TOS PROTOCOL AND PROCEDURE: MEASUREMENT OF VEGETATION STRUCTURE

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Change Record

REVISION	DATE	ECO #	DESCRIPTION OF CHANGE
A	01/10/2014	ECO-01139	Initial release
B	03/20/2014	ECO-01661	Production release, template change, and other changes as detailed in Appendix C
C	4/10/2014	ECO-01792	Added Appendix H with site-specific information
D	10/01/2014	ECO-02287	Migration to new template. Reorganization of content and updates to datasheets. Change to sampling strategy in 40 m x 40 m Tower plots.
E	02/25/2015	ECO-02537	Update of TOS protocol based on 2014 field experience and budget analysis.
F	02/29/2016	ECO-03583	Summary of protocol changes: • Updated key definitions in Section 2.4 Table 1, and added growth form definitions in Section B.1 Table 7 • Section 4.1: Clarified timing language for fern sampling • SOP B: Reorganized to focus only on classification, mapping, and tagging. Flow charts, figures, and information pertaining to measurements removed and inserted to SOP C when appropriate. • SOP B.1: Classification to growthForm now dependent on stem count, DBH, height, and species-specific knowledge • SOP B.2: Nested subplot text moved from SOP C to SOP B • SOP B.2: Added mechanism to change nested subplot size in consultation with NEON Science Operations. • SOP B.3: 'Selecting the Optimal Measurement Area' moved from SOP C to SOP B. • SOP B.5: Added standardized taxonID text to step 9 • SOP C: Broken bole measurement strategy no longer requires confusing data entry into canopy diameter fields. • SOP C: Cactus measurements removed, moved to newly developed Cactus SOP (RD[11]) • SOP C: Calipers now required for diameter measurements on self-supporting stems with lianas. Multi-bole tree measurement strategy now consistent with FIA approach, no longer based on liana guidelines. • SOP C: Changed 'stemStatus' to 'status', updated code definitions, added a new code for 'no longer measured' • SOP C: Added paragraph calling out types of 'other' growth forms that require measurement, provided cross-reference to Appendix D for details. • SOP E: Added standardized data entry text

REVISION	DATE	ECO #	DESCRIPTION OF CHANGE
			• Appendix: Removed *Toxicodendron* handling appendix, due to imminent release of *Toxicodendron* handling SOP.
G	03/09/2017	ECO-04408	Summary of protocol changes: • Sampling completion: Specified that bouts must be completed within 4 months of sampling onset. • Expanded instructions for recording Plot Metadata, and changed to annual basis to improve tracking and reporting of sampling effort. • Updated numerous field names to be consistent with Data Products implementation. • Added more guidance for recording `identificationReferences` in the Plot Metadata table, and in the growth-form-specific tables. • Added `tagStatus` to facilitate tracking individuals through time. • Changed `status` to `plantStatus` to comply with pre-existing Data Products term definitions, and added new plantStatus choices. • Expanded broken bole guidance. • Appendix D.2: Updated forking guidelines to be consistent with 2016 Forest Service FIA rules. • Appendix D.5: Clarified that ddh is not measured if access is denied along first 30 cm of stem. • Appendix D.6: Added measurement guidelines for 'sap' and 'sms' individuals. • Appendix F: Clarified that agave and other yucca-like growth forms with large basal rosettes should be measured similar to yucca. • Appendix H: Converted dates from DOY to MM/DD • To address problem with consistent field implementation, shrub 'shape' no longer limited to leafy crown, now consider the entire individual. • Appendix I: Added site-specific modifications, including changes to annual Tower Plot measurement frequency at cold/dry sites (identified 'efficiency' required to be implemented in 2017).
H	7/26/2018	ECO-05698	• Sections 1 and 3: Re-organized and simplified text. • Section 3.1: New section with protocol implementation guidelines by plot type, including reference to new Survey Method for Assessment of Vegetation Cover SOP. • Section 4.1: Change to schedule Distributed and Tower Plots in different years at a site. • Section 4.2.1: Clarified that bouts should be completed within 60 d at sites with no distinct growing season.

REVISION	DATE	ECO #	DESCRIPTION OF CHANGE
			• Section 6: Updated equipment list to support move away from Maximo. • SOP B: Integrated support for digital data collection workflow. • SOP B.1: Clearly called out Shrub Group designation criteria. • SOP B.2, B.3: Added 3 m^2 nested subplot size. • SOP B.4: Nails no longer used to tag small trees; loose aluminum wire only to avoid damage. • SOP B.6: Added 'Mapping QA/QC' section to integrate use of 'VST Mapper' application into workflow. • SOP C: Integrated support for digital data collection workflow. • SOP C.1: Simplified tagStatus to 'ok', 'replaced', and 'notTagged'. • SOP C.1: Added plantStatus = 'downed'. • SOP C.1.2: Added explicit guidance to avoid sloughing off bark during DBH measurement. • SOP C.3: Combined agave and yucca growthForm into one 'yucca' growthForm, due to identical measurements. • SOP C.3.2: Added guidance for measuring tree ferns. • SOP E: Added content to support digital data workflow • Appendix I: New site-specific appendices for D04, D14; added WREF to list of sites in Appendix I.1.

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1 OVERVIEW

1.1 Background

The measurement of vegetation structure and the mapping of free-standing woody stems within NEON Terrestrial Observation System (TOS) plots enables calculation of per stem, per plot, and site-level woody biomass and productivity. Within Tower Plots, woody biomass increment is often a dominant component of total aboveground net primary productivity. Understanding changes in woody biomass stocks and fluxes is therefore an important prerequisite for predicting ecosystem carbon balance. Recording the types and stature of woody species also provides insight into habitat quality and ecosystem responses to environmental change.

Vegetation Structure data are also an important complement to data streams generated by the NEON Airborne Observation Platform (AOP) and Terrestrial Instrument System (TIS). When combined with AOP data, these ground-collected data will validate LiDAR data used to map the structural complexity of vegetation, and will enable mapping of plant biomass at the site scale. In conjunction with TIS carbon flux data, vegetation structure data will facilitate understanding how biomass in different plant growth forms contributes to ecosystem level carbon flux.

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

Benjamin Chemel, of the Northern Rockies Conservation Cooperative, contributed substantially to the initial development and testing of this protocol. NEON Field Ecologists have been invaluable with respect to subsequent revision and refinement.

