TOS PROTOCOL AND PROCEDURE: PLANT PHENOLOGY

PREPARED BY	ORGANIZATION	DATE
Katie Jones	FSU	06/2/2015
Sarah Elmendorf	DPS	03/29/2013

APPROVALS	ORGANIZATION	APPROVAL DATE
Mike Stewart	PSE	8/18/2015
Dave Tazik	SCI	7/08/2015

RELEASED BY	ORGANIZATION	RELEASE DATE
Anne Balsley	CM	08/24/2015

See configuration management system for approval history.

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.

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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.

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[05]	NEON.DOC.050005	Field Operations Job Instruction Training Plan
AD[06]	NEON.DOC.000907	NEON Science Design for Plant Phenology
AD[07]	NEON.DOC.014051	Field Audit Plan
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.005003	NEON Scientific 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.001025	TOS Protocol and Procedure: Plot Establishment
RD[07]	NEON.DOC.000987	TOS Protocol and Procedure: Measurement of Vegetation Structure
RD[08]	NEON.DOC.014042	TOS Protocol and Procedure: Plant Diversity
RD[09]	NEON.DOC.01324	Phenology quadrat assembly instructions
RD[10]	NEON.DOC.001246	NEON Algorithm Theoretical Basis Document for TOS Plant Phenology: QA/QC of Raw Field and Lab Data

2.3 Acronyms

All acronyms used in this document are defined in RD [01].

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 – trees and shrubs bearing flat leaves; leaves present during growing season then senesce and fall off during dormant periods (typically winter)

Deciduous conifer - cone bearing trees; needles last through a single growing season then senesce and fall off during dormant periods

Drought deciduous broadleaf – trees and shrubs bearing flat leaves; leaves are typically evergreen but may senesce and drop under drought conditions

Evergreen broadleaf – trees and shrubs bearing flat leaves; leaves may persist for multiple growing seasons, no distinct dormant period

Evergreen conifer - Cone bearing trees and shrubs; needles persist for multiple growing seasons

Evergreen forb - Non-woody flowering plants with aboveground structures that persist for multiple years

Forb - Perennial herbaceous flowering plants

Graminoid - 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 - members of the genus *Pinus*; cone bearing plants; needles typically bundled in sets of 1-6

Semi-evergreen broadleaf- trees and shrubs bearing flat leaves; leaves are typically evergreen in mild climates but may senesce and drop leaves in more extreme climates or under stress conditions

3 METHOD

The strategy for phenology sampling is divided into two phases over the life of the Observatory. The first phase will focus on the phenology of dominant species and will last for the first three years of Operations. Three dominant species will be selected at each site. These three species shall be selected 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. In sites with >50% canopy closure, the two most abundant overstory species shall be selected, along with the single most abundant understory species. NEON Science will specify target species and number of individuals to be selected at each site. In the first phase, up to thirty individuals of each species shall be selected and marked for regular phenological observation. In the next phase, a more diverse suite of plants will be monitored at each site ($n \leq 20$ species), with fewer replicates per species ($n \geq 5$); the total number of species to monitor 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) but 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 range of interest (ROI) does not cover the phenology transect, NEON technicians 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 visible range of interest 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 to define an appropriate region of interest.

NEON plant phenology protocol consists of three procedures, which are assumed to begin following plot establishment (see RD[06]):

- Initial selection of individuals 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.

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 technicians **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 technicians document the problem and enter it in NEON's problem tracking system.

The procedures described in this protocol will be audited according to the Field Audit Plan (AD[07]). Additional quality assurance will be performed on data collected via these procedures according to the NEON Algorithm Theoretical Basis Document for TOS Plant Phenology: QA/QC of Field and Lab Data (RD[10]).

4 SAMPLING SCHEDULE

4.1 Sampling Frequency and Timing

At sites with limited or no pronounced dormant season (e.g.,tropical, southeast), or >1 growing season/year, sampling will take place throughout much of the year though at a lower frequency such that a similar number of bouts is possible (roughly 50 bouts/year or once a week for sites with no defined growing season).

Some sites, especially in arid environments may be driven by moisture rather than temperature. In this case, sampling dates and frequency may be more episodic but sampling should have the same goal of maintaining a similar number of bouts per year with higher frequency during periods of rapid change.

At sites with a well-defined, discrete, growing season, 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 plant phenological activity (variably defined as breaking leaf buds, breaking needle buds or emerging needles; see column 2 in Table 1). Intensive sampling (three times a week) 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 to monitor for reproductive phenology. A second intensive stage (sampling twice a week) begins again in the fall to capture leaf senescence/coloring and reduces to once a week through the end of the season. Sampling then slows through the middle of the growing season and escalates again to capture fall color change and senescence **Table 1**.

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 year of less rapid change (Table 1).

Technicians are required to take phenological measurements on all individuals each time monitoring is performed, unless the end-of-season phenophase/trigger has been reached for a particular individual, 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 approximately 2-3 days apart.

When sampling at 2x a week frequency, monitoring bouts should be every 3-5 days.

When sampling at 1x a week frequency monitoring bouts should be 6-9 days apart.

When sampling 1x every other week frequency monitoring bouts should be 10-18 days apart.

Some sites, especially in arid environments, phenology may be driven by moisture rather than temperature. In this case, sampling dates and frequency may be more episodic. but sampling should have the same goal of maintaining a similar number of bouts per year with higher frequency during periods of rapid change. Sampling schedule will be determined by Field Operations staff based on local conditions including the timing and annual patterns of plant growth at the site. One strategy may be to increase sampling frequency to 3x / week following precipitation events in order to catch phenologically active transition periods. However, if periods of growth occur throughout the year or phenology of the selected species are not responding to similar drivers (i.e.,they are out of sync with one another), these sites may be monitored on a once a week, year round schedule to limit total number of bouts. Whenever possible, phenology is the driver of monitoring frequency, not absolute number of monitoring bouts, however to keep phenology monitoring within logistical constraints, Field Operations staff should select a sampling strategy to keep the total number of bouts to about 50 per year.

Table 1. Rule sets for specific growth forms for phenology sampling at sites with a well-defined growing season[1]

Growth form	Monitor indicator individual for:	Sample 3x/week until all tagged individuals show:	Sample 1x/week until all tagged individuals show:	Then[2]:	Then:	Sample 2x/week until all individuals show:	Sample 1x/week until:	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	>50% of canopy is full with leaves or three consecutive bouts of no change	95% or more of canopy is full with leaves	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	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	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	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[3]	One or more colored leaves	<5% of canopy full with green or colored leaves	End sampling season
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 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 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 show:	Sample 1x/week until all tagged individuals show:	Then[2]:	Then:	Sample 2x/week until all individuals show:	Sample 1x/week until:	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	End sampling season
Graminoid	Initial growth	>50% of plant is green or three consecutive bouts of no change	>95% of plant is green	Commence every-other week monitoring for 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	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[4]	Breaking leaf or flower buds	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	Commence every-other week monitoring for open flowers	Monitor indicator individuals for one or more colored leaves[3]	One or more colored leaves	<5% of canopy full with green or colored leaves	End sampling season

[1] This is generally applicable to temperate or boreal systems; 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 flowering phenology precedes leaf/needle bud break 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.

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

[4] Semi-evergreen broadleaf growthform may be used for species in which life history varies with latitude. GrowthForm assignment will be provided by Science, consistent with USA-NPN guidelines. Monitoring strategy should be driven by phenophase observations.

4.2 Criteria for Determining Onset and Cessation of Sampling

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 'no' record; therefor 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 regionaland site specific basis based on knowledge of the local flora. MODIS data in Appendix B provide the earliest recorded increase in NDVI. 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 the species of interest.

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 not monitored throughout the growing season; they are instead used to help guide the start of seasonal sampling and to inform transition to fall monitoring frequency. 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. 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).

In temperate sites with defined growing seasons, sampling ends when 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 an individual is 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 throughout much of the year. 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 must be adaptable as timing will be determined by phenology and may not be limited to a pre-defined time of the 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; record in the comments that x number or bouts were missed due to…[explain] so that missing bouts may be accounted for in the metadata. Be especially mindful of missed phenophase transitions and determine sampling frequency based on the phenology occurring when monitoring resumes.

When selecting individuals for 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. If the required number of individuals are not present on the entire transect, select as many as are available, make a note for metadata that only x number of the selected species were available for phenology monitoring. If during the Phase II phenology monitoring a selected species is not present on the transect for monitoring, move to the next species on the list; 50% contingency will be provided for on the site list.

If an individual is lost or killed mid-season and a near-by suitable replacement is not available, 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.

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 for the metadata 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 1**).

Table 2. Contingent decisions

Delay/Situation	Action	Outcome for Data Products
1 hr-2 days	Resume monitoring as soon as feasible	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, inability to generate some L1 summary data for a given site
> 2 months	Suspend phenology monitoring for the year	Estimation of transition dates for multiple phenophases for multiple species will not be possible. Inability to generate L1 summary data for the growing season.

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.

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.

