derived according to the logic presented in Section 4.2. Because individual years may vary widely from the average dates provided below, it is essential that domain staff monitor real-time conditions to determine when to start (and stop) sampling, as described in Section 4 of this protocol.

The dates in **Error! Reference source not found.** were generated from previously collected phenology data from NEON sites or data from the ORNL DACC MODIS/Terra Vegetation Indices (NDVI/EVI) 'MODIS Phenology time series' report for an area 2 km on a side centered on the lat/long of the Tower location at each site. These dates are intended to provide general guidance on historic phenophase transitions to inform scheduling for future sampling seasons.

The date of bud break within a given year for a selected species may be affected by interactions between temperature, precipitation, and day length. Accumulated Growing Degree Days (AGDD) is one variable often associated year to year variability in start of season, and may be useful for tracking temperature accumulation for a given year and predicting when plants at a given site are likely to become phenologically active. The 'Temperature Accumulations, Current Day' maps in the USA-NPN data visualization tool (http://data.usanpn.org/npn-viz-tool/) enables tracking of the current year's AGDD and allows comparison to the previous year and 30-year average for a given site. When planning observation bouts domain staff are encouraged to use the summary of past years' data provided here, direct observations of indicator individuals, and the AGDD maps and forecasts available through the USA-NPN website to plan initiation of sampling at a given site (seasonal sampling) for the calendar year.

**Error! Reference source not found.** Data Fields and assumptions:

- **Domain ID** – Domain identifier
- **Site ID** – Site identifier
- **Schedule** – identifies dynamic (Seasonal, Hybrid) vs. consistent (Year-round) sampling frequency
- **Data Source** –either NEON collected data from the site or satellite derived, MODIS, EVI transition dates
- **Source Year** – years of data analyzed
    - NEON collected data, the first sampling year omitted from, typically not a full season
    - MODIS data, sites with < 1 full season of data collection or year-round sampling scheudule
- **Spring High Frequency** – early season frequency, reflects iteration with sites to reduce number of bouts conducted during spring transitions, based on extended sampling seasons
- **Start Season** – NEON data: earliest recorded phenophaseStatus = 'yes' – 7 days (to capture pre-season dormant bout)
    - MODIS: earliest increasing EVI – 14 days
- **Start Spring High** – earliest recorded phenophaseStatus = 'yes' for 'Breaking leaf buds', 'Breaking needle buds', 'Emerging needles' & 'Initial growth' phenophases

- **End Spring High** – mean date on which the number of individuals with >50% leaves phenophase intensity peaks
- **Start Fall High** – forested sites: mean earliest recorded phenophaseStatus = 'yes' date, > end Spring High, for 'Colored leaves' or 'Colored needles' phenophase.
    - Herbaceous dominated sites and Hybrid schedule: mean start of decreasing EVI (greenness) date from MODIS data
- **End Fall High** - forested sites: latest recorded first date where phenophaseStatus = 'yes' for 'colored leaves' and 'colored needles' peaks
    - Herbaceous sites and Hybrid schedule: Begin Fall High + 30 days
- **End Season** – NEON data: latest recorded phenophaseStatus = 'yes' + 7 days (to capture end of season no bout)
    - MODIS: latest return to minimum EVI + 14 days
- **Suggested Bout Count** – number of bouts recommended by this analysis, details of calculation below
- **Source Year Mean Bouts** – mean number of bouts conducted at each site across previous full sampling seasons

Suggested Bout Count Calculation:

- From **start Season** till **start Spring High** = # wks * 1
- From **start Spring High** till **end Spring High** = # wks *springHiFrequency
- From **end Spring High** till **start Fall High** = # wks * 0.5 (1x/2weeks)
- From **start Fall High** till **end Fall High** = # wks * 2
- From **end Fall High** till **end Season** = # wks * 1
- Hybrid Sites: data informed transition dates and sampling bouts provided (sum) as well total number of weeks from **start Season** till **end Season** (wks). Variable sampling frequency based on multiple, episodic periods of growth or species with dissimilar phenologies are expected to result in a total number of bouts between the two values.

**Table 12**. Suggested Phenology Scheduling by Site

| Domain ID | Site ID | Phase I schedule | Data Source | Source Year Range | Phase I Spring High Frequency* | Start Season | Start Spring High | End Spring High | Start Fall High | End Fall High | End Season | Suggested Bout Count | Source Year Mean Bouts |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| D01 | BART | Seasonal | NEON data | 2015-2017 | 2x/week | 30-Mar | 23-Apr | 18-May | 11-Jul | 4-Oct | 24-Nov | 43 | 48.7 |
| D01 | HARV | Seasonal | NEON data | 2014-2017 | 2x/week | 5-Mar | 12-Apr | 10-Jun | 23-Jul | 12-Oct | 4-Dec | 50 | 51.8 |
| D02 | BLAN | Seasonal | NEON data | 2016-2017 | 2x/week | 17-Feb | 24-Feb | 13-May | 12-Aug | 2-Sep | 19-Dec | 44 | 51.5 |
| D02 | SCBI | Seasonal | NEON data | 2015-2017 | 2x/week | 11-Mar | 18-Mar | 29-Apr | 12-Jul | 5-Sep | 19-Dec | 41 | 53.7 |
| D02 | SERC | Seasonal | NEON data | 2016-2017 | 2x/week | 23-Feb | 2-Mar | 22-May | 26-Jul | 9-Oct | 10-Dec | 51 | 47 |
| D03 | DSNY | Year round | MODIS | 2005-2014 | | | | | | | | 50 | |
| D03 | JERC | Year round | MODIS | 2005-2014 | | | | | | | | 50 | |
| D03 | OSBS | Year round | MODIS | 2005-2014 | | | | | | | | 50 | |
| D04 | GUAN | Year round | MODIS | 2005-2014 | | | | | | | | 50 | |
| D04 | LAJA | Year round | MODIS | 2005-2014 | | | | | | | | 50 | |
| D05 | TREE | Seasonal | NEON data | 2016-2017 | 3x/week | 5-Apr | 22-Apr | 28-May | 2-Aug | 23-Sep | 1-Nov | 36 | 39 |
| D05 | UNDE | Seasonal | NEON data | 2015-2017 | 3x/week | 3-Apr | 10-Apr | 4-Jun | 6-Aug | 27-Sep | 10-Nov | 42 | 46 |
| D06 | KONZ | Seasonal | NEON data | 2016-2017 | 3x/week | 16-Mar | 23-Mar | 27-May | 7-Sep | 7-Oct | 13-Dec | 45 | 39.5 |
| D06 | UKFS | Seasonal | NEON data | 2016-2017 | 2x/week | 8-Mar | 15-Mar | 13-May | 16-Jul | 4-Oct | 19-Dec | 48 | 48 |
| D07 | GRSM | Seasonal | NEON data | 2016-2017 | 2x/week | 16-Feb | 19-Mar | 8-May | 7-Aug | 28-Oct | 12-Dec | 46 | 50 |
| D07 | MLBS | Seasonal | MODIS | 2005-2014 | 3x/week | 24-Mar | 07-Apr | 6-Jun | 8-Aug | 7-Sep | 29-Nov | 42 | |
| D07 | ORNL | Seasonal | NEON data | 2015-2017 | 2x/week | 23-Feb | 6-Mar | 7-May | 6-Sep | 2-Nov | 29-Dec | 41 | 50.3 |
| D08 | DELA | Year round | MODIS | 2005-2014 | | | | | | | | 50 | |
| D08 | TALL | Year round | MODIS | 2005-2014 | | | | | | | | 50 | |
| D08 | LENO | Hybrid | MODIS | | | | | | | | | | |
| D09 | NOGP | Seasonal | NEON data | 2017 | 2x/week | 13-Mar | 20-Mar | 3-Jul | 24-Jul | 31-Aug | 28-Nov | 53 | 45 |
| D09 | WOOD | Seasonal | NEON data | 2015-2017 | 3x/week | 23-Feb | 2-Mar | 24-Apr | 29-Jul | 28-Aug | 16-Dec | 45 | 45.7 |
| D10 | CPER | Year round | MODIS | 2005-2014 | | | | | | | | 50 | |
| D10 | RMNP | Seasonal | MODIS | 2005-2014 | 3x/week | 5-Apr | 19-Apr | 3-Jul | 2-Aug | 1-Sept | 19-Oct | 48 | |

