

<i>Title:</i> TOS Protocol and Procedure: Plant Phenology		<i>Date:</i> 10/02/20144
<i>NEON Doc. #:</i> NEON.DOC.014040	<i>Author:</i> K. Jones	<i>Revision:</i> E

TOS PROTOCOL AND PROCEDURE: PLANT PHENOLOGY

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See configuration management system for approval history.

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Change Record

REVISION	DATE	ECO #	DESCRIPTION OF CHANGE
A_DRAFT	10/03/2011	ECO-00280	Initial draft release
B_DRAFT	01/10/2014	ECO-01138	Draft release, updates from field season
C	03/25/2014	ECO-01666	Production release, template change, and other changes as detailed in Appendix C (rev C only)
D	04/10/2014	ECO-01792	Updated Appendix E with site-specific information
E	10/02/2014	ECO-02334	Migration to new protocol template

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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 events 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. Phenology is affected by forces such as length of growing season, 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 National Phenology Network www.usanpn.org (Denny et al. 2013); where pertinent (e.g. phenophase definitions, recommendations for marking plants), descriptive material has been taken directly from their Nature's Notebook monitoring program. The overall sampling framework was developed by the NEON plant phenology working group.

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2 RELATED DOCUMENTS AND ACRONYMS

2.1 Applicable Documents

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

AD[01]	NEON.DOC.004300	EHS Safety Policy and Program Manual
AD[02]	NEON.DOC.004316	Operations Field Safety and Security Plan
AD[03]	NEON.DOC.000724	Domain Chemical Hygiene Plan and Biosafety Manual
AD[04]	NEON.DOC.001155	NEON Training Plan
AD[05]	NEON.DOC.050005	Field Operations Job Instruction Training Plan
AD[06]	NEON.DOC.000907	NEON Science Design for Plant Phenology
AD[07]	NEON.DOC.014051	Field Audit Plan
AD[08]	NEON.DOC.000824	Data and Data Product Quality Assurance and Control 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

2.3 Acronyms

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

2.4 Definitions

N/A

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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 on 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. 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 (≤ 20 species), with fewer replicates per species ($n \geq 5$). The basic sampling protocol, however, will remain the same. For sites where the tower phenocam range of interest 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, where appropriate individuals should be located and marked outside the required disturbance buffer zones but within the visible range of interest of the phenocam. Selection of additional individuals to monitor will occur once processed phenocam images become available to define an appropriate region of interest.

At sites with a well-defined, discrete, growing season, the seasonal sampling frequency varies to capture rapid changes during phenological transition periods. The greatest sampling frequency is three times per week during the initial ‘green up’ period from bud break until 50% adult leaf. Sampling then slows through the middle of the growing season and escalates again to capture fall color change and senescence. At sites that lack a well-defined growing season (e.g. tropical latitudes) sampling will occur less frequently for a longer duration.

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

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procedure. To properly collect and process samples, field technicians **must** follow the protocol and associated SOPs. Use NEON’s problem reporting system to 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 life 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 Data and Data Product Quality Assurance and Control Plan (AD[08]).

4 SAMPLING SCHEDULE

4.1 Sampling Frequency and Timing

Sample frequency varies dynamically throughout the growing season. The objective of the plant phenology sampling is to have at least one observation each year **before** springtime plant phenological activity begins (variably defined as young leaves, young needles, 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.

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 reach for a particular individual, in which case, monitoring of that individual is not required for the remainder of the season.

- When sampling at 3x a week frequency, sampling bouts should be approximately 2-3 days apart.
- When sampling at 2x a week frequency, sampling bouts should be every 3-5 days.
- When sampling at 1x a week frequency sampling bouts should be 6-9 days apart.
- When sampling 1x every other week frequency sampling bouts should be 10-18 days apart.

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

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:
Pine	Emerging needles or pollen cone development	Young needles	No young leaves	Commence every-other week monitoring for cone phenology unless pollen release occurred prior to leaf bud break	End sampling season when no more fresh pollen cones visible	NA	NA	NA
Grass/Rush/Sedge/Forb	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
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 unless flowering occurred prior to leaf bud break	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 leaves	One or more colored leaves	<5% or canopy full with green or colored needles	End sampling season
Evergreen conifer	Breaking needle buds	Young needles	No more young needles visible	Commence every-other week monitoring for open pollen cones	End sampling when all pollen cones are wilted/dried	NA	NA	NA
Broadleaf evergreen	Breaking leaf buds	Young leaves	No more young leaves visible	Commence every-other week monitoring for open flowers	End sampling when no more fresh flowers are present	NA	NA	NA

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.

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4.2 Criteria for Determining Onset and Cessation of Sampling

Start of sampling will be determined by Field Operations personnel and will differ across the Observatory on a regional, site, and potentially site specific basis based on knowledge of the local flora. MODIS data in Appendix D provide the earliest recorded increase in NDVI derived from available MODIS data. 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], by a permanent field or tower technician. Indicator individuals are not monitored throughout the growing season; they are instead used to help guide the start of seasonal sampling. One individual of each dominant species should be monitored opportunistically for phenological activity. 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).

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.

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, 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 phenophases 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 or more closely spaced individuals. If the required

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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 community phenology phase (20 species) 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, unseasonal freeze event), record disturbance for the metadata, 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.

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	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

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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 individual 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.