6 PERSONNEL AND EQUIPMENT

6.1 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 3. Equipment list – Marking phenology transect

Item No.	R/S	Description	Purpose	Quantity*	Special Handling
Durable Items					
MX100703	R	GPS receiver, recreational accuracy	Navigate to sampling location	1	N
MX100318	R	Measuring tape, 100 m	Measure transect distances during annual transect establishment	1	N
MX104361	R	Chaining pins or other suitable anchor	Anchor measuring tapes	2 sets	N
Consumable items					
	S	AA battery	Spare battery for GPS receiver	2	N
	R	Permanent marker	Record transect distance/location information on pin flag	1	N

MX106653	S	Rectangular unnumbered aluminum tag, yellow	Replace broken or missing markers	Variable	N
		Flagging tape	Mark access route to phenology loop	Variable	N
	R	Survey marking flag, PVC or fiberglass stake	Delineate sampling area	80	N

R/S=Required/Suggested

Table 4. Equipment list – Selecting, marking, and mapping individuals and patches

Item No.	R/S	Description	Purpose	Quantity*	Special Handling
Durable Items					
	R	Hammer	Drive nails	1	N
MX103480	R	Hand stamp steel die set	Label blank tags	1 set	N
MX100322	S	Laser Rangefinder, ½ foot (15 cm) accuracy	Measure location information for selected individuals	1	N
MX100318	S	Measuring tape, 100 m	Measure location information for selected individuals	1	N
EG05390000	R	Phenology quadrat	Delineate patches for monitoring	1	N
MX103881	S	Plastic spike	Delineate patch corners	As needed	N

Item No.	R/S	Description	Purpose	Quantity*	Special Handling
	R	Wire cutter	Cut wire to desired length	1	N
Consumable items					
MX103224	R	Aluminum nail	Affix tag to stems with DBH ≥ 5 cm	100	N
MX107336	R	Aluminum wire, 20 gauge	Affix tag to stems with DBH ≥ 5 cm	1 spool	N
	S	Pigtail stake	Affix tag and plant card to mark grasses and forbs	Variable	N
	S	Flagging tape	Mark individuals for monitoring	1 roll	N
	S	Field notebook	Record field notes	1	N
	S	CR123A battery	Spare battery for laser rangefinder	1-2 each	N
MX106653	S	Rectangular unnumbered aluminum tag, yellow	Tag monitored individual or patch	10	N
MX105814	R	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	N
MX105816	R	Round unnumbered aluminum tag, blue	Tag woody stemmed individuals selected for both phenology and productivity measurement	1	N

Item No.	R/S	Description	Purpose	Quantity*	Special Handling
	S	Survey marking flag, PVC or fiberglass stake	Flag individuals/patches selected for monitoring and replace missing flags	80	N

R/S=Required/Suggested

Many of the suggested items in Table 5 will only be used in the event that an individual or patch must be dropped and a new individual or patch selected, mapped and marked.

Table 5. Equipment list – Collecting phenology data

Item No.	R/S	Description	Purpose	Quantity*	Special Handling
Durable Items					
MX102191	R	Binoculars	Observe tree phenophase at a distance	1	N
MX100696	R	Digital camera, 12 megapixel	Capture images of plants for photo reference book	1	N
	R	Field guide, Site-specific phenophase photobook	QA/QC phenophase observations and taxa-specific image libraries	1	N
MX100703	S	GPS receiver, recreational accuracy	Navigate to sampling location	1	N

Item No.	R/S	Description	Purpose	Quantity*	Special Handling
	S	Hammer	Drive nails	1	N
MX104742	S	Laser Rangefinder, 1 yard accuracy	Measure location information for new/replacement individuals	1	N
EG05390000	R	Phenology quadrat	Monitor patches	1	N
MX103881	S	Plastic spike	Replace missing markers	As needed	N
	S	Wire cutter	Cut wire to desired length	1	N
Consumable items					
	S	AA battery	Spare battery for GPS receiver	2	N
MX103224	S	Aluminum nail	Affix replacement tag to stems	10	N
MX107336	S	Aluminum wire, 20 gauge	Affix replacement tag to stems	1 spool	N
	S	Digital camera battery	Spare battery	2	N
		Laser Rangefinder battery	Spare battery for laser rangefinder	2	N
MX106653	S	Rectangular unnumbered aluminum tag, yellow	Replace tags on woody stemmed individuals	1	N

Item No.	R/S	Description	Purpose	Quantity*	Special Handling
MX105814	S	Round numbered aluminum tag, blue; 6001-8000	Tag replacement individuals	10	N
Resources					
RD[05]	R	Field datasheet	Record data		N

R/S=Required/Suggested

Table 6. Equipment list – Collecting annual data

Item No.	R/S	Description	Purpose	Quantity*	Special Handling
Durable Items					
MX106349	R	DBH tape, 200 cm	Measure stem diameter. Stems present with diameter > 64 cm	1	N
MX106348	R	DBH tape, 64 cm	Measure stem diameter. Stems present with 5 cm < diameter < 64 cm	1	N
MX103218	R	Foliage filter	Allow laser rangefinder use in dense vegetation	1	N
	R	Handheld caliper, 0.1 cm precision	Measure stem diameters < 5 cm	1	N

Item No.	R/S	Description	Purpose	Quantity*	Special Handling
MX100322	R	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	N
MX105823	R	Measuring stick, 2 m folding	Measure heights of small-stature woody vegetation	1	N
EG05390000	R	Phenology quadrat	Monitor patches	1	N
Consumable items					
	R	CR123A battery	Spare battery for laser rangefinder	2	N
Resources					
	R	Field datasheet	Record data		N

R/S=Required/Suggested

6.2 Training Requirements

All technicians must complete required safety training and protocol-specific training for safety and implementation of this protocol as required in Field Operations Job Instruction Training Plan (AD[05]).

6.3 Specialized Skills

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

All technicians 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.

6.4 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.

Annual marking of the transect – This task only occurs once a year and may take a team of 2 people as much as 4-5 hours to complete, depending on the complexity of the understory vegetation.

Selection of individuals/patches to monitor – With the exception of replacing lost or dead indivdiuals, selection of perennial and long-lived individuals typically only occurs twice at each site, once for Phase Isampling and then again, three years later, for Phase II sampling. New individuals of annual and biennial individuals will be selected each year. This task may require 4-8 hours to complete.

Regular monitoring bouts – Once practiced and able to quickly assess phenophase status and intensity of an individual or patch, regular monitoring bouts should take a team of 2 about 2 hours to complete.

7 STANDARD OPERATING PROCEDURES

SOP A Preparing for Sampling

Prior to each field season, review pre-selected species for each site (Appendix C).

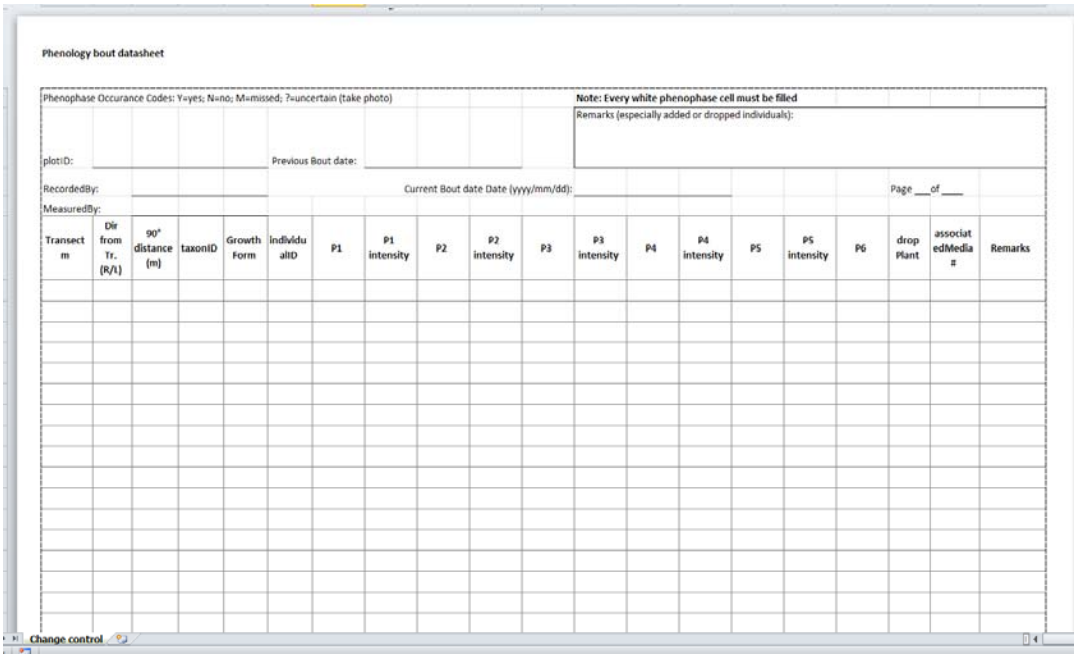
Prior to each data collection bout locate sampling equipment; familiarize yourself with the phenophase definitions and photos as required. Bringing photos with you to the field is advised for all technicians.

A.1 Pre-populating Paper Datasheets

Formatted, pre-populated datasheets with individual location, tagID, species and growth form facilitate field data collection. Data sheets 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. Updating this list will be the responsibility of field technicians at each domain.