| Domain ID | Site ID | Phase I schedule | Data Source | Source Year Range | Phase I Spring High Frequency* | Start Season | Start Spring High | End Spring High | Start Fall High | End Fall High | End Season | Suggested Bout Count | Source Year Mean Bouts |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| D11 | CLBJ | Year round | MODIS | 2005-2014 | | | | | | | | 50 | |
| D11 | OAES | Year round | MODIS | 2005-2014 | | | | | | | | 50 | |
| D12 | YELL | Hybrid | MODIS | 2005-2014 | 3x/week | 2-Apr | 16-Apr | 18-Jun | 2-Aug | 1-Sep | 12-Oct | 45 | |
| D13 | MOAB | Year round | NEON data | 2016-2017 | 3x/week | 15-Feb | 22-Feb | 12-May | 13-Aug | 12-Sep | 12-Dec | 55 (sum); 41 (wks) | 34.5 |
| D13 | NIWO | Hybrid | NEON data | 2016-2017 | 3x/week | 24-May | 31-May | 3-Jul | 8-Aug | 7-Sep | 1-Nov | 28 (sum); 22 (wks) | 25.5 |
| D14 | JORN | Year round | MODIS | 2005-2014 | | | | | | | | 50 | |
| D14 | SRER | Year round | MODIS | 2005-2014 | | | | | | | | 50 | |
| D15 | ONAQ | Year round | NEON data | 2015-2017 | 3x/week | 8-Feb | 15-Feb | 5-May | 3-Jun | 10-Jun | 6-Dec | 61 (sum); 42 (wks) | 29.3 |
| D16 | ABBY | Seasonal | NEON data | 2017 | 2x/week | 23-Feb | 10-Apr | 16-Jun | 23-Aug | 28-Aug | 20-Nov | 45 | 52 |
| D16 | WREF | Seasonal | MODIS | 2005-2014 | 3x/week | 23-Mar | 7-Apr | 21-Jun | 28-Jul | 27-Aug | 16-Nov | 61 | |
| D17 | SJER | Year round | MODIS | 2005-2014 | | | | | | | | 50 | |
| D17 | SOAP | Year round | MODIS | 2005-2014 | | | | | | | | | |
| D17 | TEAK | Hybrid | MODIS | 2005-2014 | 3x/week | 4-Mar | 18-Mar | 7-Jun | 8-Jul | 7-Aug | 26-Nov | 59 | |
| D18 | BARR | Seasonal | MODIS | 2005-2014 | 3x/week | 4-Jun | 18-Jun | 13-Jul | 27-Jul | 26-Aug | 13-Sep | 22 | |
| D18 | TOOL | Seasonal | MODIS | 2005-2014 | 3x/week | 14-May | 28-May | 4-Jul | 26-Jul | 25-Aug | 16-Sep | 30 | |
| D19 | BONA | Seasonal | MODIS | 2005-2014 | 3x/week | 21-Apr | 5-May | 27-Jun | 26-Jul | 25-Aug | 27-Sep | 37 | |
| D19 | DEJU | Seasonal | NEON data | 2017 | 3x/week | 26-Apr | 3-May | 5-Jun | 25-Jul | 28-Aug | 12-Oct | 27 | 40 |
| D19 | HEAL | Seasonal | NEON data | 2016-2017 | 3x/week | 30-Apr | 7-May | 5-Jun | 26-Jul | 17-Aug | 11-Oct | 26 | 30 |
| D20 | PUUM | Year round | MODIS | 2005-2014 | | | | | | | | 50 | |

*Phase II spring high frequency is 2x/week at all sites.

**Table 13**. Summary of Phase I/II transitions and sampling schedule

| Domain ID | Site ID | Sampling locations* | Primary Transect Collocation | Phase I schedule | Phase I Sampling First Year | Phase II schedule* | Phase II Sampling First Year |
|---|---|---|---|---|---|---|---|
| D01 | BART | 2 | Tower | Seasonal | 2014 | Seasonal | 2021 |
| D01 | HARV | 2 | Tower | Seasonal | 2013 | Seasonal | 2021 |
| D02 | BLAN | 2 | Tower | Seasonal | 2015 | Year round | 2021 |
| D02 | SCBI | 2 | Tower | Seasonal | 2014 | Year round | 2021 |
| D02 | SERC | 2 | Tower | Seasonal | 2015 | Year round | 2021 |
| D03 | DSNY | 2 | Tower | Year round | 2013 | Year round | 2021 |
| D03 | JERC | 2 | Tower | Year round | 2014 | Year round | 2021 |
| D03 | OSBS | 2 | Tower | Year round | 2013 | Year round | 2021 |
| D04 | GUAN | 2 | Tower | Year round | 2015 | Year round | 2021 |
| D04 | LAJA | 1 | Tower | Year round | 2016 | Year round | 2021 |
| D05 | TREE | 2 | Tower | Seasonal | 2015 | Seasonal | 2022 |
| D05 | UNDE | 2 | Tower | Seasonal | 2014 | Seasonal | 2022 |
| D06 | KONZ | 2 | Tower | Seasonal | 2015 | Seasonal | 2021 |
| D06 | UKFS | 2 | Tower | Seasonal | 2015 | Year round | 2021 |
| D07 | GRSM | 2 | Tower | Seasonal | 2015 | Seasonal | 2021 |
| D07 | MLBS | 1 | Tower | Seasonal | 2017 | Seasonal | 2022 |
| D07 | ORNL | 2 | Tower | Seasonal | 2014 | Seasonal | 2021 |
| D08 | DELA | 2 | Tower | Year round | 2015 | Year round | 2021 |
| D08 | TALL | 1 | Tower | Year round | 2014 | Year round | 2021 |
| D08 | LENO | 2 | Tower | Hybrid | 2016 | Year round | 2021 |
| D09 | NOGP | 2 | Tower | Seasonal | 2016 | Seasonal | 2022 |
| D09 | WOOD | 2 | Tower | Seasonal | 2014 | Seasonal | 2022 |
| D10 | CPER | 2 | Tower | Year round | 2013 | Year round | 2021 |
| D10 | RMNP | 2 | Distributed | Seasonal | 2017 | Seasonal | 2022 |
| D11 | CLBJ | 2 | Tower | Year round | 2016 | Year round | 2022 |
| D11 | OAES | 2 | Tower | Year round | 2015 | Year round | 2022 |
| D12 | YELL | 2 | Distributed | Hybrid | 2018 | Year round | 2023 |
| D13 | MOAB | 2 | Tower | Year round | 2015 | Year round | 2022 |
| D13 | NIWO | 2 | Tower | Hybrid | 2015 | Year round | 2021 |
| D14 | JORN | 2 | Tower | Year round | 2015 | Year round | 2022 |
| D14 | SRER | 2 | Tower | Year round | 2016 | Year round | 2021 |
| D15 | ONAQ | 2 | Tower | Year round | 2014 | Year round | 2022 |
| D16 | ABBY | 2 | Tower | Seasonal | 2016 | Year round | 2021 |
| D16 | WREF | 2 | Tower | Seasonal | 2018 | Year round | 2023 |
| D17 | SJER | 2 | Tower | Year round | 2017 | Year round | 2022 |
| D17 | SOAP | 2 | Tower | Year round | 2018 | Year round | 2023 |
| D17 | TEAK | 2 | Tower | Hybrid | 2019 | Seasonal | 2024 |
| D18 | BARR | 2 | Tower | Seasonal | 2017 | Seasonal | 2022 |
| D18 | TOOL | 2 | Tower | Seasonal | 2017 | Seasonal | 2022 |
| D19 | BONA | 2 | Tower | Seasonal | 2017 | Seasonal | 2022 |
| D19 | DEJU | 2 | Tower | Seasonal | 2016 | Seasonal | 2021 |
| D19 | HEAL | 2 | Tower | Seasonal | 2015 | Seasonal | 2021 |
| D20 | PUUM | 1 | Tower | Year round | 2018 | Year round | 2023 |