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	EHSS Policy, Program and Management Plan
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.000914	NEON Science Design for Plant Biomass, Productivity, and Leaf Area Index
AD[07]	NEON.DOC.004104	NEON Science Performance QA/QC Plan

2.2 Reference Documents

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

RD[01]	NEON.DOC.000008	NEON Acronym List
RD[02]	NEON.DOC.000243	NEON Glossary of Terms
RD[03]	NEON.DOC.002652	NEON Level 1, Level 2, and Level 3 Data Products Catalog
RD[04]	NEON.DOC.001271	AOS/TOS Protocol and Procedure: Data Management
RD[05]	NEON.DOC.001573	Datasheets for TOS Protocol and Procedure: Measurement of Vegetation Structure
RD[06]	NEON.DOC.014037	TOS Protocol and Procedure: Measurement of Herbaceous Structure and Biomass
RD[07]	NEON.DOC.014042	TOS Protocol and Procedure: Plant Diversity Sampling
RD[08]	NEON.DOC.001025	TOS Protocol and Procedure: Plot Establishment
RD[09]	NEON.DOC.001717	TOS Standard Operating Procedure: TruPulse Rangefinder Use and Calibration
RD[10]	NEON.DOC.002150	NEON Algorithm Theoretical Basis Document: TOS Vegetation Structure – QA/QC of Raw Field Data
RD[11]	NEON.DOC.001715	TOS Standard Operating Procedure: Cactus Biomass and Handling
RD[12]	NEON.DOC.001716	TOS Standard Operating Procedure: Toxicodendron Biomass and Handling
RD[13]	NEON.DOC.005023	TOS Standard Operating Procedure: Survey Method for Assessing Vegetation Cover
RD[14]	NA	Manual for Fulcrum Application: TOS Vegetation Structure [PROD] – All SOPs

2.3 Acronyms

Acronym	Definition
BH	Breast height; defined here as 130 cm above the ground
DBH	Diameter at breast height
ddh	Diameter at decimeter height
Ha	hectare(s)
LAI	Leaf Area Index
LiDAR	Light Detection and Ranging
NEE	Net Ecosystem Exchange
NEP	Net Ecosystem Productivity
NPP	Net Primary Productivity

2.4 Definitions

Common terms used throughout this document are defined here, in alphabetical order. Criteria for defining trees, saplings and shrubs generally follow those outlined and adopted by the USDA PLANTS database.

Table 1. Definitions for common terms used throughout the Vegetation Structure protocol.

Term	Definition
apparent individual	A stem or group of stems that form(s) an individual with a canopy that is discernable from other apparent individuals. Apparent individuals may have multiple stems, provided they are clearly connected above, at, or just below ground level. The word "individual" here does not refer to "genetic" individuals. For example, in an Aspen clone, many apparent individuals are all part of one genetic individual, and each apparent individual is measured.
bole	Typically, the trunk of a tree. A bole differs from a lateral branch in that it is a primary support structure for the individual, supports lateral branches, and tends toward the canopy at angles < 45˚ off of vertical (but not true for decumbent growth forms).
crown	The part of a woody individual that, when drawn in silhouette from branch tip to branch tip, contains all of the foliage. Crown implies parts of plants that could (or did) hold leaves (modified FIA definition). Broken boles that do not bear leaves are not included as part of the crown.
emergent bole	Part of a multi-bole tree or shrub that comes out of the ground separate from other boles, but is attached to the root collar either at or below ground level.
overstory	The overstory is typically formed by the tallest individuals in the plot, and overstory individuals are often mapped.
primary stem	A stem that supports smaller stems and lateral branches, and is not itself connected to a larger branch or bole. Often emerges from the ground and is connected directly to the root system.
qualifying stem	A stem that meets listed criteria for a given growth form.

Term	Definition
understory	Relatively small-stature vegetation, either woody stemmed or herbaceous, that exists in the presence of an overstory.
vdApex BreakHeight	Height from observer to the average height at which a bole broke.
vdBase BreakHeight	Height from observer to the base of a broken bole (typically a negative value).
woody stem	Lignified aboveground tissue that persists from year to year, typically increasing in diameter due to the addition of new secondary woody growth as the plant ages.

3 METHOD

There are numerous methods for measuring and mapping woody stems. The recommended procedure depends greatly on available resources, ecosystem type, and the intended application of resulting datasets. The overarching goal of this protocol is to utilize methods that are robust across a wide-variety of field conditions and ecosystem types, are relatively easy to implement in the field, are not prone to user error, and are capable of producing high-quality data.

A combination of NEON Distributed Plots and Tower Plots are employed for collecting vegetation structure data (**Figure 1** and **Figure 2**). Within these plots, this protocol generates data that describe the spatial location, structure, volume, and biomass of the woody-stemmed plant community, including tree, sapling/shrub, liana, and other growth forms. Data are collected with hand-held tools in the field, using methods with a long, substantiated history in the forestry community. There is no laboratory component to the work. The SOPs provide detailed methods for measuring the following key parameters:

- SOP B – Offset mapping methods to enable calculation of the location of measured stems.
- SOP C – Methods to collect vegetation structure data, including:
    - Stem diameter (Diameter at Breast Height, DBH; and diameter at decimeter height, ddh)
    - Total stem height
    - Crown diameter
    - Taxon ID
    - Plant status (i.e. healthy, snag, damaged, etc.)