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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					
MX100322	R	TruPulse 360R Laser Rangefinder	Recording location information for selected individuals	1	N
	R	GPS, recreational accuracy	Navigating to transect start point if access trail is not already marked	1	N
	R	100 meter fiberglass measuring tape –	Used to measure transect distances - for annual transect establishment only	1	N
	S	Extra batteries for TruPulse and camera	Replacement if primary batteries fail	1-2 each	N
Consumable items					
	R	Flags, PVC stake	Marking transect trail	80	N

R/S=Required/Suggested

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

Item No.	R/S	Description	Purpose	Conditions Used	Quantity	Special Handling
Durable items						
MX100322	R	TruPulse 360R Laser Rangefinder	Recording location information for selected individuals	All	1	N
	R	Blue aluminum plant tags, numbered >6000	Permanently marking selected individuals for monitoring. Color and number separates phenology from vegetation structure tags.	Woody stemmed species	10	N
	R	Hammer	Driving nails	Used with nails	1	N
	R	Wire clippers	Clipping bailing wire to desired length	Used with bailing wire	1	N
	R	Spike, 6-8 inches L, 3/8 inch Diameter, Plastic,; Barrier or Equivalent.	Marking patch corners	Patches		N
NEON.DOC.001324	R	Calibrated 0.25m x 0.25m quadrat frame (sites with patches only)	Delineates the monitoring area for annual or mat-forming growth forms	Patches	1	N
	R	Tag, Round, Unnumbered, 1.25 inch, Anodized, Blue; Forester's or Equivalent.	Marking individuals selected for both phenology and productivity measurement	Woody stems in Tower plots	1	N
	R	Hand stamp steel die set	Labeling blank aluminum tags	Blank tags	1 set	

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Item No.	R/S	Description	Purpose	Conditions Used	Quantity	Special Handling
	S	Extra batteries for TruPulse and camera	Replacement if primary batteries fail	All	1-2 each	N
	S	Blank Tag, Material Aluminum, Yellow, Height 3/4 In., Width 3-1/2 In., Rectangle, Package Quantity 500	Flagging patch location	Patches	10	N
	S	GPS, recreational accuracy	Navigating to transect corners	All	1	N
	S	Field notebook	Auxiliary observations or questions for follow-up	All	1	N
Consumable items						
	R	Aluminum nails	Affixing tags to larger woody stems	Woody stems >5 cm diameter	10	N
	R	Bailing wire – 1m	Affixing tags to branches or small diameter woody stems	Woody stems <5 cm diameter	1	N
	S	Flags, PVC stake	Replacing lost flags and marking individuals/patches selected for monitoring	All	80	N

R/S=Required/Suggested

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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 data

Item No.	R/S	Description	Purpose	Conditions Used	Quantity	Special Handling
	R	Binoculars	Making phenology observations at a distance	Trees	1	N
	R	Digital camera capable of producing high quality .jpeg files ≥6MP for	QA/QC and taxa-specific image libraries	All	1	N
	R	Site specific reference ‘photobook’	Establishing consistency for phenophase determination within a site	All	1	N
NEON.DOC.001324	R	Calibrated 0.25m x 0.25m quadrat frame (sites with patches only)	Monitoring patches	Patches	1	N
	S	Laser Rangefinder	Recording location information for new/replacement individuals	All	1	N
	S	Blue aluminum plant tags, numbered >6000	Tagging replacement individuals	All	10	N
	S	Hammer	Driving nails	Trees	1	N

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Item No.	R/S	Description	Purpose	Conditions Used	Quantity	Special Handling
	S	Wire clippers		Bailing wire	1	N
	S	Spike, 6-8 inches L, 3/8 inch Diameter, Plastic; Barrier or Equivalent.	Replacement	Patches	As needed	N
	S	Blank Tag, Material Aluminum, Yellow, Height 3/4 In., Width 3-1/2 In., Rectangle, Package Quantity 500	Replacement	Woody vegetation	10	N
	S	GPS, recreational accuracy	Navigating to transect corner	All	1	N
	S	Ruler, metric	Assessing percent cover	Patches	1	
	S	Aluminum nails	Replacement	Trees	10	N
	S	Bailing wire – 1m	Replacement	Small diameter woody stems	1	N

R/S=Required/Suggested

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Table 6. Equipment list – Collecting annual data

Item No.	R/S	Description	Purpose	Conditions Used	Quantity	Special Handling
Durable items						
	R	TruPulse 360R Laser Rangefinder for recording location information for selected individuals	Measuring heights > 2 m	Vegetation > 2 m	1	N
NEON.DOC.001324	R	Calibrated 0.25m x 0.25m quadrat frame (sites with patches only)	Making observations on patches	Patches	1	N
	R	DBH tape	Measuring stem diameter	Woody stems > 5 cm	1	N
	R	Measuring Tape, Fiberglass, 30 m, 0.5 in Wide, with Folding Locking Rewind Handle, with Stake Point	Measuring heights < 2 m	Low stature vegetation	1	N
Consumable items						
(None)						

R/S=Required/Suggested

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6.2 Training Requirements

All technicians must complete required safety training as defined in the NEON Training Plan (AD[04]). Additionally, technicians must complete protocol-specific training for safety and implementation of this protocol as required in Field Operations Job Instruction Training Plan (AD[05]).

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 the botany tech and that a botany technician is available for periodic QA/QC checks in the field and of photos, and to provide guidance.

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 dormant individuals, 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.