* For year round sampling schedules, at sites with brief but distinct and predictable dormant periods, bouts may be shifted from dormant periods to spring/fall transitions.

## APPENDIX D SITE-SPECIFIC INFORMATION

List of species selected for phenology monitoring. Species selection is based on a quantitative survey of vegetation within the NEON Tower airshed. Phase I species represent three of the most dominant species at a site. In forested sites, the two most abundant overstory species and the single most abundant understory are selected for phenology monitoring. Shrublands or ecosystems with few trees, the single most abundant overstory species and the two most abundant understory species are selected. In grasslands, all species are selected from the herbaceous community. Selection of Phase II species is ordered sequentially based on each species relative abundance at the site. All species selected in Phase I are also included in Phase II observations. See the Plant Phenology Science Design (AD[06]) for more details.

Approximate timing for Annual measurements is listed for each site. The actual timing is dependent on phenology at the site in a given year and may differ based on growth form.

### D.1 D01 – HARV – Harvard Forest

Annual measurement bout –Forb late July and DBL late September

| Phase I Species | Phase II Species |
|---|---|
| *Acer rubrum* – Deciduous broadleaf | *Prunus serotina* - Deciduous broadleaf |
| *Quercus rubra* – Deciduous broadleaf | *Acer pensylvanicum* - Deciduous broadleaf |
| *Aralia nudicaulis* – Forb | *Betula alleghaniensis* - Deciduous broadleaf |
| | *Betula lenta* - Deciduous broadleaf |
| | *Fagus grandifolia* - Deciduous broadleaf |
| | *Maianthemum canadense* - Forb |
| | *Medeola virginiana* - Forb |
| | *Mitchella repens* - Semi-evergreen broadleaf |
| | *Pinus strobus* - Pine |
| | *Quercus velutina* - Deciduous broadleaf |
| | *Trientalis borealis* - Forb |
| | *Tsuga canadensis* - Evergreen conifer |
| | *Uvularia sessilifolia* - Forb |
| | *Vaccinium angustifolium* - Deciduous broadleaf |
| | *Vaccinium corymbosum* - Deciduous broadleaf |

### D.2 D01 – BART – Bartlett Experimental Forest

Annual measurement bout – late September

| Phase I Species | Phase II Species |
|---|---|
| *Acer rubrum* – Deciduous broadleaf | *Abies balsamea* - Evergreen conifer |
| *Fagus grandifolia* – Deciduous broadleaf | *Acer saccharum* - Deciduous broadleaf |
| *Acer pensylvanicum* – Deciduous broadleaf | *Betula alleghaniensis* - Deciduous broadleaf |
| | *Betula papyrifera* - Deciduous broadleaf |
| | *Epifagus virginiana* - Forb |
| | *Gaultheria procumbens* - Evergreen broadleaf |

| Phase I Species | Phase II Species |
|---|---|
| | *Maianthemum canadense* - Forb |
| | *Medeola virginiana* - Forb |
| | *Mitchella repens* - Semi-evergreen broadleaf |
| | *Picea rubens* - Evergreen conifer |
| | *Pinus strobus* - Pine |

### D.3 D02 – SCBI – Smithsonian Conservation Biology Institute

Annual measurement bout – GRS early September, and DBL late November

| Phase I Species | Phase II Species |
|---|---|
| *Liriodendron tulipifera* – Deciduous broadleaf | *Acer rubrum* - Deciduous broadleaf |
| *Juglans nigra* – Deciduous broadleaf | *Alliaria petiolata* - Forb |
| *Microstegium vimineum* – Graminoid | *Asimina triloba* - Deciduous broadleaf |
| | *Cornus florida* - Deciduous broadleaf |
| | *Elaeagnus umbellata* - Deciduous broadleaf |
| | *Elymus villosus* - Graminoid |
| | *Lindera benzoin* - Deciduous broadleaf |
| | *Persicaria longiseta* - Forb |
| | *Persicaria virginiana* - Forb |
| | *Rosa multiflora* - Deciduous broadleaf |
| | *Rubus phoenicolasius* - Deciduous broadleaf |
| | *Sassafras albidum* - Deciduous broadleaf |
| | *Stellaria media* - Forb |
| | *Symphoricarpos orbiculatus* - Deciduous broadleaf |

### D.4 D02 – SERC – Smithsonian Environmental Research Center

Annual measurement bout – mid November

| Phase I Species | Phase II Species |
|---|---|
| *Liriodendron tulipifera* – Deciduous broadleaf | *Acer rubrum* - Deciduous broadleaf |
| *Fagus grandifolia* – Deciduous broadleaf | *Ailanthus altissima* - Deciduous broadleaf |
| *Lindera benzoin* – Deciduous broadleaf | *Berberis thunbergii* - Deciduous broadleaf |
| | *Celastrus orbiculatus* - Deciduous broadleaf |
| | Cornus florida L. - Deciduous broadleaf |
| | *Liquidambar styraciflua* - Deciduous broadleaf |
| | *Lonicera japonica* - Semi-evergreen broadleaf |
| | *Microstegium vimineum* - Graminoid |
| | *Rosa multiflora* - Deciduous broadleaf |