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

1. 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:

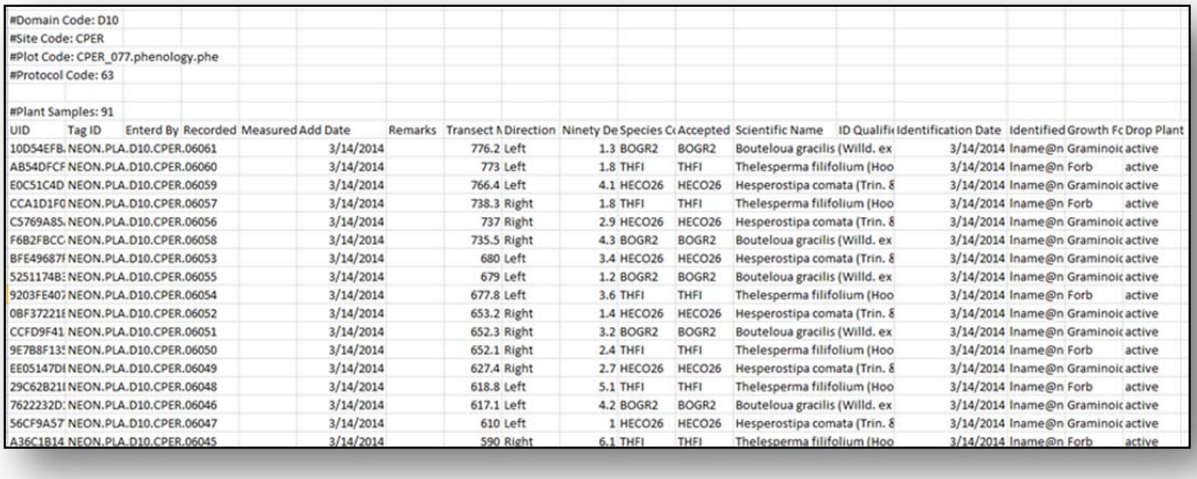
RecordedBy: Current Bout date Date (yyyy/mm/dd): Page __ of __

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

2. Open the perindividual review csv downloaded from the Web UI following the initial selection of individuals for sampling (the actual format of the csv may differ from the format displayed here but the fields will be the same)

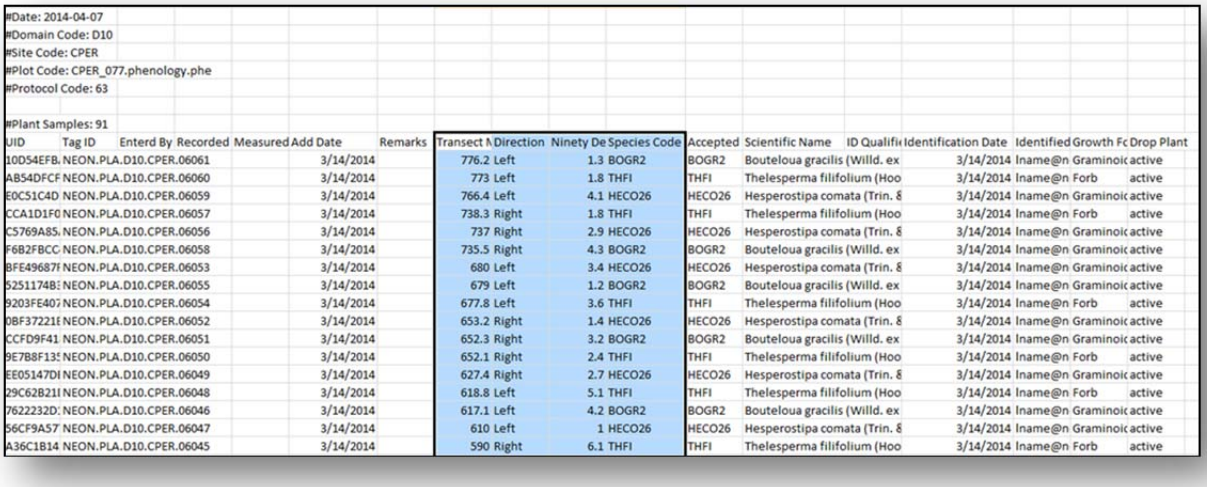


#Domain Code: D10
#Site Code: CPER
#Plot Code: CPER_077.phenology.phe
#Protocol Code: 63

#Plant Samples: 91

UID	Tag ID	Enterd By	Recorded	Measured	Add Date	Remarks	Transect M	Direction	Ninety De	Species Co	Accepted	Scientific Name	ID Qualifie	Identification Date	Identified	Growth Fo	Drop Plant
10D54EFB	NEON.PLA	D10.CPER.06061			3/14/2014		776.2	Left	1.3	BOGR2	BOGR2	Bouteloua gracilis (Willd. ex		3/14/2014	lname@n	Graminoi	active
AB54DFCF	NEON.PLA	D10.CPER.06060			3/14/2014		773	Left	1.8	THFI	THFI	Thelesperma filifolium (Hoo		3/14/2014	lname@n	Forb	active
E0C51C4D	NEON.PLA	D10.CPER.06059			3/14/2014		766.4	Left	4.1	HECO26	HECO26	Hesperostipa comata (Trin. &		3/14/2014	lname@n	Graminoi	active
CCA1D1F0	NEON.PLA	D10.CPER.06057			3/14/2014		738.3	Right	1.8	THFI	THFI	Thelesperma filifolium (Hoo		3/14/2014	lname@n	Forb	active
C5769A85	NEON.PLA	D10.CPER.06056			3/14/2014		737	Right	2.9	HECO26	HECO26	Hesperostipa comata (Trin. &		3/14/2014	lname@n	Graminoi	active
F6B2FBCC	NEON.PLA	D10.CPER.06058			3/14/2014		735.5	Right	4.3	BOGR2	BOGR2	Bouteloua gracilis (Willd. ex		3/14/2014	lname@n	Graminoi	active
BFE49687	NEON.PLA	D10.CPER.06053			3/14/2014		680	Left	3.4	HECO26	HECO26	Hesperostipa comata (Trin. &		3/14/2014	lname@n	Graminoi	active
5251174B	NEON.PLA	D10.CPER.06055			3/14/2014		679	Left	1.2	BOGR2	BOGR2	Bouteloua gracilis (Willd. ex		3/14/2014	lname@n	Graminoi	active
9203FE40	NEON.PLA	D10.CPER.06054			3/14/2014		677.8	Left	3.6	THFI	THFI	Thelesperma filifolium (Hoo		3/14/2014	lname@n	Forb	active
0BF37221	NEON.PLA	D10.CPER.06052			3/14/2014		653.2	Right	1.4	HECO26	HECO26	Hesperostipa comata (Trin. &		3/14/2014	lname@n	Graminoi	active
CCFD9F41	NEON.PLA	D10.CPER.06051			3/14/2014		652.3	Right	3.2	BOGR2	BOGR2	Bouteloua gracilis (Willd. ex		3/14/2014	lname@n	Graminoi	active
9E7B8F13	NEON.PLA	D10.CPER.06050			3/14/2014		652.1	Right	2.4	THFI	THFI	Thelesperma filifolium (Hoo		3/14/2014	lname@n	Forb	active
EE05147D	NEON.PLA	D10.CPER.06049			3/14/2014		627.4	Right	2.7	HECO26	HECO26	Hesperostipa comata (Trin. &		3/14/2014	lname@n	Graminoi	active
29C62B21	NEON.PLA	D10.CPER.06048			3/14/2014		618.8	Left	5.1	THFI	THFI	Thelesperma filifolium (Hoo		3/14/2014	lname@n	Forb	active
7622232D	NEON.PLA	D10.CPER.06046			3/14/2014		617.1	Left	4.2	BOGR2	BOGR2	Bouteloua gracilis (Willd. ex		3/14/2014	lname@n	Graminoi	active
56CF9A57	NEON.PLA	D10.CPER.06047			3/14/2014		610	Left	1	HECO26	HECO26	Hesperostipa comata (Trin. &		3/14/2014	lname@n	Graminoi	active
A36C1B14	NEON.PLA	D10.CPER.06045			3/14/2014		590	Right	6.1	THFI	THFI	Thelesperma filifolium (Hoo		3/14/2014	lname@n	Forb	active

3. Copy fields:
   a. **transectMeter**
   b. **directionFromTransect**
   c. **ninetyDegreeDistance**
   d. **Species Code (taxonID)**

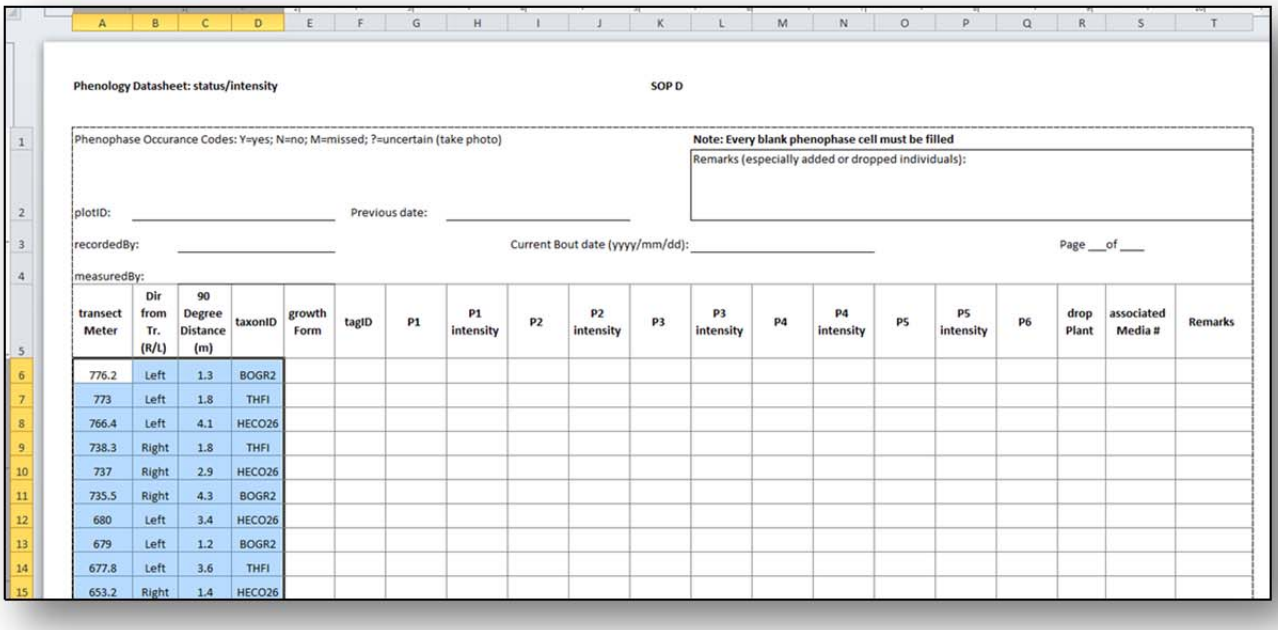


#Date: 2014-04-07
#Domain Code: D10
#Site Code: CPER
#Plot Code: CPER_077.phenology.phe
#Protocol Code: 63