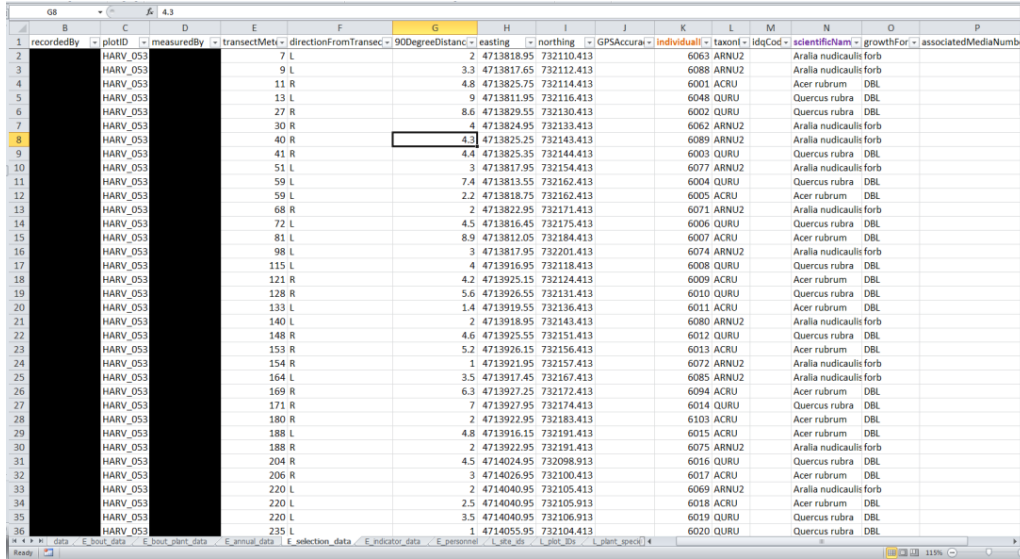
Annual marking of the transect – This task only occurs once a year and may take a team of 2 people as much as 4-5 hours to complete, depending on the complexity of the understory vegetation.

Selection of individuals/patches to monitor – Selection of individuals only occurs twice at each site, once for Phase I sampling and then again, three years later, for Phase II sampling. 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.

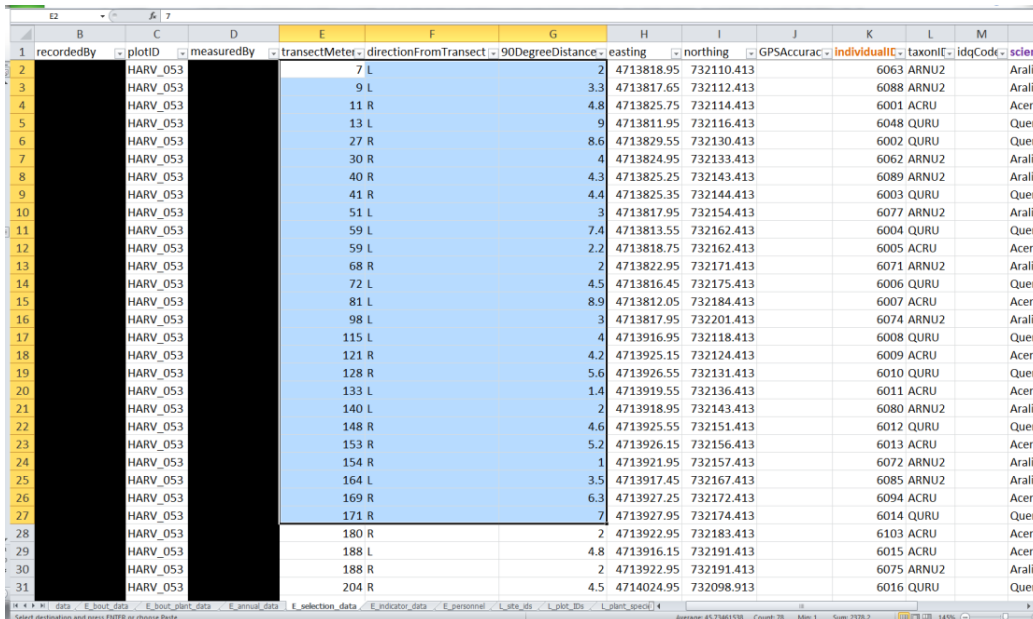
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- Open the selection_data tab in the phenology data ingest workbook where data has been entered following the initial selection of individuals for sampling