### D.5 D02 – BLAN – Blandy Experimental Farm

Annual measurement bout – Forb mid-September, DBL mid-November

| Phase I Species | Phase II Species |
|---|---|
| *Rhamnus davurica* – Deciduous broadleaf | *Acer negundo* - Deciduous broadleaf |
| *Lonicera maackii* – Deciduous broadleaf | *Ailanthus altissima* - Deciduous broadleaf |
| *Solidago altissima* – Forb | *Alliaria petiolata* - Forb |
| | *Celastrus orbiculatus* - Deciduous broadleaf |
| | *Elaeagnus umbellata* - Deciduous broadleaf |
| | *Juglans nigra*- Deciduous broadleaf |
| | *Juniperus virginiana* - Evergreen conifer |
| | *Microstegium vimineum* - Graminoid |
| | *Potentilla indica* - Forb |
| | *Rubus phoenicolasius* - Deciduous broadleaf |
| | *Tetradium daniellii* - Deciduous broadleaf |

### D.6 D03 – OSBS – Ordway-Swisher Biological Station

Annual measurement bout – late September

| Phase I Species | Phase II Species |
|---|---|
| *Pinus palustris* – Pine | |
| *Quercus laevis* – Deciduous broadleaf | |
| *Aristida beyrichiana* – Graminoid | |

### D.7 D03 – DSNY – Disney Wilderness Preserve

Annual measurement bout – late August

| Phase I Species | Phase II Species |
|---|---|
| *Andropogon virginicus* – Graminoid | |
| *Aristida beyrichiana* – Graminoid | |
| *Euthamia caroliniana* – Forb | |

### D.8 D03 – JERC – Jones Ecological Research Center

Annual measurement bout – early September

| Phase I Species | Phase II Species |
|---|---|
| *Pinus palustris* – Pine | |
| *Quercus falcata* – Deciduous Broadleaf | |
| *Aristida beyrichiana* – Graminoid | |

### D.9 D04 – GUAN – Guanica Forest

Annual measurement bout – early October

| Phase I Species | Phase II Species |
|---|---|
| *Bursera simaruba* – Drought deciduous broadleaf | |
| *Gymnanthes lucida* – Evergreen broadleaf | |
| *Pisonia albida* – Drought deciduous broadleaf | |
| *Bucida buceras* – Drought deciduous broadleaf (Phenocam) | |

### D.10 D04 – LAJA – Lajas Experimental Station

Annual measurement bout – early October

| Phase I Species | Phase II Species |
|---|---|
| *Pithecellobium dulce* – Semi-evergreen broadleaf | |
| *Cynodon nlemfuensis* – Graminoid | |
| *Urochloa maxima* – Graminoid | |

### D.11 D05 – UNDE – UNDERC

Annual measurement bout – mid October

| Phase I Species | Phase II Species |
|---|---|
| *Acer saccharum* – Deciduous broadleaf | |
| *Populus tremuloides* – Deciduous broadleaf | |
| *Corylus cornuta* – Deciduous broadleaf | |

### D.12 D05 – TREE – Treehaven

Annual measurement bout – late October

| Phase I Species | Phase II Species |
|---|---|
| *Acer saccharum* – Deciduous broadleaf | *Carex pensylvanica* - Graminoid |
| *Acer rubrum* – Deciduous broadleaf | *Ostrya virginiana* - Deciduous broadleaf |
| *Abies balsamea* – Evergreen conifer | *Picea glauca* - Evergreen conifer |
| | *Pinus strobus* - Pine |
| | *Trientalis borealis* - Forb |

### D.13 D06 – KONZ – Konza Prairie Biological Station

Annual measurement bout – mid July

| Phase I Species | Phase II Species |
|---|---|
| *Sorghastrum nutans* – Graminoid | *Ambrosia psilostachya* - Forb |
| *Schizachyrium scoparium* – Graminoid | *Amorpha canescens* - Deciduous broadleaf |
| *Andropogon gerardii* – Graminoid | *Artemisia ludoviciana* - Forb |
| | *Bouteloua curtipendula* - Graminoid |
| | *Ceanothus herbaceus* - Deciduous broadleaf |
| | *Cornus drummondii* - Deciduous broadleaf |
| | *Panicum virgatum* - Graminoid |
| | *Quercus muehlenbergii* - Deciduous broadleaf |
| | *Rhus aromatica* - Deciduous broadleaf |
| | *Rhus glabra* - Deciduous broadleaf |
| | *Rosa arkansana* - Deciduous broadleaf |
| | *Solidago missouriensis* - Forb |
| | *Symphoricarpos orbiculatus* - Deciduous broadleaf |
| | *Symphyotrichum ericoides* - Forb |

| Phase I Species | Phase II Species |
|---|---|
| | Symphyotrichum oblongifolium - Forb |
| | *Vernonia baldwinii* - Forb |
| | *Zanthoxylum americanum* - Deciduous broadleaf |

### D.14 D06 – UKFS – The University of Kansas Field Station

Annual measurement bout – mid July

| Phase I Species | Phase II Species |
|---|---|
| *Symphoricarpos orbiculatus* – Deciduous broadleaf | *Alliaria petiolata* - Forb |
| *Celtis occidentalis* – Deciduous broadleaf | *Desmodium glutinosum* - Forb |
| *Carya ovata* – Deciduous broadleaf | *Diarrhena obovata* - Graminoid |
| | *Gleditsia triacanthos* - Deciduous broadleaf |
| | *Juglans nigra* - Deciduous broadleaf |
| | *Laportea canadensis* - Forb |
| | *Maclura pomifera* - Deciduous broadleaf |
| | *Parthenocissus quinquefolia* - Deciduous broadleaf |
| | *Quercus muehlenbergii* - Deciduous broadleaf |
| | *Ribes missouriense* - Deciduous broadleaf |
| | *Rosa multiflora* - Deciduous broadleaf |
| | *Sanicula odorata* - Forb |
| | *Toxicodendron radicans* - Deciduous broadleaf |
| | *Ulmus americana* - Deciduous broadleaf |

### D.15 D07 – ORNL – Oak Ridge

Annual measurement bout – mid-November

| Phase I Species | Phase II Species |
|---|---|
| *Quercus montana* – Deciduous broadleaf | *Acer saccharum* - Deciduous broadleaf |
| *Liriodendron tulipifera* – Deciduous broadleaf | *Carya tomentosa* - Deciduous broadleaf |
| *Cornus florida* – Deciduous broadleaf | *Cercis canadensis* - Deciduous broadleaf |
| *Acer rubrum* – Deciduous broadleaf (Phenocam) | *Fagus grandifolia* - Deciduous broadleaf |
| | *Liquidambar styraciflua* - Deciduous broadleaf |
| | *Lonicera japonica* - Semi-evergreen broadleaf |
| | *Nyssa sylvatica* - Deciduous broadleaf |
| | *Oxydendrum arboreum* - Deciduous broadleaf |
| | *Pinus strobus* - Pine |
| | *Prunus serotina* - Deciduous broadleaf |
| | *Quercus alba* - Deciduous broadleaf |
| | *Quercus coccinea* - Deciduous broadleaf |
| | *Quercus rubra* - Deciduous broadleaf |
| | *Toxicodendron radicans* - Deciduous broadleaf |
| | *Vaccinium pallidum* - Deciduous broadleaf |

| Phase I Species | Phase II Species |
|---|---|
| | *Vitis rotundifolia* - Deciduous broadleaf |

### D.16 D07 – MLBS – Mountain Lake Biological Station

Annual measurement bout – late October

| Phase I Species | Phase II Species |
|---|---|
| *Acer pensylvanicum* – Deciduous broadleaf | |
| *Acer rubrum* – Deciduous broadleaf | |
| *Quercus alba* – Deciduous broadleaf | |