#Plant Samples: 91

UID	Tag ID	Enterd By	Recorded	Measured	Add Date	Remarks	Transect M	Direction	Ninety De	Species Code	Accepted	Scientific Name	ID Qualifie	Identification Date	Identified	Growth Fo	Drop Plant
10D54EFB	NEON.PLA	D10.CPER.06061			3/14/2014		776.2	Left	1.3	BOGR2	BOGR2	Bouteloua gracilis (Willd. ex		3/14/2014	lname@n	Graminoi	active
AB54DFCF	NEON.PLA	D10.CPER.06060			3/14/2014		773	Left	1.8	THFI	THFI	Thelesperma filifolium (Hoo		3/14/2014	lname@n	Forb	active
E0C51C4D	NEON.PLA	D10.CPER.06059			3/14/2014		766.4	Left	4.1	HECO26	HECO26	Hesperostipa comata (Trin. &		3/14/2014	lname@n	Graminoi	active
CCA1D1F0	NEON.PLA	D10.CPER.06057			3/14/2014		738.3	Right	1.8	THFI	THFI	Thelesperma filifolium (Hoo		3/14/2014	lname@n	Forb	active
C5769A85	NEON.PLA	D10.CPER.06056			3/14/2014		737	Right	2.9	HECO26	HECO26	Hesperostipa comata (Trin. &		3/14/2014	lname@n	Graminoi	active
F6B2FBCC	NEON.PLA	D10.CPER.06058			3/14/2014		735.5	Right	4.3	BOGR2	BOGR2	Bouteloua gracilis (Willd. ex		3/14/2014	lname@n	Graminoi	active
BFE49687	NEON.PLA	D10.CPER.06053			3/14/2014		680	Left	3.4	HECO26	HECO26	Hesperostipa comata (Trin. &		3/14/2014	lname@n	Graminoi	active
5251174B	NEON.PLA	D10.CPER.06055			3/14/2014		679	Left	1.2	BOGR2	BOGR2	Bouteloua gracilis (Willd. ex		3/14/2014	lname@n	Graminoi	active
9203FE40	NEON.PLA	D10.CPER.06054			3/14/2014		677.8	Left	3.6	THFI	THFI	Thelesperma filifolium (Hoo		3/14/2014	lname@n	Forb	active
0BF37221	NEON.PLA	D10.CPER.06052			3/14/2014		653.2	Right	1.4	HECO26	HECO26	Hesperostipa comata (Trin. &		3/14/2014	lname@n	Graminoi	active
CCFD9F41	NEON.PLA	D10.CPER.06051			3/14/2014		652.3	Right	3.2	BOGR2	BOGR2	Bouteloua gracilis (Willd. ex		3/14/2014	lname@n	Graminoi	active
9E7B8F13	NEON.PLA	D10.CPER.06050			3/14/2014		652.1	Right	2.4	THFI	THFI	Thelesperma filifolium (Hoo		3/14/2014	lname@n	Forb	active
EE05147D	NEON.PLA	D10.CPER.06049			3/14/2014		627.4	Right	2.7	HECO26	HECO26	Hesperostipa comata (Trin. &		3/14/2014	lname@n	Graminoi	active
29C62B21	NEON.PLA	D10.CPER.06048			3/14/2014		618.8	Left	5.1	THFI	THFI	Thelesperma filifolium (Hoo		3/14/2014	lname@n	Forb	active
7622232D	NEON.PLA	D10.CPER.06046			3/14/2014		617.1	Left	4.2	BOGR2	BOGR2	Bouteloua gracilis (Willd. ex		3/14/2014	lname@n	Graminoi	active
56CF9A57	NEON.PLA	D10.CPER.06047			3/14/2014		610	Left	1	HECO26	HECO26	Hesperostipa comata (Trin. &		3/14/2014	lname@n	Graminoi	active
A36C1B14	NEON.PLA	D10.CPER.06045			3/14/2014		590	Right	6.1	THFI	THFI	Thelesperma filifolium (Hoo		3/14/2014	lname@n	Forb	active

4. 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):

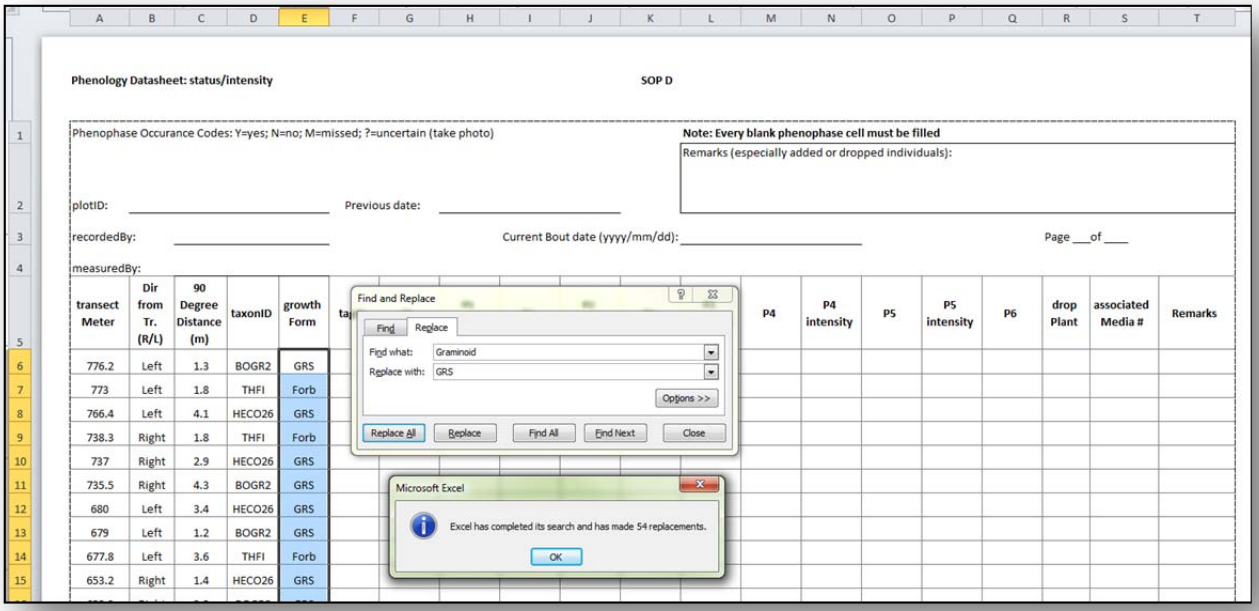
plotID: _____ Previous date: _____

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																

5. Copy/paste (values only) growth form into the datasheet. Use the find/replace (Crtl + h) function to convert growth form names to code.



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):