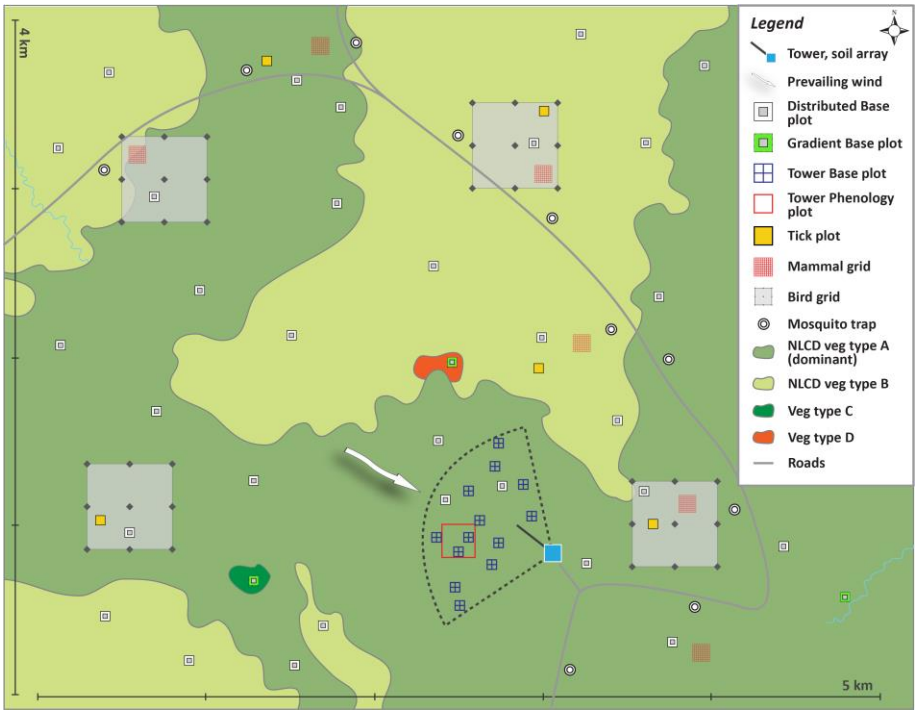


Figure 1. Generalized TOS sampling schematic, showing the placement of NEON TOS Plots.

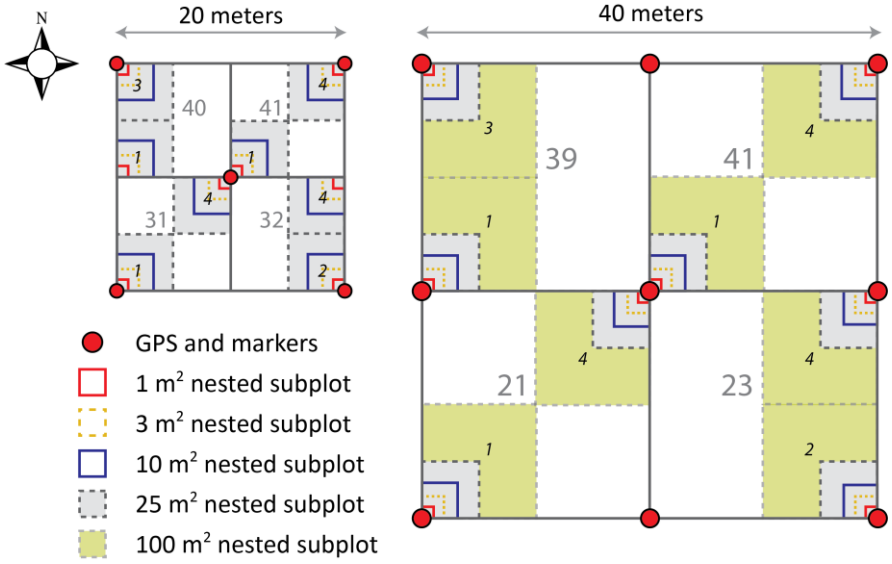


Figure 2. A 20m × 20m base plot (left; larger destructive sampling portion of the plot not shown), a 40m × 40m base plot (right), and associated nested subplots used for measuring woody stem vegetation. The 20m x 20m plot size may be used for either Distributed Plots or Tower Plots, and the 40m x 40m plot size is only for Tower Plots. Numbers in plain grey text indicate subplotIDs and numbers in italic black text indicate nested subplotIDs. The pointIDs associated with markers (red circles) are provided in Appendix G.

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 data in the 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, and keep abreast of mid-season changes documented in NEON's problem-tracking system. In the event that local conditions create uncertainty about carrying out these steps, it is critical that technicians document the problem and enter it into NEON's problem tracking system.

Quality assurance will be performed on data collected via these procedures according to the NEON Science Performance QA/QC Plan (AD[07]).

3.1 Method Implementation Guidelines

Criteria for implementing the Vegetation Structure protocol varies by plot type (**Table 2**).

Table 2. Vegetation Structure protocol implementation guidelines by plot type.

Plot Type	Guidelines

Distributed	• Measurement of Vegetation Structure is determined on a plot-by-plot basis.
	• Collect data from a plot if any of the following criteria are true:
	  ○ NLCD vegetation type is Deciduous Forest, Evergreen Forest, or Mixed Forest.
	  ○ The plot contains at least one single-bole or multi-bole tree individual.
	  ○ Qualifying woody or non-woody perennial vegetation cover is ≥ 25 % (visual estimate).
	• If the above criteria are not met, but qualifying woody or non-woody perennial vegetation is present in the plot:
	  ○ Implement the Survey Method for Assessing Vegetation Cover SOP (RD[13]).
	  ○ Collect Vegetation Structure data from the plot if qualifying woody or non-woody perennial vegetation is ≥ 10% cover.
	• Exceptions:
	  ○ Ferns, Xerophyllum, and Yucca growth forms are not measured when NLCD = Deciduous Forest, Evergreen Forest, or Mixed Forest.
	  ○ Ferns are not measured when aerial cover is < 50% of the plot by visual estimate AND NLCD is not forest.Data collection:
	• Data collection:
	  ○ Create Plot Meta-Data records for all Distributed Plots assigned to the Vegetation Structure protocol if at least one plot contains qualifying vegetation (SOP 0).
	  ○ 'Mapping and Tagging' and 'Apparent Individual' records are not created for those Distributed Plots no qualifying vegetation – i.e., Target Taxa Present = 'No' for the entire plot.

Tower	• Collect Vegetation Structure data from all plots if any of the following criteria are true:
	  ○ There is at least one single-bole or multi-bole tree in ≥ 10% of plots.
	  ○ Qualifying woody or non-woody perennial vegetation cover is ≥ 25 % *averaged across all plots* (visual estimate).
	• If the above criteria are not met, but qualifying woody or non-woody perennial vegetation is present in ≥ 10% of plots:
	  ○ Implement the Survey Method for Assessing Vegetation Cover SOP (RD[13]) in all plots.
	  ○ Collect Vegetation Structure data from plots if qualifying woody or non-woody perennial vegetation is ≥ 10% cover *averaged across all plots.*
	• Data collection:
	  ○ Create 'Plot Meta-Data' records for all Tower Plots if Vegetation Structure data are collected from any plots.
	  ○ Create 'Mapping and Tagging' and 'Apparent Individual' records as above.