### D.17 D07 – GRSM – Great Smoky Mountains National Park, Twin Creeks

Annual measurement bout – mid November

| Phase I Species | Phase II Species |
|---|---|
| *Liriodendron tulipifera* – Deciduous broadleaf | *Amphicarpaea bracteate* - Forb |
| *Acer rubrum* – Deciduous broadleaf | *Betula lenta* - Deciduous broadleaf |
| *Acer pensylvanicum* – Deciduous broadleaf | *Cornus florida* - Deciduous broadleaf |
| | *Halesia tetraptera* - Deciduous broadleaf |
| | *Kalmia latifolia* - Evergreen broadleaf |
| | *Lindera benzoin* - Deciduous broadleaf |
| | *Magnolia fraseri* - Deciduous broadleaf |
| | *Oxydendrum arboretum* - Deciduous broadleaf |
| | *Pyrularia pubera* - Deciduous broadleaf |
| | *Quercus montana* - Deciduous broadleaf |
| | *Quercus rubra* - Deciduous broadleaf |
| | *Rhododendron maximum* - Evergreen broadleaf |
| | *Robinia pseudoacacia* - Deciduous broadleaf |
| | *Sanicula canadensis* - Forb |
| | *Toxicodendron radicans* - Deciduous broadleaf |
| | *Tsuga canadensis* - Evergreen conifer |

### D.18 D08 – TALL – Talladega National Forest

Annual measurement bout – late October

| Phase I Species | Phase II Species |
|---|---|
| *Pinus palustris* – Pine | |
| *Liquidambar styraciflua* – Deciduous broadleaf | |
| *Vaccinium arboreum* – Semi-evergreen broadleaf | |

### D.19 D08 – DELA – Dead Lake

Annual measurement bout – late November

| Phase I Species | Phase II Species |
|---|---|
| *Celtis laevigata* – Deciduous broadleaf | |
| *Ligustrum sinense* – Semi-evergreen broadleaf | |

| Phase I Species | Phase II Species |
|---|---|
| *Liquidambar styraciflua* – Deciduous broadleaf | |
| *Quercus alba* – Deciduous broadleaf (phenocam) | |
| *Quercus nigra* – Deciduous broadleaf (phenocam) | |
| *Quercus pagoda* – Deciduous broadleaf (phenocam) | |

### D.20 D08 – LENO – Lenoir Landing

Annual measurement bout – mid November

| Phase I Species | Phase II Species |
|---|---|
| *Liquidambar styraciflua* – Deciduous broadleaf | |
| *Carpinus caroliniana* – Deciduous broadleaf | |
| *Ilex decidua* – Deciduous broadleaf | |

### D.21 D09 – WOOD – Woodworth

Annual measurement bout – late July

| Phase I Species | Phase II Species |
|---|---|
| *Poa pratensis* – Graminoid | |
| *Bromus inermis* – Graminoid | |
| *Artemisia absinthium* – Forb | |

### D.22 D09 – NOGP – Northern Great Plains Research Laboratory

Annual measurement bout – late July

| Phase I Species | Phase II Species |
|---|---|
| *Poa pratensis* – Graminoid | |
| *Symphoricarpos occidentalis* – Deciduous broadleaf | |
| *Bromus inermis* – Graminoid | |

### D.23 D10 – CPER – Central Plains Experimental Range

Annual measurement bout – mid July

| Phase I Species | Phase II Species |
|---|---|
| *Bouteloua gracilis* – Graminoid | |
| *Hesperostipa comata* – Graminoid | |
| *Thelesperma filifolium* – Forb | |

### D.24 D10 – RMNP – Rocky Mountain National Park, CASTNET

Annual measurement bout – mid-September

| Phase I Species | Phase II Species |
|---|---|
| *Abies lasiocarpa* – Evergreen conifer | |

| Phase I Species | Phase II Species |
|---|---|
| *Juniperus communis* – Evergreen conifer – no needles | |
| *Pinus contorta* – Pine | |
| *Populus tremuloides* – Deciduous broadleaf | |

### D.25 D11 – CLBJ – LBJ National Grassland

Annual measurement bout – mid October

| Phase I Species | Phase II Species |
|---|---|
| *Quercus stellate* – Deciduous broadleaf | |
| *Schizachyrium scoparium* – Graminoid | |
| *Bothriochloa ischaemum* – Graminoid | |

### D.26 D11 – OAES – Klemme Range Research Station

Annual measurement bout – mid May

| Phase I Species | Phase II Species |
|---|---|
| *Bouteloua gracilis* – Graminoid | |
| *Aristida purpurea* – Graminoid | |
| *Calylophus hartwegii* ssp. *fendleri* – Forb | |

### D.27 D12 – YELL – Yellowstone Northern Range (Frog Rock)

Sampling at Phenocam plot at this site will not occur March 10 – July 1

Annual measurement bout – Mid-July

| Phase I Species | Phase II Species |
|---|---|
| *Artemisia tridentata* – Drought deciduous broadleaf | |
| *Eriogonum umbellatum* – Forb | |
| *Pseudotsuga menziesii* – Evergreen conifer | |

### D.28 D13 – NIWO – Niwot Ridge Mountain Research Station

Annual measurement bout – late July

| Phase I Species | Phase II Species |
|---|---|
| *Geum rossii* var. *turbinatum* – Forb | |
| *Carex rupestris* var. *drummondiana* – Graminoid | |
| *Minuartia obtusiloba* – Forb | |

### D.29 D13 – MOAB – Moab

Annual measurement bout – late July

| Phase I Species | Phase II Species |
|---|---|
| *Ephedra viridis* – Evergreen broadleaf – no leaves | |

| Phase I Species | Phase II Species |
|---|---|
| *Bouteloua gracilis* – Graminoid | |
| *Krascheninnikovia lanata* – Drought deciduous broadleaf | |

### D.30 D14 – SRER – Santa Rita Experimental Range

Annual measurement bout – early October

| Phase I Species | Phase II Species |
|---|---|
| *Larrea tridentata* – Evergreen broadleaf-no leaf buds | |
| *Prosopis velutina* – Drought deciduous broadleaf | |
| *Zinnia acerosa* – Drought deciduous broadleaf | |

### D.31 D14 – JORN – Jornada LTER

Annual measurement bout – mid October

| Phase I Species | Phase II Species |
|---|---|
| *Prosopis glandulosa* – Drought deciduous broadleaf | |
| *Yucca elata* – Evergreen broadleaf – no leaves | |
| *Bouteloua eriopoda* – Graminoid | |

### D.32 D15 – ONAQ – Onaqui-Ault

Annual measurement bout – April, June, and September

| Phase I Species | Phase II Species |
|---|---|
| *Artemisia tridentata* ssp. *tridentata* – Drought deciduous broadleaf | |
| *Ceratocephala testiculata* – Forb | |
| *Bromus tectorum* – Graminoid | |

### D.33 D16 – WREF – Wind River Experimental Forest

Annual measurement bout – mid September

| Phase I Species | Phase II Species |
|---|---|
| *Gaultheria shallon* – Evergreen broadleaf | |
| *Pseudotsuga menziesii* – Evergreen conifer | |
| *Tsuga heterophylla* – Evergreen conifer | |