recordedBy	plotID	measuredBy	transectMeter	directionFromTransect	90DegreeDistance	easting	northing	GPSAccuracy	individualID	taxonID	idgCod	scientificName	growthForm	associatedMediaNumber
HARV_053			7	L		2	4713818.95	732110.413		6063	ARNU2	Aralia nudicaulis	forb	
HARV_053			9	L		3.3	4713817.65	732112.413		6088	ARNU2	Aralia nudicaulis	forb	
HARV_053			11	R		4.8	4713825.75	732114.413		6001	ACRU	Acer rubrum	DBL	
HARV_053			13	L		9	4713811.95	732116.413		6048	QRUR	Quercus rubra	DBL	
HARV_053			27	R		8.6	4713829.55	732130.413		6002	QRUR	Quercus rubra	DBL	
HARV_053			30	R		4	4713824.95	732133.413		6062	ARNU2	Aralia nudicaulis	forb	
HARV_053			40	R		4.3	4713825.25	732143.413		6089	ARNU2	Aralia nudicaulis	forb	
HARV_053			41	R		4.4	4713825.35	732144.413		6003	QRUR	Quercus rubra	DBL	
HARV_053			51	L		3	4713817.95	732154.413		6077	ARNU2	Aralia nudicaulis	forb	
HARV_053			59	L		7.4	4713813.55	732162.413		6004	QRUR	Quercus rubra	DBL	
HARV_053			59	L		2.2	4713818.75	732162.413		6005	ACRU	Acer rubrum	DBL	
HARV_053			68	R		2	4713822.95	732171.413		6071	ARNU2	Aralia nudicaulis	forb	
HARV_053			72	L		4.5	4713816.45	732175.413		6006	QRUR	Quercus rubra	DBL	
HARV_053			81	L		8.9	4713812.05	732184.413		6007	ACRU	Acer rubrum	DBL	
HARV_053			98	L		3	4713817.95	732201.413		6074	ARNU2	Aralia nudicaulis	forb	
HARV_053			115	L		4	4713916.95	732118.413		6008	QRUR	Quercus rubra	DBL	
HARV_053			121	R		4.2	4713925.15	732124.413		6009	ACRU	Acer rubrum	DBL	
HARV_053			128	R		5.6	4713926.55	732131.413		6010	QRUR	Quercus rubra	DBL	
HARV_053			133	L		1.4	4713919.55	732136.413		6011	ACRU	Acer rubrum	DBL	
HARV_053			140	L		2	4713918.95	732143.413		6080	ARNU2	Aralia nudicaulis	forb	
HARV_053			148	R		4.6	4713925.55	732151.413		6012	QRUR	Quercus rubra	DBL	
HARV_053			153	R		5.2	4713926.15	732156.413		6013	ACRU	Acer rubrum	DBL	
HARV_053			154	R		1	4713921.95	732157.413		6072	ARNU2	Aralia nudicaulis	forb	
HARV_053			164	L		3.5	4713917.45	732167.413		6085	ARNU2	Aralia nudicaulis	forb	
HARV_053			169	R		6.3	4713927.25	732172.413		6094	ACRU	Acer rubrum	DBL	
HARV_053			171	R		7	4713927.95	732174.413		6014	QRUR	Quercus rubra	DBL	
HARV_053			180	R		2	4713922.95	732183.413		6103	ACRU	Acer rubrum	DBL	
HARV_053			188	L		4.8	4713916.15	732191.413		6015	ACRU	Acer rubrum	DBL	
HARV_053			188	R		2	4713922.95	732191.413		6075	ARNU2	Aralia nudicaulis	forb	
HARV_053			204	R		4.5	4714024.95	732098.913		6016	QRUR	Quercus rubra	DBL	
HARV_053			206	R		3	4714026.95	732100.413		6017	ACRU	Acer rubrum	DBL	
HARV_053			220	L		2	4714040.95	732105.413		6069	ARNU2	Aralia nudicaulis	forb	
HARV_053			220	L		2.5	4714040.95	732105.913		6018	ACRU	Acer rubrum	DBL	
HARV_053			220	L		3.5	4714040.95	732106.913		6019	QRUR	Quercus rubra	DBL	
HARV_053			235	L		1	4714055.95	732104.413		6020	QRUR	Quercus rubra	DBL	