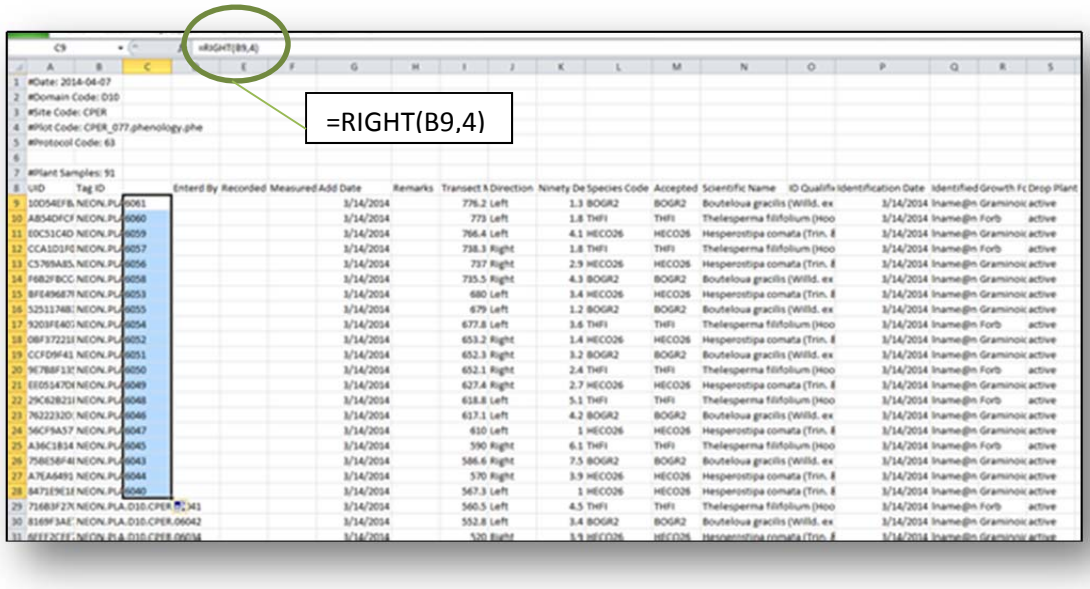
plotID: _____ Previous date: _____

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

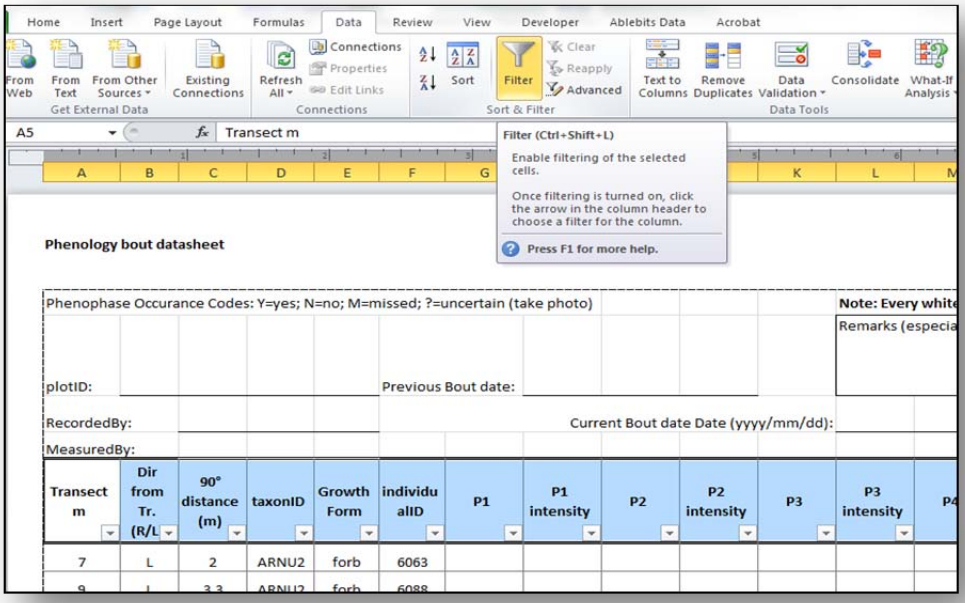
measuredBy:

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								

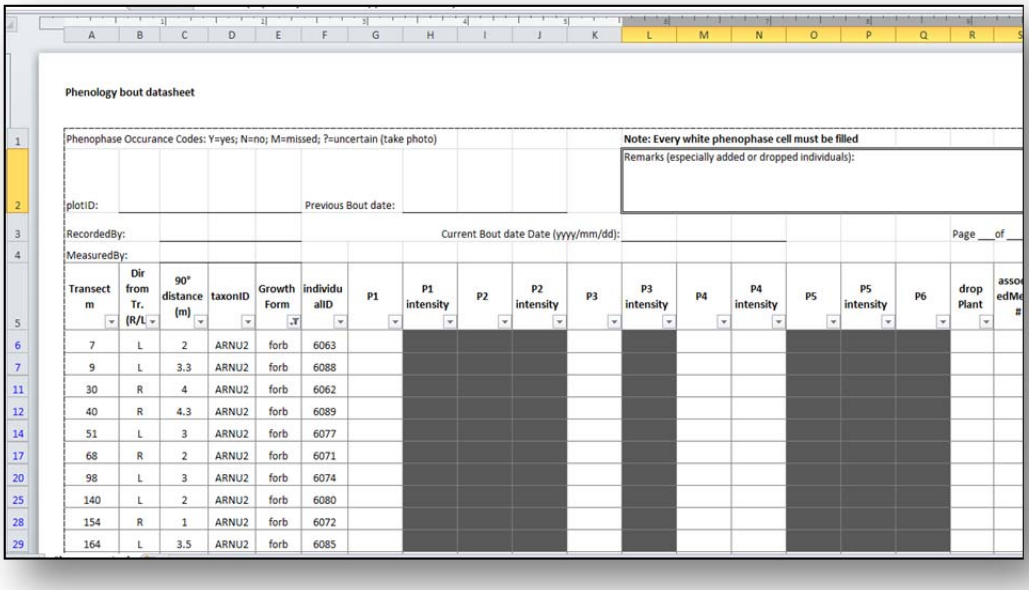
6. Extract tagID from the globally unique individual ID (labeled 'Tag ID' on the csv)
   a. Highlight the Tag ID column, right click, select 'Insert'
   b. In the blank cell to the right of the first Tag ID enter : '=RIGHT([click adjacent cell], 4)'
      1) If phenology tag IDs are >=10,000, enter 5 instead of 4
   c. Click Enter
   d. Click the right corner of the cell, drag function down through the column
   e. Copy/paste values from the new row into the tagID field of the datasheet



7. Double check that all columns are properly aligned and that the location information matches the individual ID
8. Add filters to the datasheet
   a. Highlight the row containing field names
   b. In the 'Data' tab click filter, arrows will appear next to field names

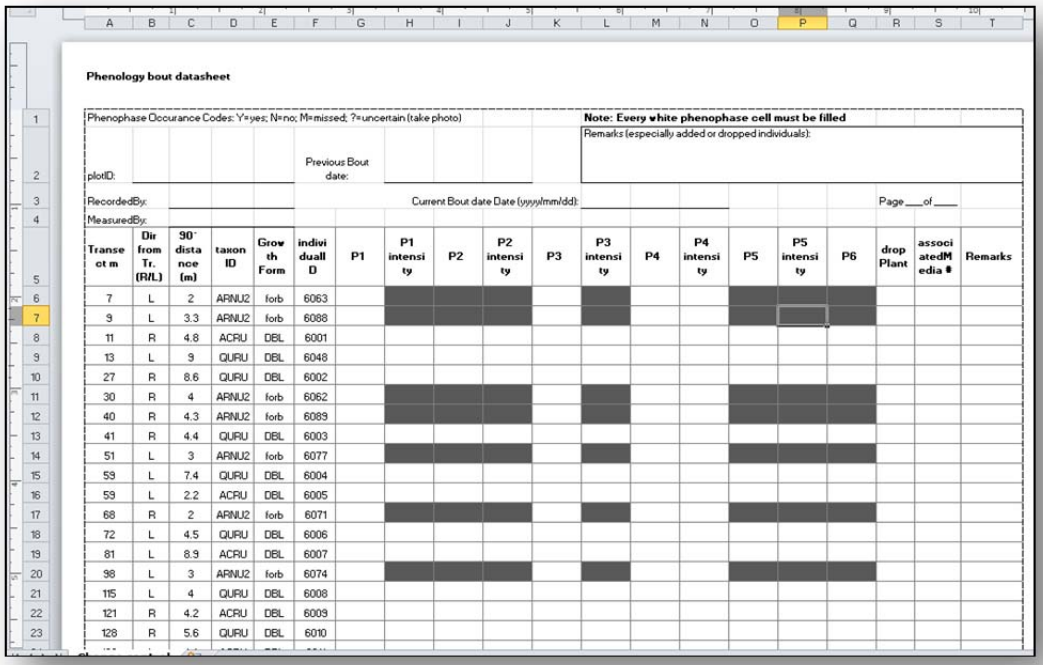


9. Filter by **growthForm**, select one growthForm at a time
10. Shade in cells for all phenophases which are not required for that growthForm (summary table available in Appendix B).



11. Repeat this process for all growthForms

12. Un-filter growthForms 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	individuall D	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														
53	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														

13. Remove filters from field names
14. Sort by **transectMeter** so that individuals are organized as they occur sequentially along the transect
15. Save datasheet to local drive
16. Print datasheets
17. 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 as described in RD[06] must be completed prior to or concurrently with this procedure.

1. **Navigate** to the permanent plot marker at the southwest corner; this is the plot origin (meter 0).
2. 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.
3. **Stretch a 100 meter tape** between each point. Use chaining pins or similar stake at each end to hold the tape in place.
4. **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.

5. **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.
6. While marking the transect, **replace** any faded, broken or missing plant cards, marking patches to facilitate easy location of previously marked individuals/patches.
7. Use flagging to mark an **access route** to the phenology sampling loop outside of the site-specific tower and soil array buffer area. Technicians must use the designated route when accessing the phenology loop to reduce trampling damage within the tower airshed.
8. 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 Selecting individuals

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 perindividual table of plant phenology PDA 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 to Field Operations by Science for each phase of phenology monitoring. These lists are developed based on a quantitative survey of the Tower airshed. The lists provided by Science will be ordered by priority for selection and will include extra 'contingency' species; if one of the prioritized species is not present in sufficient enough numbers along the phenology transect for sampling that species may be rejected and the next on the list selected.

Phase II species are selected to include

1. the three dominant species from Phase I
2. any species present already targeted by an existing national phenology monitoring network (USA-NPN or Project BudBurst) and
3. random selection from remaining species, weighted by relative abundance.

State and Federally recognized Threatened and Endangered (T&E) species will not be selected for phenology monitoring as information about these species cannot be made publically 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 rejected, regardless of their presence/abundance on the transect.