### D.34 D16 – ABBY – Abby Road

Annual measurement bout – late September

| Phase I Species | Phase II Species |
|---|---|
| *Gaultheria shallon* – Evergreen broadleaf | *Acer circinatum* - Deciduous broadleaf |

| Phase I Species | Phase II Species |
|---|---|
| *Pseudotsuga menziesii* var. *menziesii* – Evergreen conifer | *Alnus rubra* - Deciduous broadleaf |
| *Corylus cornuta* var. *californica* – Deciduous broadleaf | *Chamerion angustifolium* - Forb |
| | *Frangula purshiana* - Deciduous broadleaf |
| | *Holodiscus discolor* - Deciduous broadleaf |
| | *Lotus aboriginus* - Forb |
| | *Rubus laciniatus* - Deciduous broadleaf |
| | *Rubus spectabilis* - Deciduous broadleaf |
| | *Rubus ursinus* - Deciduous broadleaf |
| | *Sambucus nigra* - Deciduous broadleaf |
| | *Sambucus racemosa* - Deciduous broadleaf |
| | *Thermopsis montana* - Forb |
| | *Vaccinium parvifolium* - Deciduous broadleaf |

### D.35 D17 – SJER – San Joaquin Experimental Range

Annual measurement bout – Forb and Graminoid - mid-April, SEB - mid-November

| Phase I Species | Phase II Species |
|---|---|
| *Quercus douglasii* – Semi-evergreen broadleaf | |
| *Erodium botrys* – Forb | |
| *Bromus diandrus* – Graminoid | |

### D.36 D17 – SOAP – Soaproot Saddle

Annual measurement bout – mid-October

| Phase I Species | Phase II Species |
|---|---|
| *Arctostaphylos viscida* – Evergreen broadleaf | |
| *Quercus kelloggii* – Deciduous broadleaf | |
| *Chamaebatia foliosa* | |

### D.37 D17 – TEAK – Lower Teakettle

Annual measurement bout – Forb – July, EC - late October

| Phase I Species | Phase II Species |
|---|---|
| *Abies magnifica* – Evergreen conifer | |
| *Abies concolor* – Evergreen conifer | |
| *Dodecatheon jeffreyi* – Forb | |

### D.38 D18 – TOOL – Toolik Lake

Annual measurement bout – late July

| Phase I Species | Phase II Species |
|---|---|
| *Betula glandulosa/nana* – Deciduous broadleaf | |
| *Eriophorum vaginatum* – Graminoid | |

| Phase I Species | Phase II Species |
|---|---|
| *Vaccinium vitis-idaea* – Evergreen broadleaf | |

### D.39 D18 – BARR – Barrow Environmental Observatory

Annual measurement bout – early August

| Phase I Species | Phase II Species |
|---|---|
| *Carex aquatilis* – Graminoid | |
| *Dupontia fisheri* – Graminoid | |
| *Petasites frigidus* – Forb | |

### D.40 D19 – BONA – Caribou Creek - Poker Flats Watershed

Annual measurement bout – early July

| Phase I Species | Phase II Species |
|---|---|
| *Picea mariana* – Evergreen conifer | *Alnus viridis* - Deciduous broadleaf |
| *Populus tremuloides* – Deciduous broadleaf | *Betula glandulosa/nana* - Deciduous broadleaf |
| *Vaccinium vitis-idaea* – Evergreen broadleaf | *Betula neoalaskana* - Deciduous broadleaf |
| *Ledum groenlandicum* – Evergreen broadleaf (phenocam) | *Calamagrostis lapponica* - Graminoid |
| *Vaccinium uliginosum* – Deciduous broadleaf (phenocam) | *Cornus unalaschkensis* - Deciduous broadleaf |
| | *Eriophorum vaginatum* - Graminoid |
| | *Geocaulon lividum* - Forb |
| | *Larix laricina* - Deciduous conifer |
| | *Ledum palustre* - Evergreen broadleaf |
| | *Picea glauca* - Evergreen conifer |
| | *Rosa acicularis* - Deciduous broadleaf |
| | *Rubus chamaemorus* - Forb |
| | *Salix bebbiana* - Deciduous broadleaf |
| | *Salix pulchra* - Deciduous broadleaf |
| | *Salix scouleriana* - Deciduous broadleaf |
| | Vaccinium oxycoccos - Evergreen broadleaf |

### D.41 D19 – DEJU – Delta Junction

Annual measurement bout – early July

| Phase I Species | Phase II Species |
|---|---|
| *Picea mariana* – Evergreen conifer | *Alnus viridis* - Deciduous broadleaf |
| *Vaccinium vitis-idaea* – Evergreen broadleaf | *Arctostaphylos uva-ursi* - Evergreen broadleaf |
| *Betula glandulosa /nana* – Deciduous broadleaf | *Arnica frigida* ssp. *frigida* - Forb |
| *Vaccinium uliginosum* – Deciduous broadleaf (phenocam) | *Cornus unalaschkensis* - Deciduous broadleaf |
| | *Empetrum nigrum*. - Evergreen broadleaf |
| | *Geocaulon lividum* - Forb |
| | *Ledum groenlandicum* - Evergreen broadleaf |

| Phase I Species | Phase II Species |
|---|---|
| | *Ledum palustre* - Evergreen broadleaf |
| | *Lupinus arcticus* - Forb |
| | *Pedicularis labradorica* - Forb |
| | *Pedicularis lanata* - Forb |
| | *Poa arctica* ssp. *arctica* - Graminoid |
| | *Populus tremuloides* - Deciduous broadleaf |
| | *Rosa acicularis* - Deciduous broadleaf |
| | *Salix alaxensis* - Deciduous broadleaf |
| | *Sanguisorba officinalis* - Forb |

### D.42 D19 – HEAL – Healy

Annual measurement bout – late August

| Phase I Species | Phase II Species |
|---|---|
| *Betula glandulosa /nana* – Deciduous broadleaf | |
| *Picea glauca* – Evergreen conifer | |
| *Ledum palustre* – Evergreen broadleaf | |

### D.43 D20 – PUUM – Pu'u Maka'ala Natural Area Reserve

Annual measurement bout – TBD

| Phase I Species | Phase II Species |
|---|---|
| *Metrosideros polymorpha* – Evergreen broadleaf | |
| *Styphelia tameiameiae* – Evergreen broadleaf | |
| *Acacia koa* – Evergreen broadleaf | |

## APPENDIX E EXAMPLE SCHEDULE FOR A HYBRID SITE

D15 – Onaqui-Ault, precipitation driven, nearly year-round potential growing season, species with different environmental drivers of phenology.