- Copy fields:
 - transectMeter
 - directionFromTransect
 - ninetyDegreeDistance



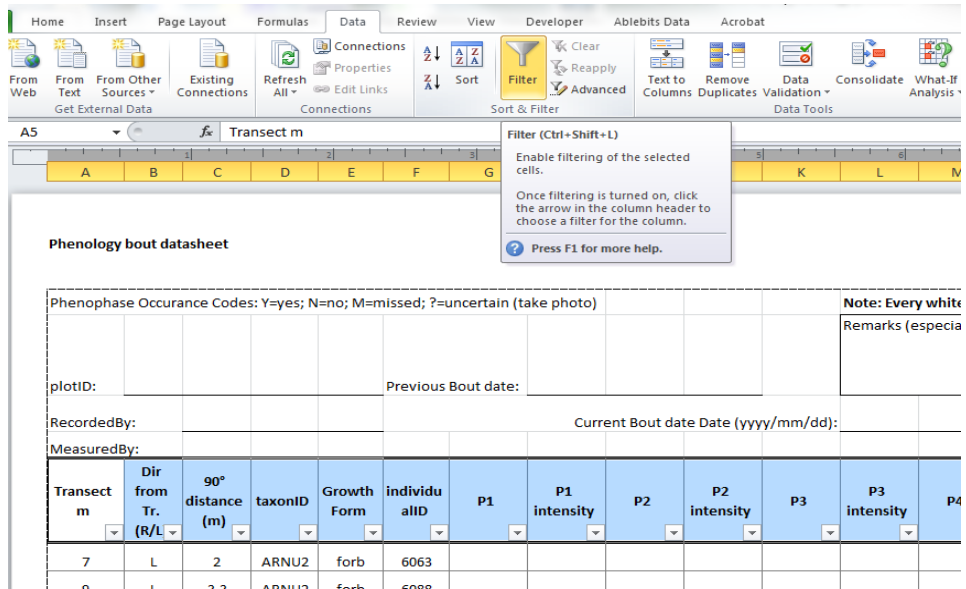
recordedBy	plotID	measuredBy	transectMeter	directionFromTransect	90DegreeDistance	easting	northing	GPSAccuracy	individualID	taxonID	idgCod	scientificName	growthForm	associatedMediaNumber
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HARV_053			11	R		4.8	4713825.75	732114.413		6001	ACRU	Acer rubrum	DBL	
HARV_053			13	L		9	4713811.95	732116.413		6048	QRUR	Quercus rubra	DBL	
HARV_053			27	R		8.6	4713829.55	732130.413		6002	QRUR	Quercus rubra	DBL	
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HARV_053			41	R		4.4	4713825.35	732144.413		6003	QRUR	Quercus rubra	DBL	
HARV_053			51	L		3	4713817.95	732154.413		6077	ARNU2	Aralia nudicaulis	forb	
HARV_053			59	L		7.4	4713813.55	732162.413		6004	QRUR	Quercus rubra	DBL	
HARV_053			59	L		2.2	4713818.75	732162.413		6005	ACRU	Acer rubrum	DBL	
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HARV_053			81	L		8.9	4713812.05	732184.413		6007	ACRU	Acer rubrum	DBL	
HARV_053			98	L		3	4713817.95	732201.413		6074	ARNU2	Aralia nudicaulis	forb	
HARV_053			115	L		4	4713916.95	732118.413		6008	QRUR	Quercus rubra	DBL	
HARV_053			121	R		4.2	4713925.15	732124.413		6009	ACRU	Acer rubrum	DBL	
HARV_053			128	R		5.6	4713926.55	732131.413		6010	QRUR	Quercus rubra	DBL	
HARV_053			133	L		1.4	4713919.55	732136.413		6011	ACRU	Acer rubrum	DBL	
HARV_053			140	L		2	4713918.95	732143.413		6080	ARNU2	Aralia nudicaulis	forb	
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HARV_053			169	R		6.3	4713927.25	732172.413		6094	ACRU	Acer rubrum	DBL	
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HARV_053			180	R		2	4713922.95	732183.413		6103	ACRU	Acer rubrum	DBL	
HARV_053			188	L		4.8	4713916.15	732191.413		6015	ACRU	Acer rubrum	DBL	
HARV_053			188	R		2	4713922.95	732191.413		6075	ARNU2	Aralia nudicaulis	forb	
HARV_053			204	R		4.5	4714024.95	732098.913		6016	QRUR	Quercus rubra	DBL	
HARV_053			206	R		3	4714026.95	732100.413		6017	ACRU	Acer rubrum	DBL	
HARV_053			220	L		2	4714040.95	732105.413		6069	ARNU2	Aralia nudicaulis	forb	
HARV_053			220	L		2.5	4714040.95	732105.913		6018	ACRU	Acer rubrum	DBL	
HARV_053			220	L		3.5	4714040.95	732106.913		6019	QRUR	Quercus rubra	DBL	
HARV_053			235	L		1	4714055.95	732104.413		6020	QRUR	Quercus rubra	DBL	

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

5. Repeat the process for the remaining fields
- a. taxonID
 - b. growthForm
 - c. tagID

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6. Double check that all columns are properly aligned and that the location information matches the individual ID
7. 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

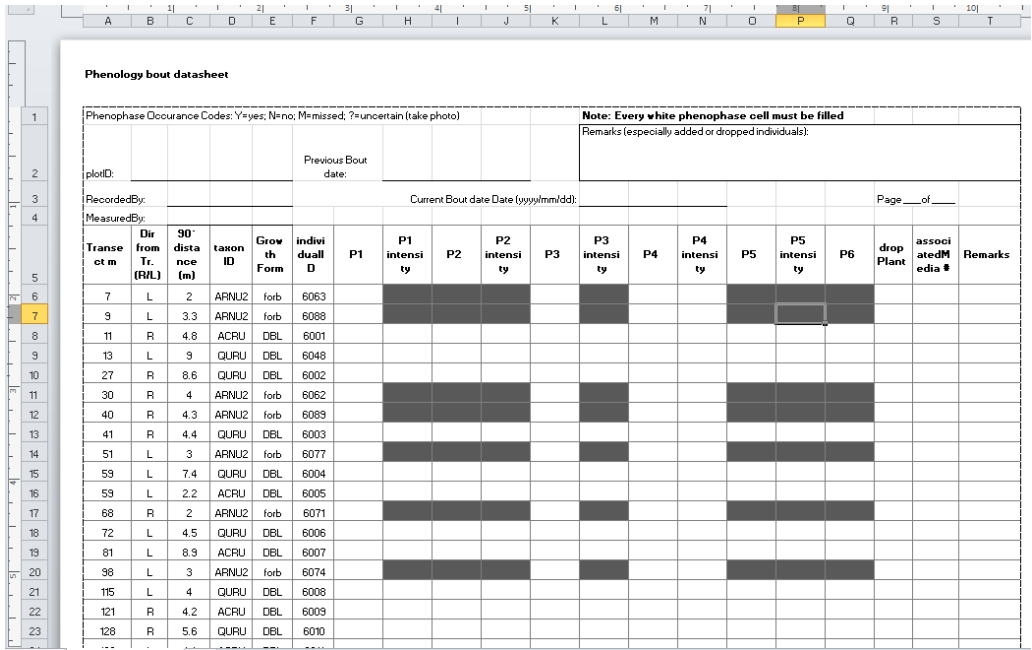


8. Filter by growthForm, select one growthForm at a time
9. Shade in cells for all phenophases which are not required for that growthForm (summary table available in Appendix B).