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 technician 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 patches 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:

Spatial Criteria – Choose individual/patches that are:

- **Visible from the loop**
  - Between 1 and 10 m from the loop

- More than 10 m from roads or buildings

- **Health Criteria – Choose individual/patches that:**
  - Represent the average health for that species at the site.
  - 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
  - For woody stemmed species, trees and shrubs, select individuals with a stemDiameter > 1 cm.
  - 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.

Location Criteria:

- Prioritize individuals for monitoring that are included in productivity sampling, if feasible.
- Only select individuals that may be monitored 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 of a single species for Phase I monitoring.

- **Annual and Biennial Criteria:**
  - For annuals, select a patch (rather than an individual).
  - 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.

C.2 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 location is measured from (e.g.,199.9/L ok; 200.01/L ok; 200/L not ok)

- **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.

C.3 Marking selected individuals/patches

Blue aluminum plant tags with unique numbers >6000, are designated for phenology sampling; plant cards or flagging may be used to increase visibility (Figure 1 and

Figure 3). Tags will be placed according to the specifications provided in

Table 7, consistent with guidelines in the vegetation structure protocol (RD[07]).

Figure 1. 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
    - **idQ –** if species identification is uncertain (i.e.,if selection of individuals occurs prior to development of diagnostic morphological features) enter the assumed geneus and species and apply an identification qualifier code to note the uncertainty and follow up at a later date
    - **Remarks**- record the camera assigned file code for photos in this field if using PDA, otherwise use 'associatedMedia#' field
2. For individuals selected prior to development of diagnostic morphological features:
    - record the identificationQualifier (idqCode Table 8) if species identification is unclear
    - once positive ID is possible, these records will need to be updated (see SOP F)

Table 7. Methods for marking individuals for phenology observations

Plant Type	Marking Method
Trees	Nail tag to trunk at height of 1.4 m.
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. 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. 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.

NOTE: *It is import 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, enabling stretching as needed or maintaining an appropriate hanging length when not needed (Figure 2). For example, do not wind wire around a tree branch or trunk where it could cut into the bark and interfere with the tree's growth. Trees - When nailing tags to trees, leave room for future tree growth. The nail should be deep enough that it cannot easily be removed, but not flush to the bark.

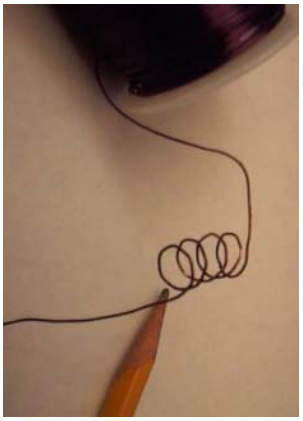


Figure 2. Bailing wire coiled around a pencil

Table 8. Identification qualifier codes (idQ) to designate species with uncertain identification

idqCode	Identification Qualifier Description*
UNK	Unknown species
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”

C.4 Steps for marking patches

For small plants that grow in clusters of individual stems, it can be difficult to single out a few individuals to observe over time. Instead **set up a 0.25*0.25 m patch** and report on the phenophases for the patch as a whole as if it were an individual. 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.

2. **Lay out a 0.25 x 0.25 m quadrat** over the densest or most central portion of a group of plants. **Orient the quadrat** so that one side is parallel with the transect.
3. **Mark all four corners** of the square with non-oxidizing metal tag stakes, PVC, 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.

4. Attach a blue tag to the lower corner of the transect-side of the patch. Though 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.
5. 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.
6. Annuals occasionally live more than a single season. In order to capture this if it occurs, do not remove plant ID (where allowed) cards until the following year.
7. Measure and record (RD[05] - perindividual:
    - **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)
    - location information; map coordinates (transect meter, distance and direction from transect) in RD[05] for the tagged corner.

Flag individuals. Small metal tags can be obscured by vegetation making individuals difficult to locate from afar. Add florescent pin flags (plant cards in tag stakes preferred) and/or flagging tape near marked individuals to aid technicians 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 3. Examples of flagging to increase visibility

SOP D Collecting Data

D.1 Observing phenophases

Regular data collection, observation of phenological development will occur throughout the growing season. Use the Plant Phenology PDA App, or formatted, pre-populated (if available) 'statusintensityr' 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.

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

- *Note: if technician 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 is entered*

3. Collect phenophase data from the plant phenology transect

- Traverse loop in a clockwise direction.
- 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.

- Use Datasheet to ensure you 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, still walk in a clockwise direction.

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

- **date** – YYYYMMDD
- **Phenophase -** Y/N/?/M/X for each phenophase required for that growth form (see Appendix B for full descriptions of phenophases). *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 ingest documents to reflect new information.

o Missed Phase (M) – if a phase occurred between sampling bouts that was not previously observed and you have reason to believe that it occurred (such as dried flowers on the ground below the plant.
- Intensity values for missed phenophases are not recorded.
- Do not use missed for skipped plants, not observed during a given bout

o Unnecessary (X) - Check for **every** required phenophase for every individual/patch during each sampling bout.
- If data are not being recorded on a formatted datasheet or PDA, 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

5. Select an appropriate phenophase **intensity range** (
6. Table **9**) for each phenophase for which 'Yes' is selected. Growth-form specific phenophases and their descriptions are listed in Appendix B.

Table 9. Intensity ranges.

Codes (paper datasheet only)	1	2	3	4	5	6
#	< 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

7. Take a photograph of at least 3 examples of that phenophase*intensity combination on the first encounter in each species. Record **associatedMediaNumber** in the 'statusintensity' RD[05]. Frame the shot so the image may be used to:

- Build site-specific training materials and a reference collection
- Conduct QA/QC.

D.2 Replacing lost, dead, or diseased plants

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 PDA table.
    - 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).
    - If the original plant dies (annual plants), data should be recorded as 0% green leaf, phenological monitoring for that individual/patch can end for the season.
    - Record dropped plants as either D = dropped permanently (for one of the reasons listed above (specify the reason in the notes field) or S=dropped for the season if the individual reached the 'end seasonal sampling' trigger.
        - The 'Seasonally dropped' option 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. 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 via a re-activate option on the PDA. If using paper datasheets, take 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.

SOP E Collecting Annual Data

Once each year, record size and location information for each individual/patch selected for phenology monitoring. 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. Record this data during a routine data collection bout. Use the 'perindividual_peryear' datasheet for this SOP.

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

- **Location Information** (may be pre-populated on a datasheet)
  - transectMeter (0-799mm)
  - directionFromTransect (R/L)
  - tagID (tag#)
- **taxonID** – use United States Department of Agriculture Natural Resources Conservation Services (USDA-NRCS) PLANTS species codes
- **patchOrIndividual**
- **canopyPosition** Class (1-5) - Table 10
- Record biomass/productivity measurements consistent with NEON vegetation structure protocols (Table 10, RD[07]). Use the laser rangefinder (15 cm accuracy) canopy diameter and height measurements where appropriate.
  - *Note:* 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.
- **diseaseStatus** (H/D – healthy/diseased)
- **diseaseType** – if known

Table 10. Canopy Position classes

Code	Description
1	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.
2	Dominant – **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.
3	Co-dominant – **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.
4	Intermediate –**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.
5	Overtopped – **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 11. Biomass and productivity measurements

Vegetation Structure	Required Measurements*	Tools to Measure
Individuals	▪ stemDiameter (cm) – woody species only ▪ maxCanopyDiameter: max. diameter (m) ▪ ninetyCanopyDiameter: Perpendicular to max. diameter (m) ▪ Height (m) ▪ Average adult leaf length* (DBL only) (cm)	▪ Diameter tape ▪ Laser rangefinder ▪ Ruler ▪ Calipers for DDH
Patches**	▪ Cover Percent ▪ Average height (m)	▪ 0.25 m x 0.25 m calibrated quadrat** ▪ Ruler or short tape

***** 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 site specific reference materials

**** 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.1 Tissue samples for archive

Leaf tissue will be collected from each individual/patch monitored for phenology at NEON sites. Frequency of collection varies by life history.

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. 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).

Before entering data, all personnel must read RD[04] for complete instructions regarding manual data transcription. Prior to entering data via a web user interface (webUI), each technician shall enter one bout of data into the protocol-specific webUI housed on the Training portal, as described in RD[04].

Protocol-specific instructions and the associated data ingest workbook for entering plant phenology data can be found on the NEON intranet in the FSU-FOPs folder. 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 Entering and uploading 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.
   a. Confirm uncertain phenophases (i.e.,phenophaseStatus = ?) with local expert. Update datasheets and note that data were post-corrected in the lab.
   b. Verify phenophase/intensity for any data collected by inexperienced technician (i.e.,first 3 bouts). All photos must pass QA/QC procedure before being included in phenology reference library.
   c. Place all photos from a given year in a single folder labeled by date.
      suggested file structure : ~/Site/yyyy
   d. Append taxonID_phenophaseName (use camelCase) to the camera-assigned file name to enable searching and maintain link to data.
      1) Ex: D16_1692_TSHE_breakingNeedleBud
2. 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.
3. For data collected on paper datasheets: Transcribe data into phenology WebUI in accordance with data entry and data QA/QC protocols (AD[08]).
   a. Training materials for entering phenology data into the NEON WebUI are available on the NEON Intranet, Sharepoint, in the : Interdepartmental / Document Collaboration / FSU-FOPS / Web UI Data Entry / Plant Phenology Web UI folder. Any technician entering data in the Web UI must review these materials and must enter practice data on the SOM Portal Testing and Development Server before entering actual bout data on the Production Server.
4. For data collected on the NEON digital data collection device (PDA): Download all data according to the protocols for data handling. Address any QA/QC concerns.