**ONAQ Plant Phenology Timing driven by each species**

| Species | Growth Form | Monitor indicator individual for: | | **Sample 3x/week** until all tagged individuals of a given species show: | | **Sample 1x/week** until all tagged individuals of a given species show: | | Flowering **every other week** | | Monitor for change | **Sample 2x/week** until all individuals show: | | **Sample 1x/week** until: | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CETE5** | Forb | Initial growth | | One or more fully unfolded leaves | | N/A | | Commence every-other week monitoring for flowering phenology | | Monitor indicator individuals for evidence of senescence | N/A | | No more full sized leaves are present OR three consecutive bouts with no change | | |
| (monitored as patches) | | Start | End | Start | End | Start | End | Start | End | | Start | End | Start | End | |
| | | 2/1 | 3/15 | 2/15 | 4/1 | N/A | N/A | 3/1 | 4/1 | | N/A | N/A | 4/1 | 6/1 | |
| *Ceratocephala testiculata*: "Bur buttercup is a winter annual that emerges, flowers, and sets fruits in the spring, when temperatures climb into the 45-50 degree range."- USU Extension | | | | | | | | | | | | | | | |
| **BRTE** | GRS | Initial growth | | >50% of plant is green or three consecutive bouts of no change | | >95% of plant is green OR three consecutive bouts with no change | | Commence every-other week monitoring for open flowers | | Monitor indicator individuals for >5% Leaf senescence (i.e., percentage of plant that is green <95%) | <95% green leaves | | <5% of plant is green OR three consecutive bouts with no change | | |
| (monitored as patches) | | Start | End | Start | End | Start | End | Start | End | | Start | End | Start | End | |
| | | 2/1 | 3/31 | 3/1 | 4/15 | 4/15 | 4/30 | 4/30 | 7/1 | | 5/1 | 7/1 | 7/1 | 8/1 | |
| *Bromus tectorum:* Germination occurs in fall through winter to early spring & flowering occurs from April to mid-June -USDA Fact Sheet A second, sparse generation of B. tectorum has occurred in summer 2014 and 2015 at ONAQ though they did not fully mature/produce flowers | | | | | | | | | | | | | | | |
| ARTR2 | DDB | Breaking leaf buds | | Young leaves | | No more young leaves | | Commence every-other week monitoring for open flowers | | Monitor indicator Individuals for one or more colored leaves: Seasonal monitoring may end at this point if senescence does not occur. | One or more colored leaves | | <5% of canopy full with green or colored leaves OR three consecutive bouts with no change | | |
| | | Start | End | Start | End | Start | End | Start | End | | Start | End | Start | End | |
| | | 3/1 | 4/1 | 4/1 | 5/1 | 5/1 | 9/15 | 8/15 | 11/30 | End ARTR2 Sampling | N/A | N/A | N/A | N/A | |
| *Artemisia tridentata*: "Although characterized as an evergreen shrub, *A. tridentata* functionally has a semi-drought deciduous habit" [1] "Growth of vegetative and reproductive structures in *Artemisia tridentata* is temporally separated during the growing season; vegetative growth occurs during spring and early summer …while reproductive growth occurs during summer and fall …"[2] " … There are three types of leaves on most sagebrush species … "persistent , ephemeral… The third leaf type is on the flowering stalk."[3] | | | | | | | | | | | | | | | |

At ONAQ we have two early season annuals: *Ceratocephala testiculata* and *Bromus tectorum*. *C. testiculata* will emerge essentially as the snow is melting and rapidly progress through its phenophases; having fully senesced by the end of May. *B. tectorum* will begin emerging in March (with a slight delay from snow melt) and flower from April to June. Artemisia on the other hand will continuously put on perennial, ephemeral and flowering stalk leaves during the spring and summer; then flower in late summer/fall.

To maintain less than 50 visits per year, re-distributing emphasis on visits during the spring during green-up then a slow in monitoring during the summer which will still capture Artemisia flowering. The proposed sampling schedule allows a little wiggle room for a late pulse in greenness or variability in spring onset/duration of green-up.

**Proposed ONAQ Plant Phenology schedule to reduce effort**

| Pre-Budburst (opportunistic) | | 3x/week | | 1x/week | | every other week | | 2x/week | | 1x/week | | Estimated # of Bouts |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Start | End | Start | End | Start | End | Start | End | Start | End | Start | End | |
| 2/1 | 2/15 | 2/15 | 4/15 | 4/15 | 6/1 | 6/1 | 11/30 | - | | - | - | |
| 2 | | 27 Visits | | 7 visits | | 14 visits | | | | | | **50** |

**Sources:**

1. Kolb, K. J., & Sperry, J. S. (1999). Transport constraints on water use by the Great Basin shrub, Artemisia tridentata. *Plant Cell and Environment*, *22*, 925-936.
2. Evans, R. D., & Black, R. A. (1993). Growth, Photosynthesis, and Resource Investment for Vegetative and Reproductive Modules of Artemisia Tridentata. *Ecology*, *74*(5), 1516-1528.
3. Rosentreter, R. (2005). Sagebrush identification, ecology, and palatability relative to sage-grouse

## APPENDIX F PHENOCAM PLOT AND SITE BOUNADRY

The phenocam plots listed below have a portion of the 200m by 200m plot that falls outside of the site boundary. Since phenocam field individuals must be within the permitted area use the following workflow to ensure selected individuals are within the boundary.

1. Before heading out in the field make sure the site boundary .imp file has been uploaded to the Trimble unit.
    a. Following steps in A.4 – A.6 (RD [06]) for background files.
2. When out in the field turn the boundary layer on as a background layer.
    a. In **MDD** select **Map**
    b. In **SDD** select **Layers**
    c. Select **Background Files…**
    d. Click the box for the boundary layer
    e. Select **Done**
3. When in “Map” view your current location will be illustrated by an “X”.
4. When selecting the phenocam individuals be sure that the “X” is within in the boundary layer.

| Domain | Site |
|---|---|
| D02 | BLAN |
| D05 | TREE |
| D05 | STEI |
| D08 | LENO |
| D06 | KONA |
| D09 | NOGP |
| D10 | RMNP |

## APPENDIX G EQUIPMENT

The following equipment is needed to implement the procedures in this document. Equipment lists are organized by task. They do not include standard field and laboratory supplies such as charging stations, first aid kits, drying ovens, ultra-low refrigerators, etc.

**Table 14**. Equipment list – Marking phenology transect

R/S=Required/Suggested

| Supplier/ Item No. | Exact Brand | Description | Purpose | Quantity |
|---|---|---|---|---|
| Amazon<br><br>Cabela's: # IK270217<br><br>REI: # 895022 | N | GPS receiver, recreational accuracy | GPS receiver, recreational accuracy | 1 |
| Ben Meadows: # 122733<br><br>Forestry Suppliers: # 39986 | N | Measuring tape, 100 m | Measure transect distances during annual transect establishment | 1 |
| Ben Meadows: # 100952 Forestry Supplier: # 39167 | N | Chaining pins or other suitable anchor | Anchor measuring tapes | 2 sets |
| | N | AA battery | Spare battery for GPS receiver | 2 |
| | N | Permanent marker | Record transect distance/location information on pin flag | 1 |
| Grainger: # 9WGF5 | N | Rectangular unnumbered aluminum tag, yellow | Replace broken or missing markers | Variable |
| | N | Flagging tape | Mark access route to phenology loop | Variable |
| | N | Survey marking flag, PVC or fiberglass stake | Delineate sampling area | 80 |