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	associated #
7	L	2	ARNU2	forb	6063													
9	L	3.3	ARNU2	forb	6088													
30	R	4	ARNU2	forb	6062													
40	R	4.3	ARNU2	forb	6089													
51	L	3	ARNU2	forb	6077													
68	R	2	ARNU2	forb	6071													
98	L	3	ARNU2	forb	6074													
140	L	2	ARNU2	forb	6080													
154	R	1	ARNU2	forb	6072													
164	L	3.5	ARNU2	forb	6085													

10. Repeat this process for all growthForms

11. Un-filter growthForms so that all are displayed



Phenology bout datasheet

Phenophase Occurrence Codes: Y=yes; N=no; M=missed; ?=uncertain (take photo) **Note: Every white phenophase cell must be filled**
Remarks (especially added or dropped individuals):

Previous Bout date: _____

plotID: _____

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

MeasuredBy: _____

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

12. Remove filters from field names
13. Sort by transectMeter so that individuals are organized as they occur sequentially along the transect
14. Save datasheet to local drive
15. Print datasheets
16. Update as necessary as individuals are added/dropped

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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** 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.
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.

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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 ‘Selection Datasheet’ to record data from this SOP.

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.
 - 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 DBH > 1 cm.
 - Select individuals which are mature enough they are likely to survive, i.e. do not select saplings.

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- **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 evenly spaced individuals of a single species (Phase I).
- **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. Record the **transectMeter**, the location along the transect (0-799 m) at which the individual is perpendicular. Use the permanent markers or labeled flags and pacing, tape, or the TruPulse in **HD mode** (preferred method) to determine the transect meter.
2. Record the **directionFromTransect**, whether the individual is to the right or left of the transect (facing towards increasing transect meters).
3. Measure the **ninetyDegreeDistance**, the distance from the transect to the individual, using a TruPulse 360R in HD mode.

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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 RD[07].



Figure 1. Examples of recommended phenology markers. Photo credit: National phenology network (left), Ben Meadows (center), Forestry Suppliers (right)

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 bailing wire. Mark individual with florescent flagging (if permitted by site host) to aid in finding plant.
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: Wrap wire loosely to avoid damaging stem as the plant grows. *It is important to ensure that the method of marking chosen does not change the growing conditions of the plant or injure the plant in any way.* 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.

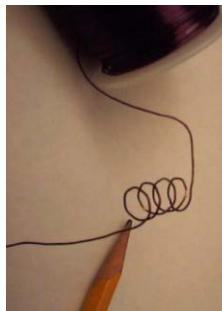


Figure 2. Bailing wire coiled around a pencil

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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.

1. **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.
2. **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 : Avoid placing a broad stake next to a small plant that would shade it or cause root damage.*
3. 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.
4. 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.
5. 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.
6. Record tagID (unique number from pre-stamped blue tag) and 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. Photo credit: National Phenology Network and NEON field crews 2011.

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SOP D Collecting Data

D.1 Observing phenophases



Regular data collection, observation of phenological development will occur throughout the growing season. Use the formatted, pre-populated (if available) ‘perindividual_peryear’ RD[05] to record data. 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.
 - 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, Species Code and Growth Form – should be prepopulated).
 - **date** – YYYYMMDD
 - **Phenophase** - Y/N/?/M/X for each (P1-P6, Table 8) required for that growth form (see Appendix B for full descriptions of phenophases)
 - 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.
 - 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).

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- Do not record a phenophase as missed if a phenophase occurred prior to initiating phenology sampling for the current growing season
- Intensity values for missed phenophases are not recorded.
- Unnecessary (X) - Check for **every** required phenophase for every individual/patch during each sampling bout. If not working with a site specific formatted datasheet, 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

Table 8 Phenophases (see Appendix B)

Phenophase #	Phenophase title
P1	Breaking leaf buds
	Breaking needle buds
	Emerging needles
	Initial growth
P2	Increasing Leaf size
	Young Leaves
	Young needles
P3	Canopy
	Leaves
	Needles
P4	Open flowers
	Open pollen cones
P5	Colored leaves
	Colored needles
P6	Falling leaves
	Falling needles

5. Select an appropriate phenophase **intensity category** (1-6, see Table 9) for each phenophase for which 'Yes' is selected. Growth-form specific phenophases and their descriptions are listed in Appendix B.

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Table 9. Intensity class categories

Intensity Classes	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 (P2 only)	< 5	5- 25	25-49	50-74	75-95	≥ 95

6. 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 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.
- If a long lived species that was healthy becomes diseased or experiences >50% mortality, replace as for missing plants 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 (perennials only), replace as for missing plants.
- 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 for good (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.

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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 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 TruPulse 360R canopy diameter and height measurements where appropriate.
- **diseaseStatus** (H/D – healthy/diseased)
- **diseaseType** – if known

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Table 10. Canopy crown classes

Crown Class	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))

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Table 11. Biomass and productivity measurements

Vegetation Structure	Required Measurements	Tools to Measure
Single-stemmed individuals	<ul style="list-style-type: none"> • DBH/DDH (cm) • maxCanopyDiameter: max. diameter (m) • ninetyCanopyDiameter: Perpendicular to max. diameter (m) • Height (m) • Average adult leaf length (DBL only) (cm) 	<ul style="list-style-type: none"> • Diameter tape • TruPulse • Ruler
Multi-stemmed shrubs and herbaceous perennials	<ul style="list-style-type: none"> • maxCanopyDiameter: max. diameter (m) • ninetyCanopy diameter: Perpendicular to max. diameter (m) • Height (m) • Average adult leaf length (DBL only) (cm) 	<ul style="list-style-type: none"> • TruPulse or tape • Ruler
Patches*	<ul style="list-style-type: none"> • Cover Percent • Average height (m) 	<ul style="list-style-type: none"> • 0.25 m x 0.25 m calibrated quadrat • Ruler or short tape

*** Tips for measuring patches:**



- Each frame should be calibrated (painted in 10 cm sections) 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 subplot frame.
- Visually group individuals together into a percent cover. Fine tune that estimate by subtracting out any spaces or gaps. There will often be overlap of plants species.
- Cover should be recorded as the total aerial coverage of the target species. Estimates should not exceed 100% for the target species.