4 SAMPLING SCHEDULE

4.1 Sampling Frequency and Timing

***Frequency**:*

All SOPs are executed every time the Vegetation Structure protocol is implemented at a site. Implementation frequency for Vegetation Structure depends on plot type. Site specific exceptions are documented in Appendix I. In general:

- Distributed Plots: 5-year sampling interval
- Tower Plots:
    - Mesic sites: Annual sampling interval for a subset of plots, 5-year sampling interval for all plots.
    - Cold/dry sites: 5-year sampling interval.
- Schedule Distributed Plots and measurement of all Tower Plots in different years in order to maximize the number of years that Vegetation Structure data are collected at a site.
    - Stagger VST Distributed and Tower Plot implementation as evenly as possible through time.
    - Schedule Distributed Plot VST, CDW, and HBP in the same year, and staggered such that Distributed Plot implementation of these protocols does not overlap with scheduling of synchronized Biogeochemistry protocols (BGB, CFC, LAI, LTR, NTR, SLS).

Timing: Estimated sampling windows, including estimated sampling onset and cessation dates, are provided on a per site basis in Appendix H. The dates in the appendix are multi-year averages derived from satellite data, and as such, individual future years will vary somewhat with respect to these dates. Once a sampling onset date has been selected for vegetation structure measurements at a given site by Field Operations, the onset of sampling in subsequent years should be consistent – i.e. within the same season and vegetation phenophase. Measurement of woody stemmed individuals (i.e. trees, shrubs, lianas) should ideally be coincident with measurement of species classified as 'other' (e.g., ferns, cacti), in order to enable a single sampling effort per year for vegetation structure work. This idealized sampling schedule means that, at a typical north temperate site, ferns will not be measured at peak greenness. However, for those sites with fern species that senesce aboveground every year (e.g., Bracken Fern [*Pteridium aquilinum*]), a separate bout may be required to measure ferns before senescent leaves and stems begin to break apart.

4.1.1 Survey Method Schedule for Assessment of Vegetation Cover

Schedule implementation of the Survey Method (RD[13]) every 5-years for Distributed Plots (evaluated on a per plot basis) and Tower Plots (evaluated across all plots) that meet the Survey Method criteria in **Table 2**.

4.2 Criteria for Determining Onset and Cessation of Sampling

Sampling onset:

The guiding principle is that vegetation structure measurements should begin after the majority of annual growth in a given growing season has completed. In many systems, the onset of sampling therefore coincides with the end-of-growing-season onset of the senescence phenophase for deciduous and herbaceous plants – i.e., the appearance of colored leaves / needles for trees and shrubs, and reduction in % green for herbaceous plants (**Table 3**).

Table 3. Sampling onset guidelines for different site and vegetation types.

Site Type	Vegetation Type	Sampling Onset Guideline
Mesic, Temperate	Deciduous forest, Mixed-deciduous forest, Shrub scrub	• Sampling may begin once approximately 50% of the deciduous woody vegetation has begun to senesce. • Use plots with deciduous woody vegetation as a guide for when to sample any evergreen forest plots – sampling onset applies to all vegetation types.
Mesic, Temperate	Evergreen forest	• Sampling may begin once approximately 50% of the herbaceous understory plants have begun to senesce. • If any plots at a site are classified into deciduous vegetation types (above row), use deciduous plots to guide sampling onset.
Wet/Dry Seasonality	Multiple	• Sampling may begin once the dry season has begun and growth rates are minimal (e.g., D04 GUAN, D14 SRER.

- Use the dates in Appendix H as a guide for when to begin monitoring the vegetation for senescence:
    - Bear in mind that the sampling start-date for individual years may deviate significantly from the average dates provided.
- At each site, the onset of sampling should be the same date for trees, saplings/shrubs, and lianas. That is, all growth forms should be measured at a given plot when that plot is sampled; technicians should **NOT** sample trees in all plots first, then re-sample plots for saplings/shrubs and lianas.

Sampling cessation:

Measurement of woody stem vegetation structure must be completed within 4 months of sampling onset, AND before the onset of the next growing season – i.e., before new leaves expand.

4.2.1 Sites with No Distinct Growing Season

For sites with no distinct growing season:

- Sampling should begin at the same time every year ± 2 weeks.
- Sampling bouts should be completed within 60 d of initiation.

Once flux time-series data are available at each site, Science Operations can provide more precise sampling windows on a site-by-site basis.

4.3 Timing for Laboratory Processing and Analysis

Not applicable.

4.4 Sampling Timing Contingencies

When unexpected field conditions require deviations from this protocol, the guidance in **Table 4** must be followed to ensure that basic data quality standards are met:

Table 4. Contingency guidelines and possible outcome for data product quality.

Delay/Situation	Action	Outcome for Data Products
Hours to 4 weeks	If delay prevents completion of measuring/mapping a plot or sub-plot, use flagging to ensure it is clear which stems have been measured/mapped and resume data collection from the plot or subplot ASAP.	None for woody stem data; ferns may senesce in this time frame, leading to increased uncertainty for this growth form.
	If delay occurs between plots or sub-plots, resume data collection from the next plot or sub-plot ASAP.	None for woody stem data; ferns may senesce in this time frame, leading to increased uncertainty for this growth form.
≥ 4 weeks	If delay prevents completion of measuring/mapping a plot or sub-plot, use flagging to ensure it is clear which stems have been measured/mapped and resume data collection from the plot or sub-plot ASAP.	Increased error in aboveground biomass and NPP estimates. Temporary flagging may be lost, causing duplicate measurements of individuals; significant wood growth could occur in fast-growing species.
	If delay occurs between plots or sub-plots, resume data collection from the next plot or sub-plot ASAP.	Increased error in aboveground biomass and NPP estimates. Significant wood growth could occur in fast-growing species.

4.5 Criteria for Permanent Reallocation of Sampling within a Site

Measurement of Vegetation Structure will occur on the schedule described above at up to 20 selected Distributed Plots, and up to the total number of established Tower Plots per site. Ideally, sampling will occur at these locations for the lifetime of the Observatory (core sites) or the duration of the site's affiliation with the NEON project (relocatable sites). However, circumstances may arise requiring that sampling within a site be shifted from one particular location to another. In general, sampling is considered to be compromised when sampling at a location becomes so limited that data quality is significantly reduced. If sampling at a given plot becomes compromised, a problem ticket should be submitted by Field Operations to Science.

There are two main pathways by which sampling can be compromised. Sampling locations can become inappropriately suited to answer meaningful biological questions (e.g., a terrestrial sampling plot becomes permanently flooded or a stream moves after a flood and the location is no longer within the stream channel). Alternatively, sampling locations may be located in areas that are logistically impossible to sample on a schedule that that is biologically meaningful.