**Table 15**. Equipment list – Selecting, marking, and mapping individuals and patches

| Item No. | Exact Brand | Description | Purpose | Quantity* |
|---|---|---|---|---|
| Compass Tools: # 88180-04 | Y | GPS receiver, decimeter accuracy (e.g., GEO XH 6000, 7X) | Loading data to GPS that generate spatial location of individuals within the phenocam plot | 1 |
| | N | Laptop | Connecting to live feed from Phenocam | 1 |
| | N | Ethernet Cable | Connecting to live feed from Phenocam | 1 |
| | N | Hand held radio | Communicating between instrument hut and field team | 2 |
| | N | Backup mobile data recorder battery, fully charged | Continue data collect in the event tablet loses charge | 1 |
| | Y | GPS Pathfinder Office Software | Loading data to GPS that will generate spatial data of individuals within the phenocam plot | 1 |
| | N | Hammer | Drive nails | 1 |
| Forestry Suppliers: # 20101601 | N | Hand stamp steel die set | Label blank tags | 1 set |
| Forestry Supplier: # 91567 | Y | Laser Rangefinder, ½ foot (15 cm) accuracy | Measure location information for selected individuals | 1 |
| Ben Meadows: # 122733 Forestry Suppliers: # 39986 | N | Measuring tape, 100 m | Measure location information for selected individuals | 1 |
| EG05390000 | Y | Phenology quadrat | Delineate patches for monitoring | 1 |

| Item No. | Exact Brand | Description | Purpose | Quantity* |
|---|---|---|---|---|
| Grainger: #6ZFY7 | N | Plastic spike | Delineate patch corners | As needed |
| | N | Fiberglass driveway marker | Delineate woody patch corners | As needed |
| | N | Wire cutter | Cut wire to desired length | 1 |
| Forestry Supplier: # 79121 | N | Aluminum nail | Affix tag to stems with DBH ≥ 5 cm | 100 |
| Grainger: # 16Y067 | N | Aluminum wire, 20 gauge | Affix tag to stems with DBH ≥ 5 cm | 1 spool |
| | N | Non-ferrous Pigtail stake | Affix tag and plant card to mark grasses and forbs | Variable |
| | N | Flagging tape | Mark individuals for monitoring | 1 roll |
| | N | Field notebook | Record field notes | 1 |
| | N | CR123A battery | Spare battery for laser rangefinder | 1-2 each |
| Grainger: # 9WGF5 | N | Rectangular unnumbered aluminum tag, yellow | Tag monitored individual or patch | 10 |
| Ben Meadows: # 227431 | Y | Round numbered aluminum tag, blue; 6001-8000 | Tag selected woody stemmed individuals for monitoring. Color and number separates phenology tags from vegetation structure tags. | 100 |
| Ben Meadows: # 152672 | Y | Round unnumbered aluminum tag, blue | Tag woody stemmed individuals selected for both phenology and productivity measurement | 1 |
| | N | Survey marking flag, PVC or fiberglass stake | Flag individuals/patches selected for monitoring and replace missing flags | 80 |

| Item No. | Exact Brand | Description | Purpose | Quantity* |
|---|---|---|---|---|
| | N | Extra battery for GPS receiver | Extend field GPS collection time | 1 |

**Table 16**. Equipment list – Collecting phenology data

| Item No. | Exact Brand | Description | Purpose | Quantity* |
|---|---|---|---|---|
| Grainger:<br># 5CFN4 | N | Binoculars | Observe tree phenophase at a distance | 1 |
| Amazon:<br>#B00HGE3D2K<br><br>B&H:<br># OLTG4B | N | Digital camera, 12 megapixel | Capture images of plants for photo reference book | 1 |
| B&H :<br># CEU80<br><br>Amazon:<br>#B00SJ0WB96<br>#B00BD5ADYO | N | 80 mm spotting scope with 20-60x zoom and angled eyepiece | Resolve tiny features e.g., leaf buds and flowers, in tall canopies. | 1 |
| | N | Tripod | Hold spotting scope | 1 |
| | N | Universal cell phone adapter mount | Mount cell phone camera to spotting scope to take pictures | 1 |
| | N | Field guide, Site-specific phenophase photobook | Calibrate phenophase status and intensity observations and taxa-specific image libraries | 1 |
| Amazon:<br>#B07RTD2PMT | S | GPS receiver, recreational accuracy | Navigate to sampling location | 1 |

| Item No. | Exact Brand | Description | Purpose | Quantity* |
|---|---|---|---|---|
| Cabela's:<br># IK270217<br><br>REI: #163569 | | | | |
| | N | Backup mobile data recorder battery, fully charged | Continue data collect in the event tablet loses charge | 1 |
| | N | Hammer | Drive nails | 1 |
| Forestry Supplier:<br># 91567 | Y | Laser Rangefinder, 1 yard accuracy | Measure location information for new/replacement individuals | 1 |
| EG05390000 | Y | Phenology quadrat | Monitor 0.25 m x 0.25 m patches | 1 |
| | Y | Sampling frame, 1m2 | Monitor 1 m x 1 m patches | 1 |
| Grainger:<br># 6ZFY7 | N | Plastic spike | Replace missing markers | As needed |
| | N | Wire cutter | Cut wire to desired length | 1 |
| | N | AA battery | Spare battery for GPS receiver | 2 |
| Forestry Supplier:<br># 79121 | N | Aluminum nail | Affix replacement tag to stems | 10 |
| Grainger:<br># 16Y067 | N | Aluminum wire, 20 gauge | Affix replacement tag to stems | 1 spool |
| | N | Digital camera battery | Spare battery | 2 |
| | N | Laser Rangefinder battery | Spare battery for laser rangefinder | 2 |
| Grainger:<br># 9WGF5 | N | Rectangular unnumbered aluminum tag, yellow | Replace tags on woody stemmed individuals | 1 |

| Item No. | Exact Brand | Description | Purpose | Quantity* |
|---|---|---|---|---|
| Ben Meadows: # 227431 | Y | Round numbered aluminum tag, blue; 6001-8000 | Tag replacement individuals | 10 |

**Table 17**. Equipment list – Collecting annual data

| Supplier Number | Exact Brand | Description | Purpose | Quantity* |
|---|---|---|---|---|
| Forestry Supplier: # 59422 | Y | DBH tape, 200 cm | Measure stem diameter. Stems present with diameter > 64 cm | 1 |
| Ben Meadows: # 122117<br><br>Forestry Supplier: # 59505 | Y | DBH tape, 64 cm | Measure stem diameter. Stems present with 5 cm < diameter < 64 cm | 1 |
| | N | Backup mobile data recorder battery, fully charged | Continue data collect in the event tablet loses charge | 1 |
| Compass Tools: # 703512<br><br>Forestry Suppliers: # 90998 | Y | Foliage filter | Allow laser rangefinder use in dense vegetation | 1 |
| | N | Handheld caliper, 0.1 cm precision | Measure stem diameters < 5 cm | 1 |

| Supplier Number | Exact Brand | Description | Purpose | Quantity* |
|---|---|---|---|---|
| Forestry Suppliers: # 91567 | Y | Laser Rangefinder, ½ foot (15 cm) accuracy | Map stems recruited into the minimum size class; measure stem height, canopy diameter. Brushy; trees with relatively large canopy diameters; slopes ≥ 20% | 1 |
| Forestry Suppliers: # 71112 | N | Measuring stick, 2 m folding | Measure heights of small-stature woody vegetation | 1 |
| EG05390000 | Y | Phenology quadrat | Monitor 0.25 m x 0.25 m patches | 1 |
| | N | Sampling frame, 1m2 | Monitor 1 m x 1 m patches | 1 |
| | N | CR123A battery | Spare battery for laser rangefinder | 2 |