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SOP F Data Entry and Verification

As a best practice, field data collected on paper datasheets should be digitally transcribed within 7 days of collection or the end of a sampling bout (where applicable). However, given logistical constraints, the maximum timeline for entering data is within 14 days of collection or the end of a sampling bout (where applicable). See RD[04] for complete instructions regarding manual data transcription.

F.1 Entering and uploading data

1. For data collected on paper datasheets: Transcribe data into phenology Field Data ingest Access database in accordance with data entry and data QA/QC protocols (AD[08]).
 - Spreadsheet fields mirror the datasheet; do not change formatting on the provided spreadsheet.
 - If technician roles switched during the course of a monitoring bout and notes have been recorded on the datasheet, make sure that information is transcribed into the measuredBy and recordedBy fields such that every record in the the 'phe_statusintensity_in' tables is attributed to the technician who made the observation.
 - Acceptable entries for each data field are provided in the 'pheFieldSummary_in' schema of the 'phenology_dataingest' database
 - For permanently dropped plants, enter the tagID and the drop date in the 'phe_perindividual_in' schema as a separate record from the initial addDate record. Do not add droppedDate to an existing record as this will cause duplicate records when ingested.
2. For data collected on the NEON digital data collection device: Download all data according to the protocols for data handling. Address any QA/QC concerns.
3. Download photos.
 - a. Place all photos in a single folder labeled by date.
 - b. Confirm uncertain phenophases (i.e. phenophase = ?) with local expert. Update datasheets and note that data were post-corrected in the lab.
 - c. 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.
 - d. Add Tags (Species, phenophase, intensity ...) to file properties to make them searchable.
 - e. Do not change file name as this links to datasheet info.
4. Scan and print a copy of original data sheets from current bout to bring into the field on the next monitoring bout.

F.2 Equipment Maintenance, Cleaning and Storage

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

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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.

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8 REFERENCES

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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

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) Young Leaves/ Young Needles	P2 intensity	(P3) Full size leaves	P3 intensity	(P4) Open Flowers / Pollen Cones	P4 intensity	(P5) Colored Leaves/ Needles	P5 intensity	(P6) Falling leaves/ Needles	P6 intensity
Deciduous trees and shrubs (DBL)	✓	#	✓	%	✓	%	✓	%	✓	%	✓	-
Broadleaf evergreen trees and shrubs (EBL)	✓	#	✓	#	-	-	✓	%	-	-	-	-
Evergreen Conifer (EC)	✓	#	✓	#	-	-	✓	%	-	-	-	-
Pine	✓	#	✓	#	-	-	✓	%	-	-	-	-
Deciduous Conifer (DC)	✓	#	-	-	✓	%	✓	%	✓	%	✓	-
Forb	✓	-	-	-	✓	-	✓	%	-	-	-	-
Grasses/Rushes/Sedges (GRS)	✓	-	-	-	✓	%	✓	%	-	-	-	-
Cactus	-	-	-	-	-	-	✓	%	-	-	-	-

B.2 Phenophase Intensity Class Categories

Intensity Classes	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 (P2 only)		< 25	25-49	50-74	75-95	≥ 95

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



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PHENOLOGY SAMPLING

STEP 1 – Lay out phenology loop in tower airshed (annually).

STEP 2 – Select individuals and patches to monitor (annually).

STEP 3 – Map location of monitored individuals and patches (annually).

STEP 4 – Mark individuals and patches with tags and tagIDs (annually).

STEP 5 – Collect phenophase data, including photographs.

STEP 6 – Select replacement individuals as needed.

STEP 7 – Enter information from data sheets onto computer.

STEP 8 – Download photographs and indicate phenophase.

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

Phenophase	
#	Description
P1	Breaking buds/emerging needles/initial growth
P2	Young leaves/needles
P3	Leaves/needles/canopy
P4	Open flowers/pollen cones
P5	Colored leaves/needles
P6	Falling leaves/needles

PHENOPHASE DEFINITIONS

Phenophase #1			
Phenophase Title	Applicable Growth Forms	Status Description	Intensity Description
Breaking leaf buds	DBL EBL	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.	# class of buds that 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.	# class of buds that 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.	# class of needles or needle bundles 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

• P1- Initial Growth (EBL, EC, DBL, DC, Pine, Forb, GRS)



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Phenophase #2			
Phenophase Title	Applicable Growth Forms	Status Description	Intensity Description
Increasing Leaf size	DBL	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.	% class of full size of most leaves
Young Leaves	EBL	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.	# class of young leaves 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.	# class of young needles present

- P2 – Young leaves/needles (DBL, EBL, EC, Pine)



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Phenophase #3			
Phenophase Title	Applicable Growth Forms	Status Description	Intensity Description
Canopy	DBL	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.	% class of the canopy that 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 - % class of the plant that 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.	% class of the canopy that is full with needles. Ignore dead branches in the estimate.