For measurement of Vegetation Structure, criteria for considering a plot compromised depend on plot type:

- Distributed Plots: If sampling cannot be completed for 2 consecutive bouts then the plot should be considered compromised.
- Tower Plots: If sampling cannot be completed for any 2 out of 3 scheduled bouts then the plot should be considered compromised.

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 woody stems as points, 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. However, as with any laser device, reasonable precautions should be taken during 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.

Additional safety issues associated with this field procedure include potential exposure to *Toxicodendron* oils. Protocol-specific equipment to mitigate exposure is listed in Section 6 (**Table 8**), and additional general mitigation strategies are discussed in RD[12].

6 PERSONNEL AND EQUIPMENT

A minimum team size of two field technicians is required for measuring and mapping woody stems, and identifying to species.

6.1 Equipment

The following equipment is needed to implement the procedures in this document. Item quantities are provided for a single team of two people collecting data. 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 5. Equipment list – Preparing for sampling (SOP A).

Supplier	Supplier Number	R/S	Description	Purpose	Quantity	Special Handling
Durable Items						
Amazon	0100078101	R	GPS receiver, recreational accuracy	Pre-load sampling locations	1	N
Forestry Suppliers	91567	R	Laser Rangefinder, ± 30 cm accuracy	Map and measure apparent individuals and shrub groups.	1	N
		R	Hammer	Label blank tags	1	N
Forestry Suppliers	57522	R	Hand stamp steel die set	Label blank tags	1 set	N
Consumable items						
Ben Meadows	010510-1	R	All weather copy paper	Print datasheets	As needed	N
Ben Meadows	152499	R	Round unnumbered aluminum tag, silver	Pre-label for tagging multi-stemmed individuals.	50	N

R/S=Required/Suggested

Table 6. Equipment list – Mapping and tagging (SOP B).

Supplier	Supplier Number	R/S	Description	Purpose	Quantity*	Special Handling
Durable Items						
		R	Mobile data collection device (tablet or equivalent), and spare battery	Collect and record data in the field.	1	N
Bioquip	3127	S	Cardboard ventilator	Press collected individuals for identification		N
Ben Meadows	100952	R	Chaining pins or other suitable anchor	Anchor measuring tapes	4	N
Ben Meadows	213379	S	Compass with mirror and declination adjustment	Determine nested subplot boundary	1	N
		S	Cooler	Chill perishable samples in field	1	N
Forestry Suppliers	59422	R	Diameter tape, 200 cm	Measure stem diameter. Stems present with diameter > 64 cm	1	N
Ben Meadows	122117	R	Diameter tape, 64 cm	Measure stem diameter. Stems present with 5 cm < diameter < 64 cm	1	N
		S	Field guide, regional flora reference guide and/or key	Identify unknown species	1	N
Compass Tools; Forestry Supplier	703512; 90998	R	Foliage filter	Allow laser rangefinder use in dense vegetation	1	N

Supplier	Supplier Number	R/S	Description	Purpose	Quantity*	Special Handling
Amazon	0100078101	S	GPS receiver, recreational accuracy	Navigate to sampling location	1	N
		S	Site map	Navigate to sampling location	1	N
		R	Hammer	Nail tags to trees, label blank tags	1	N
Forestry Suppliers	57522	R	Hand stamp steel die set	Label blank tags	1 set	N
		S	Block of wood or equivalent hard surface	Tag stamping	1	N
		R	Handheld caliper, 0.1 cm precision	Measure stem diameter < 5 cm; lianas prevent accurate diameter measurement with tape	1	N
Fisher	19067113	S	Ice pack	Chill perishable samples in field	As needed	N
Forestry Suppliers	91567	R	Laser Rangefinder, ± 30 cm accuracy	Determine nested subplot boundary; map stems; measure stem height and crown diameter. Individuals with relatively large canopies; plots with slopes > 20%	1	N
Ben Meadows	122732	R	Measuring tape, minimum 50 m	Determine nested subplot, subplot boundary	4	N
Herbarium Supply	223	S	Paper blotters	Press collected individuals for identification	As needed	N

Supplier	Supplier Number	R/S	Description	Purpose	Quantity*	Special Handling
Biquip	3115	S	Plant press	Press collected individuals for identification	As needed	N
Compass Tools	7024901	S	Tripod, non-magnetic	Hold laser rangefinder directly over plot marker	1	N
Grainger	5B317	R	White reflector or reflective tape	Reflective target for laser rangefinder; aids in measuring distance to target accurately	1	N
		R	Wire cutter	Cut wire to desired length	1	N
		S	Rod, dowel, pipe, or equivalent; 1.4 m length, max 1” diameter, marking at 1.3 m	Quickly find measurementHeight and tag height for straight boles	1	N
		S	Rod, dowel, pipe, or equivalent; 0.1 m length, max 1” diameter	Quickly find measurementHeight for ddh	1	N
Consumable items						
		R	AA battery	Spare battery for GPS receiver	4	N
Forestry Suppliers	79121	R	Aluminum nail	Affix tag to stems with DBH ≥ 5 cm	As needed	N
Grainger	16Y067	R	Aluminum wire, 20 gauge	Affix tag to stems with DBH ≥ 5 cm	As needed	N
		R	CR123A battery	Spare battery for laser rangefinder	2	N

Supplier	Supplier Number	R/S	Description	Purpose	Quantity*	Special Handling
Forestry Suppliers; Grainger	57880, 3JVZ5; 9WKP4	S	Flagging tape	Temporarily mark stems after measurement	2	N
Ben Meadows; Grainger	84516, 230916; 9TA07	R	Fluorescent lumber crayon	Mark DBH measurement location on stem	1	N
Grainger	8YAT5, 5CNK5	S	Resealable plastic bag, 1 gal	Collect voucher specimens	20	N
Ben Meadows	152580	R	Round numbered aluminum tag, silver; 0001-6000 and 8001-9999	Tag qualifying stems	As needed	N
Ben Meadows	152499	R	Round unnumbered aluminum tag, silver	Tag multi-stemmed individuals.	50	N
		S	Survey marking flag, PVC or fiberglass stake	Delineate sampling area	12	N
		S	Tabloid newspaper pages	Press collected individuals for identification		N
Resources						
		R	Field datasheet	Record data		N

R/S=Required/Suggested

Table 7. Equipment list – Biomass/productivity measurements* (SOP C).