F.2 Updating location or identification data

If the original taxonID assignment was uncertain or an individual is discovered to have been mis-identified, the originally entered perindividual records can be overwritten. The same is true for perindividual location information that must be updated.

To update a record:

1. Sign in to the WebUI for plot/date on which necessary changes to perindividual data were noted
2. Edit the perindividual record for a previously entered tagID
    a. If taxonID is being updated, the 'identifiedBy' field in the updated record must be the technician who provided the most recent identification
    b. Double check that the identifiedBy date is the date the new identification was made, not the original date of selection
    c. The data processing algorithm will pass the last entered record to the NEON data portal

F.3 Equipment Maintenance, Cleaning and Storage

1. Double check that all photos have been downloaded then delete photos from camera.
2. Charge camera and laser rangefinder batteries.
3. Charge GPS unit.

SOP G Sample Shipment

Samples are gathered for archive during annual data collection, but as of Rev E of this protocol, shipping details have not been finalized. This SOP will be updated in a future revision.

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.

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 DATASHEETS

The following datasheets are associated with this protocol:

Table 12. Datasheets associated with this protocol

NEON Doc. #	Title
NEON.DOC.001578	Datasheets for TOS Protocol and Procedure: Plant Phenology

These datasheets can be found in Agile or the NEON Document Warehouse.

APPENDIX B QUICK REFERENCES

- There may be multiple phenophases on an individual during a single bout.
- There may be multiple episodes of a phenophase within a season

B.1 Summary of Phenophases and Intensity Measurements

Use this table to assess which phenophases to measure and whether intensity should be recorded as an absolute number (#) or a percentage of the individual /patch on which the phenophase is occurring.

Growth Form	(P1) Breaking buds / Emerging Needles/ Initial Growth	P1 intensity	(P2) Increasing Leaf Size/ Young Leaves/ Young Needles	P2 intensity	(P3) Leaves/ Needles	P3 intensity	(P4) Open Flowers / Pollen Cones	P4 intensity	(P5) Colored Leaves/ Needles	P5 intensity	(P6) Falling leaves/ Needles	P6 intensity
Cactus	-	-	-	-	-	-	✓	%	-	-	-	-
Deciduous broadleaf (DBL)	✓	#	✓	%	✓	%	✓	%	✓	%	✓	-
Deciduous Conifer (DC)	✓	#	-	-	✓	%	✓	%	✓	%	✓	-
Drought deciduous broadleaf (DDB)	-	-	✓	-	✓	%	✓	%	✓	%	-	-
Evergreen broadleaf (EBL)	✓	#	✓	#	-	-	✓	%	-	-	-	-
Evergreen Conifer (EC)	✓	#	✓	#	-	-	✓	%	-	-	-	-
Evergreen Forb (EF)	-	-	✓	-	-	-	✓	-	-	-	-	-
Forb	✓	-	-	-	✓	-	✓	%	-	-	-	-
Graminoid (GRS)	✓	-	-	-	✓	%	✓	%	-	-	-	-
Pine	✓	#	✓	#	-	-	✓	%	-	-	-	-
Semi-evergreen broadleaf (SEB)	✓	#	✓✓*	#/%	✓	%	✓	%	✓	%	✓	-

* both young leaves and increasing leaf size are assessed for drought deciduous broadleaf individuals

B.2 Phenophase Intensity Class Categorie

Intensity Class Codes	1	2	3	4	5	6
#	< 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

A.2 Generalized Phenology Workflow

STEP 1 – Lay out phenology loop in tower airshed.

STEP 2 – Select individuals and patches to monitor.

STEP 3 – Map location of monitored individuals and patches.

STEP 4 – Mark individuals and patches with tags and tagIDs.

STEP 5 – Collect phenophase data, including photographs.

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

STEP 7 – Transcribe data from field datasheets to the NEON Web UI.

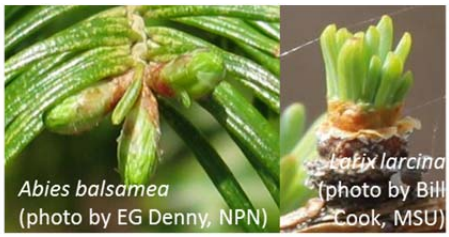
STEP 8 – Download photographs and indicate phenophase.

STEP 9 –Collect location, size, and health status data on all monitored plants (annually).

PHENOPHASE DEFINITIONS

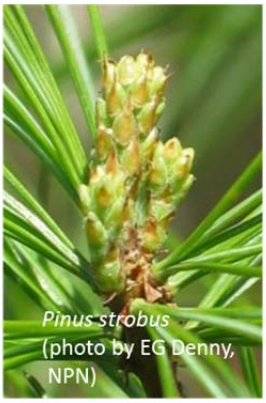
Early season growth			
Phenophase Title	**Applicable Growth Forms**	**Status Description**	**Intensity Question**
Breaking leaf buds	DBL EBL SEB	One or more breaking leaf buds are visible on the plant. A leaf bud is considered "breaking" once a green leaf tip is visible at the end of the bud, but before 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 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 needles or needle bundles are emerging?
Initial growth	Forb 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, or new green or white shoots breaking through the soil surface. 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.	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 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 DDB EF 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 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 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, 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 are present?

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 DDB 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 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 canopy is full with leaves?. Ignore dead branches in the estimate.
Leaves	Forb 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.	Do not report intensity for forbs. GRS - What percentage of the plant 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 canopy is full with needles? Ignore dead branches in the estimate.

Assessing intensity class for grasses, sedges, and rushes

For grass, sedge and rush species (GSR) where new growth is from new stems, the plant will probably be 100% green (intensity class 6) 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 technician.

Needles - DC

Leaves – GRS, Forb

Leaves – DBL, DDB, SEB

Reproductive phenophases			
Phenophase Title	**Applicable Growth Forms**	**Status Description**	**Intensity Question**
Open flowers	DBL EBL Forb GRS Cactus DDB EF 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.	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 EC 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 DDB SEB	One or more leaves (including any that have recently fallen from the plant) have turned to their late-season colors. Do not include fully dried or dead leaves that remain on the plant.	What percentage of the canopy is full with colored leaves?
Colored needles	DC	One or more needles (including any that have recently fallen from the plant) have turned to their late-season colors. Do not include fully dried or dead needles that remain on the plant.	What percentage of the canopy is full with colored needles?

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% (intensity class 4), not 30% (intensity class 3).

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 DDB SEB	One or more leaves are falling or have recently fallen from the plant.	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)

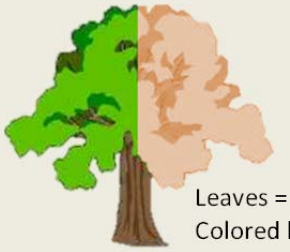
To estimate the percentage of the canopy that is full with **colored leaves/needles**, consider the proportion of colored leaves and needles that are left on the plant relative to the fully leafed out canopy.

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)

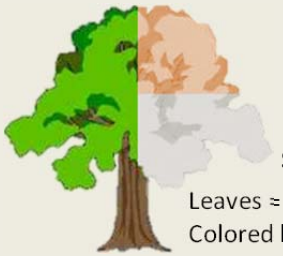
As the days go on, more of the leaves change color and some fall off, and you might eventually find that only half of the leaves remain on the plant and there is no green left in them. At this point you would report that 50% of the canopy is full with leaves and 50% of the canopy is full with colored 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 = 6 (100% leaves on)
Colored leaves = 4 (50 % colored)
Falling leaves = N



Scenario B

Leaves = 5 (75 % leaves on)
Colored leaves = 3 (25 % colored)
Falling leaves = Y

Scenario C

Leaves = 4 (50 % leaves on)
Colored leaves = 4 (50 % colored)
Falling leaves = Y

HELPFUL INFORMATION FOR INTENSITY ESTIMATION

- **Multiple phenophases** may be reported for an individual in a single bout. Evaluate each phenophase independent 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'.

- 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). In some cases, green leaves will remain on the plant in a frozen condition for part or all of the winter. If more than about 5% of the leaves have remained on the plant in this condition, you should continue to report seeing ‘Leaves’ until they fall off or appear wilted.

- 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 A 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 B ESTIMATED DATES FOR ONSET AND CESSATION OF SAMPLING

To view NDVI/EVI graphs for your sites go to the 'create subset' link a the ORNL website (http://daac.ornl.gov/MODIS/). The dates in this table were generated from the '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.

Date of earliest and latest greenness increase and latest minimum greenness date as estimated by MODIS averaged EVI values from 2001-2009. These values are provided as a rough guide for when phenology monitoring may begin (between earliest and latest greenness increase date) and end (latest return to minimum greenness date). This information should be augmented by on-the-ground phenology observations made by a tower technician on indicator individuals using the provided datasheet. Sites indicated with an asterisk (*) are ones which have an average sampling season >250 days in length and at which year- round sampling is suggested. Sites not identified here with an asterisk may still be sampled year round if dictated by phenology of the selected species; this decision is at the discretion of the Domain Manager based on site-specific conditions.