Assessing intensity class for grasses, sedges, and rushes (P3)

For grass, sedge and rush species (GSR) where new growth is from new stems, the plant will probably be 100% green (intensity class 6 for P3) 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 (P3)** 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.

• P3 – Adult Leaves (DBL, DC, Forbs, GRS)



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Phenophase #4			
Phenophase Title	Applicable Growth Forms	Status Description	Intensity Description
Open flowers	DBL EBL Forb GRS Cactus	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.	% class of all fresh flowers (buds plus unopened plus open) on the plant that 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	% class of all fresh pollen cones (unopened plus open) on the plant that 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 (P4)

When estimating intensity class for **Open Flowers (P4)** 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.

• P4 – Open flowers/pollen cones (DBL, EBL, DC, EC, Pine, Forb, GRS, Cactus)



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Phenophase #5			
Phenophase Title	Applicable Growth Forms	Status Description	Intensity Description
Colored leaves	DBL	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.	% class of the canopy that 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.	% class of the canopy full with colored needles.

Phenophase #6			
Phenophase Title	Applicable Growth Forms	Status Description	Intensity Description
Falling leaves	DBL	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

Estimating percent canopy with colored leaves/needles (P5)

To estimate the percentage of the canopy that is full with **colored leaves/needles (P5)**, consider only the colored portions of leaves and needles that are left on the plant and do not include the green portions. 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. 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. 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. 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.

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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 (P1)**, 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 young leaves/needles phenophase (P2) 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' (P3) 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 (P6) 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 (P3).

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APPENDIX C 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.

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APPENDIX D ESTIMATED DATES FOR ONSET AND CESSATION OF SAMPLING

To view NDVI/EVI graphs for your sites go to the ‘create subset’ link at 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

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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

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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

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APPENDIX E SITE-SPECIFIC INFORMATION

List of species selected for Phase I (dominants) phenology monitoring

E.1 D01 – HARV – Harvard Forest

Phase I Species	Phase II Species
<i>Acer rubrum</i>	
<i>Quercus rubra</i>	
<i>Aralia nudicaulis</i>	

E.2 D01 – BART – Bartlett Experimental Forest

Phase I Species	Phase II Species
<i>Acer rubrum</i>	

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

Phase I Species	Phase II Species

E.4 D02 – SCBI – Smithsonian Conservation Biology Institute

Phase I Species	Phase II Species
<i>Liriodendron tulipifera</i>	
<i>Quercus alba</i>	
<i>Microstegium vimineum</i>	

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E.5 D02 – SERC – Smithsonian Environmental Research Center

Phase I Species	Phase II Species

E.6 D02 – BLAN – Blandy Experimental Farm

Phase I Species	Phase II Species

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E.25 D09 – WOOD – Woodworth

Phase I Species	Phase II Species

E.26 D09 – DCFS – Dakota Coteau Field School

Phase I Species	Phase II Species

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

Phase I Species	Phase II Species

E.28 D10 – CPER – Central Plains Experimental Range

Phase I Species	Phase II Species
<i>Bouteloua gracilis</i>	
<i>Hesperostipa comata</i>	
<i>Thelesperma filifolium</i>	

E.29 D10 – STER – North Sterling, CO

Phase I Species	Phase II Species
Annual crop	

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

Phase I Species	Phase II Species

E.31 D11 – CLBJ – LBJ National Grassland

Phase I Species	Phase II Species

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E.32 D11 – OAES – Klemme Range Research Station

Phase I Species	Phase II Species

E.33 D11 – (SOFT) – Relocatable

Phase I Species	Phase II Species

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

Phase I Species	Phase II Species

E.35 D12 – BOZE – Bozeman, MT

Phase I Species	Phase II Species

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E.36 D12 – PARA – Paradise Valley, MT

Phase I Species	Phase II Species

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

Phase I Species	Phase II Species

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E.38 D13 – MOAB – Moab

Phase I Species	Phase II Species

E.39 D13 – WINT – Winter Park

Phase I Species	Phase II Species

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E.40 D14 – SRER – Santa Rita Experimental Range

Phase I Species	Phase II Species

E.41 D14 – JORN – Jornada LTER

Phase I Species	Phase II Species

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E.42 D14 – (SOFT) – Relocatable

Phase I Species	Phase II Species

E.43 D15 – ONAQ – Onaqui-Ault

Phase I Species	Phase II Species
<i>Artemisia tridentata ssp. tridentata</i>	
<i>Ceratocephala testiculata</i>	
<i>Bromus tectorum</i>	

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E.44 D15 – (SOFT) – Relocatable

Phase I Species	Phase II Species

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

Phase I Species	Phase II Species

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E.46 D16 – WREF – Wind River Experimental Forest

Phase I Species	Phase II Species

E.47 D16 – THAY – Thayer

Phase I Species	Phase II Species

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E.48 D16 – ABBY – Abby Road

Phase I Species	Phase II Species

E.49 D17 – SJER – San Joaquin

Phase I Species	Phase II Species

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E.50 D17 – SOAP – Soaproot Saddle

Phase I Species	Phase II Species

E.51 D17 – TEAK – Lower Teakettle

Phase I Species	Phase II Species

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

Phase I Species	Phase II Species

E.55 D19 – DEJU – Delta Junction

Phase I Species	Phase II Species

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E.58 D20 – OLAA – Olaa Forest Reserve

Phase I Species	Phase II Species

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

Phase I Species	Phase II Species



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

Phase I Species	Phase II Species