Supplier		R/S	Description	Purpose	Quantity*	Special Handling
Durable Items						
		R	Mobile data collection device (tablet or equivalent), and spare battery	Collect and record data in the field.	1	N
Bioquip	3127	S	Cardboard ventilator	Press collected individuals for identification		
Ben Meadows	100952	R	Chaining pins or other suitable anchor	Anchor measuring tapes	4	N
		S	Cooler	Chill perishable samples in field	1	N
Forestry Suppliers	59422	R	DBH tape, 200 cm	Measure stem diameter. Stems present with diameter > 64 cm	1	N
Ben Meadows	122117	R	DBH tape, 64 cm	Measure stem diameter. Stems present with 5 cm < diameter < 64 cm	1	N
		R	Haglof Mantax Black calipers, 95 cm	Measure stem diameters up to 95 cm when lianas are attached and a DBH tape will not work.	1	N
		R	Haglof Mantax Black calipers, 50 cm	Measure stem diameters up to 50 cm when lianas are attached and a DBH tape will not work.	1	N

Supplier		R/S	Description	Purpose	Quantity*	Special Handling
		S	Field guide, regional flora reference guide and/or key	Identify unknown species	1	N
Compass Tools; Forestry Suppliers	703512; 90998	R	Foliage filter	Allow laser rangefinder use in dense vegetation	1	N
Amazon	0100078101	S	GPS receiver, recreational accuracy	Navigate to sampling location	1	N
		S	Site map and plot list	Navigate to sampling location	1	N
		R	Hammer	Nail tags to trees, label blank tags	1	N
Forestry Suppliers	57522	R	Hand stamp steel die set	Label blank tags for multi-stem trees	1 set	N
		R	Handheld caliper, 0.1 cm precision	Measure stem diameters < 5 cm	1	N
Fisher	19067113	S	Ice pack	Chill perishable samples in field	As needed	N
Forestry Suppliers	91567	R	Laser Rangefinder, ± 30 cm accuracy	Map stems recruited into the minimum size class; measure stem height, crown diameter. Brushy; trees with relatively large canopy diameters; slopes ≥ 20%	1	N

Supplier		R/S	Description	Purpose	Quantity*	Special Handling
Ben Meadows; Forestry Suppliers	SPSO1722151; 71112	R	Measuring stick, 2 m folding	Measure heights of small-stature woody vegetation	1	N
		S	Aluminum or fiberglass measuring rod, 5 m telescoping	Measure heights of medium-stature woody vegetation, measure crown dimensions for some shrubs	1	N
Ben Meadows; Forestry Suppliers	122732; 39945	R	Measuring tape, minimum 50 m	Determine nested subplot, subplot boundary	4	N
Forestry Supplier	53740	S	Paper blotters	Press collected individuals for identification	As needed	N
Bioquip; Forestry Suppliers	3115; 53674	S	Plant press	Press collected individuals for identification	1	N
Grainger	5B317	R	White reflector or reflective tape	Reflective target for laser rangefinder; aids in measuring distance to target accurately	1	N
		R	Wire cutter	Cut wire to desired length. Stems present with DBH < 5 cm	1	N
Ben Meadows	213379	R	Compass with mirror and declination adjustment	Delineate nested subplots if markers are removed or disturbed	1	N

Supplier		R/S	Description	Purpose	Quantity*	Special Handling
		S	Rod, dowel, pipe, or equivalent; 1.4 m length, max 1” diameter, marking at 1.3 m	Quickly find measurementHeight and tag height for straight boles	1	N
		S	Rod, dowel, pipe, or equivalent; 0.1 m length, max 1” diameter	Quickly find measurementHeight for ddh	1	N
		S	Retractable metal measuring tape, 25 mm W x 10 m L, metric demarcations	Quickly measure mid-stature shrub crown dimensions	1	N
Consumable items						
		S	AA battery	Spare battery for GPS receiver		N
Forestry Suppliers	79121	R	Aluminum nail	Affix tag to stems with DBH ≥ 5 cm	As needed	N
Grainger	16Y067	R	Aluminum wire, 20 gauge	Affix tag to stems with DBH ≥ 5 cm	As needed	N
		R	CR123A battery	Spare battery for laser rangefinder	2	N
Forestry Suppliers; Ben Meadows	57880; 9WKP4, 3JVZ5	S	Flagging tape	Temporarily mark stems after measurement	2	N
Ben Meadows; Grainger	84516, 230916; 9TA07	R	Fluorescent lumber crayon	Mark DBH measurement location on stem	1	N

Supplier		R/S	Description	Purpose	Quantity*	Special Handling
		S	Graph paper	Estimate area of shrub groups	As needed	N
Ben Meadows	152580, 152581, 152582, 152583, 227423, 227426, 227427	R	Round numbered aluminum tag, silver; 0001-6000 and 8001-9999	Tag new qualifying stems	As needed	N
Ben Meadows	152499	R	Round unnumbered aluminum tag, silver	Tag new multi-stemmed individuals	50	N
		S	Survey marking flag, PVC or fiberglass stake	Delineate sampling area	12	N
		S	Newspaper pages, tabloid size	Press collected individuals for identification	As needed	N
		S	Cordless Power drill, 18V Li-ion	Pre-drill nail holes into trees with dense wood; prevent bending of aluminum nails	1	N
Resources						
		R	Field datasheet	Record data		N

Supplier		R/S	Description	Purpose	Quantity*	Special Handling
		R	'Plot Metadata' datasheets	Record data	As needed	N

* Note that much of this equipment will only be used if tags must be replaced or individuals graduate in to minimum class size.

R/S=Required/Suggested

Table 8. Equipment and materials required for a team of two to minimize exposure to toxic oils from *Toxicodendron spp.*

Supplier	Supplier Number	R/S	Description	Purpose	Quantity*	Special Handling
Durable Items						
		S	Haglof Mantax Black calipers, 95 cm	Measure stem diameters up to 95 cm when lianas are attached; label for use with *Toxicodendron* to minimize spread of oils. Accurate enough to also measure *Toxicodendron* diameter.	1	N
		S	Haglof Mantax Black calipers, 50 cm	Measure supporting stem diameters up to 50 cm when lianas are attached; label for use with *Toxicodendron* spp. to minimize spread of oils to other equipment.	1	N
		R	Handheld caliper, 0.1 cm precision	Label for use with *Toxicodendron* spp. to minimize spread of oils to other equipment	1	N
		R	Pruning shear	Label for use with *Toxicodendron* spp. to minimize spread of oils to other equipment. Used to gain access to woody stems surrounded by *Toxicodendron*.	1	N
Consumable items						
Ben Meadows	32577	R	Cleanser, urushiol-specific, Tecnu or equivalent	Clean equipment after use with *Toxicodendron* spp.	1	N

Supplier	Supplier Number	R/S	Description	Purpose	Quantity*	Special Handling
		R	Nitrile or cotton gloves	Prevent oil contact with skin	Box of 12	N
		R	PPE outer-wear	Prevent oil contact with skin, normal clothing	One set per person	N
		R	Trash bag	Dispose of used gloves and PPE to minimize toxic oil transfer	As needed	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 the Field Operations Job Instruction Training Plan (AD[05]).