Table 13. Phenology sampling window

Domain	Site	Earliest greenness increase (DOY)	Latest greenness increase (DOY)	Latest onset of Minimum greenness (DOY)	Average length of growing season	Maximum length of growing season
01	BART	100	130	305	180	205
01	BURL	95	115	320	205	225
01	HARV	100	120	310	190	210
02	BLAN	65	75	340	235	275
02	SCBI	65	95	330	235	265
02	SERC	70	85	345	245	275
03	DSNY*	40	100	340	260	300
03	JERC	50	110	310	220	260
03	OSBS*	55	85	335	245	280
04	GUAN*					365
04	LAJA*					365
04	MAME*					365
05	STEI	115	125	305	130	190
05	TREE	115	125	305	130	190
05	UNDE	110	125	280	160	170
06	KONA	80	100	320	210	240

Domain	Site	Earliest greenness increase (DOY)	Latest greenness increase (DOY)	Latest onset of Minimum greenness (DOY)	Average length of growing season	Maximum length of growing season
06	KONZ	80	100	320	210	240
06	KUFS*	70	85	360	255	290
07	GRSM	85	100	325	220	240
07	MLBS	90	115	320	200	230
07	ORNL	75	90	340	225	265
08	CHOC*	60	110	350	265	290
08	DELA*	50	70	340	270	290
08	TALL*	65	85	350	255	285
09	DCFS	105	130	315	170	210
09	NOGP	80	120	320	175	240
09	WOOD	110	130	310	170	200
10	CPER*	60	110	320	260	260
10	RMNP	110	235	315	165	205
10	STER	70	110	320	180	250
11	CLBJ*	40	80	345	265	305
11	KLEM	50	85	340	235	290
11	TBD					
12	BOZE				180	
12	PARA				180	
12	YELL	105	135	340	160	235
13	MOAB	50	90	335	215	285
13	NIWO	125	155	280	130	155
13	TBD					
14	JORN	40	110	340	240	300
14	SRER	45	190	345	180	300
14	TBD					
15	ONAQ	45	90	330	205	285
15	TBD					
15	RBUT	90	115	335	205	245

Domain	Site	Earliest greenness increase (DOY)	Latest greenness increase (DOY)	Latest onset of Minimum greenness (DOY)	Average length of growing season	Maximum length of growing season
16	ABBY	80	130	325	190	245
16	THAY	90	120	315	190	225
16	WREF	90	120	315	175	225
17	SJER	275	360	185	240	275
17	SOAP	75	115	335	200	260
17	TEAK	115	140	330	180	215
18	BARO	170	180	235	45	65
18	TOOL	150	165	250	80	100
19	BONA				115	
19	DEJU	125	135	260	120	135
19	HEAL	130	160	255	110	125
19	POKE	130	145	255	115	125
20	OLAA*					365
20	PUFO*					365
20	PUGR*					365

APPENDIX C 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 based on a random selection routine where probability of a given species being selected is based on its relative abundance at the site. See the Plant Phenology Science Design (AD[06]) for more details.

C.1 D01 – HARV – Harvard Forest

Phase I Species	Phase II Species
Acer rubrum	
Quercus rubra	
Aralia nudicaulis	

C.2 D01 – BART – Bartlett Experimental Forest

Phase I Species	Phase II Species
Acer rubrum	
Tsuga canadensis	
Acer pensylvanicum	

C.3 D01 – SAWB –-Sawmill Brook Conservation Area -Burlington, MA

Phase I Species	Phase II Species

C.4 D02 – SCBI – Smithsonian Conservation Biology Institute

Phase I Species	Phase II Species
Liriodendron tulipifera	
Juglans nigra	
Microstegium vimineum	

C.5 D02 – SERC – Smithsonian Environmental Research Center

Phase I Species	Phase II Species

C.6 D02 – BLAN – Blandy Experimental Farm

Phase I Species	Phase II Species

C.7 D03 – OSBS – Ordway-Swisher Biological Station

Phase I Species	Phase II Species
Pinus palustris	
Quercus laevis	
Aristida beyrichiana	

C.8 D03 – DSNY – Disney Wilderness Preserve

Phase I Species	Phase II Species
Andropogon virginicus	
Aristida beyrichiana	
Euthamia caroliniana	

C.9 D03 – JERC – Jones Ecological Research Center

Phase I Species	Phase II Species
Pinus palustris	
Quercus falcata	
Aristida beyrichiana	

C.10 D04 – GUAN – Guanica Forest

Phase I Species	Phase II Species

C.11 D04 – LAJA – Lajas Experimental Station

Phase I Species	Phase II Species

C.12 D04 – MAME – Mameyes

Phase I Species	Phase II Species

C.13 D05 – UNDE – UNDERC

Phase I Species	Phase II Species
Acer saccharum	
Populus tremuloides	
Corylus cornuta	

C.14 D05 – STEI – Steigerwaldt Land Services

Phase I Species	Phase II Species

C.15 D05 – TREE – Treehaven

Phase I Species	Phase II Species

C.16 D06 – KONZ – Konza Prairie Biological Station

Phase I Species	Phase II Species

C.17 D06 – UKFS – The University of Kansas Field Station

Phase I Species	Phase II Species

C.18 D06 – KONA – Konza Prairie Biological Station

Phase I Species	Phase II Species

C.19 D07 – ORNL – Oak Ridge

Phase I Species	Phase II Species
Quercus prinus	
Liriodendron tulipifera	
Cornus florida	

C.20 D07 – MLBS – Mountain Lake Biological Station

Phase I Species	Phase II Species

C.21 D07 – GRSM – Great Smoky Mountains National Park, Twin Creeks

Phase I Species	Phase II Species

C.22 D08 – TALL – Talladega National Forest

Phase I Species	Phase II Species
Pinus palustris	
Liquidambar styraciflua	
Vaccinium arboreum	

C.23 D08 – DELA – Dead Lake

Phase I Species	Phase II Species

C.24 D08 – LENO – Lenoir Landing

Phase I Species	Phase II Species

C.25 D09 – WOOD – Woodworth

Phase I Species	Phase II Species
Poa pratensis	
Bromus inermis	
Artemisia absinthium	

C.26 D09 – DCFS – Dakota Coteau Field School

Phase I Species	Phase II Species

C.27 D09 – NOGP – Northern Great Plains Research Laboratory

Phase I Species	Phase II Species

C.28 D10 – CPER – Central Plains Experimental Range

Phase I Species	Phase II Species
Bouteloua gracilis	
Hesperostipa comata	
Thelesperma filifolium	

C.29 D10 – STER – North Sterling, CO

Phase I Species	Phase II Species
Annual crop	
Triticum aestivum	
Zea mays	

C.30 D10 – RMNP – Rocky Mountain National Park, CASTNET

Phase I Species	Phase II Species

C.31 D11 – CLBJ – LBJ National Grassland

Phase I Species	Phase II Species

C.32 D11 – OAES – Klemme Range Research Station

Phase I Species	Phase II Species

C.33 D11 – (SOFT) – Relocatable

Phase I Species	Phase II Species

C.34 D12 – YELL – Yellowstone Northern Range (Frog Rock)

Phase I Species	Phase II Species

C.35 D12 – BOZE – Bozeman, MT

Phase I Species	Phase II Species

C.36 D12 – PARA – Paradise Valley, MT

Phase I Species	Phase II Species

C.37 D13 – NIWO – Niwot Ridge Mountain Research Station

Phase I Species	Phase II Species

C.38 D13 – MOAB – Moab

Phase I Species	Phase II Species

C.39 D13 – WINT – Winter Park

Phase I Species	Phase II Species

C.40 D14 – SRER – Santa Rita Experimental Range

Phase I Species	Phase II Species

C.41 D14 – JORN – Jornada LTER

Phase I Species	Phase II Species

C.42 D14 – (SOFT) – Relocatable

Phase I Species	Phase II Species

C.43 D15 – ONAQ – Onaqui-Ault

Phase I Species	Phase II Species
Artemisia tridentata	
Ceratocephala testiculata	
Bromus tectorum	

C.44 D15 – (SOFT) – Relocatable

Phase I Species	Phase II Species

C.45 D15 – RBUT – Red Butte Canyon Research Natural Area

Phase I Species	Phase II Species

C.46 D16 – WREF – Wind River Experimental Forest

Phase I Species	Phase II Species

C.47 D16 – THAY – Thayer

Phase I Species	Phase II Species

C.48 D16 – ABBY – Abby Road

Phase I Species	Phase II Species

C.49 D17 – SJER – San Joaquin

Phase I Species	Phase II Species

C.50 D17 – SOAP – Soaproot Saddle

Phase I Species	Phase II Species

C.51 D17 – TEAK – Lower Teakettle

Phase I Species	Phase II Species

C.52 D18 – TOOL – Toolik Lake

Phase I Species	Phase II Species

C.53 D18 – BASC – Barrow Environmental Observatory

Phase I Species	Phase II Species

C.54 D19 – BONA – Caribou Creek - Poker Flats Watershed

Phase I Species	Phase II Species

C.55 D19 – DEJU – Delta Junction

Phase I Species	Phase II Species

C.56 D19 – POKE – Poker Flat

Phase I Species	Phase II Species

C.57 D19 – HEAL – Healy

Phase I Species	Phase II Species

C.58 D20 – OLAA – Olaa Forest Reserve

Phase I Species	Phase II Species

C.59 D20 – PUWI – Puu Waa Waa Forest Site

Phase I Species	Phase II Species

C.60 D20 – PUWU – Puu Waa Waa Grassland Site

Phase I Species	Phase II Species