Technicians must be trained in the proper care and use of the laser rangefinder. For example:

- Although this tool is resistant to dust and water, it is important to seal open ports and use lens caps when applicable.
- Care must also be taken to avoid scratching lenses.
- Manufacturer stated accuracy is ± 30 cm for distance measurements. Although measured accuracy may be better than 30 cm, avoid using the laser rangefinder for establishing 1 m^2 and 3 m^2 nested subplots unless there are no other viable options.

Finally, technicians should be trained to carefully measure the heights of trees using the laser rangefinder/hypsometer.

6.3 Specialized Skills

At least one of the technicians executing this protocol must be able to identify woody plants to species via visual inspection and use of a dichotomous/polyclave key.

6.4 Estimated Time

The time required to implement a protocol will vary depending on a number of factors, such as stem density, skill level, species diversity, environmental conditions, and distance between plots. The timeframes provided in **Table 9** are a per plot estimate for a skilled two-person team – i.e., not the time it takes at the beginning of the bout. Use this estimate as framework for assessing progress. If a task is taking significantly longer than the estimated time, an incident should be reported.

Table 9. Estimated staff and labor hours required for implementation of Vegetation Structure SOPs.

SOP	Estimated time	Suggested staff	Total person hours
SOP A.1: Preparing mobile devices and datasheets	0.25 h	1	0.25 h
SOP A.2: Preparing equipment	1 h	1	1 h
SOP A.3: Preparing previously collected data	5 min per plot	1	5 min per plot
SOP B.1 – B.3: Classifying vegetation and selecting nested subplot sizes	1 – 3 h per plot[1]	2	2 – 6 h per plot
SOP B.4 – B.5: Mapping and tagging apparent individuals	6 – 12 h per plot[2]	2 (min)	12 – 24 h per plot
SOP C: Vegetation structure measurements	8 – 10 h per plot[2]	2 (min)	16 – 20 h per plot

[1] Dense vegetation contributes to longer plot assessment times by impeding movement, stretching tapes, and making accurate visual assessment of growth form abundance more difficult.

[2] Actual time requirements to complete vegetation structure measurements will vary greatly between sites, and depends on the variety of growth forms present and the stem density within plots.

7 STANDARD OPERATING PROCEDURES

The tasks associated with collecting vegetation structure measurements is broken up here into a series of separate SOPs.

SOP A: Preparing for Sampling. Tasks completed in the Domain lab, in preparation for the field campaign. Contains steps for loading plot data onto the GPS unit and calibrating the laser rangefinder.

SOP B: Classification, Mapping, and Tagging. Provides the following:

- Guidelines for classifying woody vegetation based on structural attributes and taxonID.
- Guidelines for using nested subplots to standardize sampling effort across plots.
- Instructions for mapping individuals relative to plot markers, and details for how to tag mapped trees, shrubs and lianas.
- Instructions for assigning appropriate taxonIDs to woody vegetation.

SOP C: Vegetation Structure Measurements. Contains detailed procedures for measuring: :

- Apparent Individuals
- Shrub Groups
- 'Other' growth forms

SOP D: Field Campaign Follow-up. Necessary steps following successful completion of field work.

SOP E: Data Entry and Verification. Guidelines and requirements for successful data entry. This SOP is NOT a substitute for AOS/TOS Protocol and Procedure: Data Management (RD[04]). Technicians must read RD[04]:

- To understand required data quality procedures
- Prior to transcription from paper data sheets.

SOP A Preparing for Sampling

A.1 Preparing Mobile Devices and Datasheets

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

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

A.2 Preparing Equipment

1. Transfer all required files containing plot marker locations to the recreational accuracy handheld GPS receiver.
2. Use the hand stamp and die set to pre-label blank aluminum tags with ‘A’, ‘B’, ‘C’, etc. for tagging multi-bole trees (‘mbt’, if present at site).
3. Check the laser rangefinder: Detailed instructions for setting declination, calibrating the tilt-sensor, and calibrating the compass are found in TOS Standard Operating Procedure: Laser Rangefinder Use and Calibration (RD[09]).
    a. Make sure the lenses on the laser rangefinder are free of dirt and debris, and clean with a lens cloth or lens tissue if necessary.
    b. Declination changes with time at each site, and should be looked up annually using the NOAA Magnetic Field Calculator (http://www.ngdc.noaa.gov/geomag-web/)
    c. TruPulse Declination Offset. Check the current declination against what is entered in the TruPulse.
    d. TruPulse Tilt-sensor Calibration. In the rare instance that the TruPulse has suffered a severe drop shock, the tilt-sensor requires re-calibration prior to continued field work.
    e. Compass Calibration. The compass should be calibrated after the batteries are changed. Be aware that interference from indoor magnetic fields can prevent accurate calibration, and can cause the calibration routine to fail. If this is the case, calibrate in the field.

A.3 Preparing Previously Collected Data

To enable accurate and expeditious field measurement of previously measured apparent individuals, it is helpful to:

1. Generate per plot lists of tagIDs, and other key identifying data, for all individuals measured within the plot the previous bout.
    a. Use the VST Mapper application to create per plot lists of previously measured tagIDs and efficiently track work progress in the field.
2. [Optional] Use the VST Mapper web application to create maps of each plot, to enable finding previously measured individuals within a spatially explicit framework.
3. Print previous bout measurements in order to save time and limit errors (e.g., measurementHeight, growthForm, shrubShape, etc.)
4. If using paper data sheets, the fields below should be pre-populated by copying previously collected data into the 'Apparent Individuals' data sheet.
    - **tagID**
    - **subplotID**
    - **nestedSubplotID**
    - **taxonID**
    - **measurementHeight**
    - **growthForm**, useful for finding an individual. Be advised the value may change from year to year, necessitating updating when data are collected in the current year.
    - **plantStatus**
    - **shape** (shrubs only)

SOP B Classification, Mapping, and Tagging

Overview

Classifying, mapping, and tagging woody vegetation is important because it allows repeat measurements to be made on identified individuals. In addition, once species and growth form are determined, it is possible to estimate biomass via appropriately chosen allometric equations. Growth form classification also allows standarized implementation of nested subplots to achieve a consistent sample size of individuals when stem density varies significantly from region to region and plot to plot.

Goals

- Identify qualifying individuals, classify to growth form, and assess density of growth forms on a per plot basis.
    - Use growth form classification and density information to determine whether nested subplots may be employed, and if so, determine the appropriate size.
    - Collect growth form presence/absence data and nested subplot size data in the ***VST: Plot Meta-Data [PROD]*** application.
- Using growth form information, map and tag qualifying woody and non-woody perennial individuals in both Distributed and Tower Plots:
    - In Distributed Plots and 20m x 20m Tower Plots, assess the entire plot for qualifying individuals.
    - In 40m x 40m Tower Plots, assess two randomly selected 20m x 20m subplots for qualifying individuals.
        - Lists of randomly selected subplots are provided by Science.
        - No mapping or measurements ***of any growth form*** will take place in those 20 m x 20 m subplots that are **NOT** selected.
    - Collect tagging, mapping, and taxonID data in the ***VST: Mapping and Tagging [PROD]*** application.

B.1 Classifying Woody Vegetation to Growth Form

Woody vegetation is broadly classified to growth form according to USDA Plants Growth Habits. Growth forms assigned to individuals are therefore informed by stem diameter (DBH or ddh), height, and site-specific knowledge of the species in question (**Table 10**, **Figure 3**, **Figure 4**, and see ***Box 1*** for examples). Note that individuals may change classification from one year to the next, due to normal growth or damage (i.e., loss of boles or stems). Additional 'other' growth forms are listed in Appendix F. The distinction between 'apparent individuals' and 'groups' is also used when classifying vegetation. In general small trees and shrubs can exist either:

- As isolated 'Apparent Individuals,' with either single stems or multiple connected stems; or
- As groups of individuals in contact with each other such that canopies of apparent individuals cannot be discerned (e.g. a continuous shrub or vine thicket, hereafter referred to as a 'Shrub Group').

The 'Apparent Individual' designation is always preferable to that of 'Shrub Group' due to the fact that allometric equations used for estimating shrub biomass typically depend on basal stem diameter or DBH measurements, and these measurements are not made for shrub groups. Shrub group measurements allow only for estimation of shrub volume, and translating volume to biomass is often not possible. Nonetheless, the shrub group designation is warranted when:

- Vegetation forms dense, impenetrable, or thorny thickets.
- Safety concerns are associated with accessing the vegetation (e.g., *Rubus* thickets).
- Excessive damage to vegetation would be required to access the vegetation (e.g., chaparral thickets).

Table 10. Growth forms into which woody vegetation is classified, and their definitions. Parentheses following the terms in the list below indicate the 3-letter code used for classifying particular defined growth forms.

Growth Form	Definition
liana (**lia**)	Non-self-supporting woody stems with DBH ≥ 1 cm. 'ddh' is not measured for lianas.
single-bole tree (**sbt**)	A self-supporting individual with a single bole ≥ 10 cm diameter at breast height. Usually greater than 4 – 5 meters height.
multi-bole tree (**mbt**)	A self-supporting individual with multiple boles at breast height. At least one bole must have DBH ≥ 10 cm; usually greater than 4 – 5 meters height. To qualify as an additional bole, the fork in question must meet the following criteria: • Be at least 1/3 the diameter of the main stem. • The angle formed with the pith of the main stem must be 45˚ or less. • The pith must intersect the pith of the main stem at or below 130 cm above the ground. • Multiple boles may also emerge independently from the ground, provided they are connected belowground.
small tree (**smt**)	Typically a self-supporting individual with the potential to grow into either a single-bole tree or a multi-bole tree; also includes tree species that, at maturity, never attain the stature of single-bole or multi-bole trees (e.g., *Acer pensylvanicum* or *Picea mariana* under some environmental conditions). Diameter at breast height for one or more stems meets the criteria 1 cm ≤ DBH < 10 cm, and usually does not exceed 4 – 5 meters height.
sapling (**sap**)	A small, self-supporting individual with the potential to grow into either a single-bole tree or a multi-bole tree. DBH is < 1 cm, or total height is < 130 cm, and ddh of at least one stem is ≥ 1 cm.
single shrub (**sis**)	A self-supporting individual, typically with multiple primary stems; may be single-stemmed under certain environmental conditions. Diameter of at least one stem at breast height meets the criteria 1 cm ≤ DBH < 10 cm. Usually does not exceed 4 – 5 meters maximum height at maturity. Uncommonly, DBH can be ≥ 10 cm; consider the USDA classification and the maximum height potential of the species (see *Rhododendron* example below).
small shrub (**sms**)	A self-supporting individual, typically with multiple primary stems; includes typical 'subshrub' species that may never exceed 130 cm height, as well as individuals that will mature into 'sis' growth form. The ddh is ≥ 1 cm for at least one stem. Individuals that have no stems with ddh ≥ 1 cm are not measured with this protocol, and will be measured as part of the herbaceous plant sampling effort.
shrub group	• Shrub Groups are defined as vegetation likely comprised of two or more individuals in contact, such that it is impossible to discern "individuals." The word "individual" here refers to "apparent" individuals, not "genetic" individuals (e.g., members of an Aspen clone). • Shrub Groups may contain multiple species (including vine masses), and both live and dead material from one or more species. • Shrub Groups that are primarily 'sms' individuals should on average have stems with ddh ≥ 1 cm; measure a subset of stems to make this determination NOT every stem. If the majority of stems in the Shrub Group have ddh < 1 cm, do not measure.

Box 1. *Growth form classification examples.*

Example 1: A *Quercus alba* individual in the eastern U.S. may be classified as either a sapling (sap), a small tree (smt), a single-bole tree (sbt), or a multi-bole tree (mbt), depending on life stage and the specific growth habit of the individual. However, a small *Q. alba* individual would not be classified as a small shrub (sms) or single shrub (sis) because this species is broadly recognized as a tree species (e.g., USDA PLANTS), and the biomass of large and small individuals can be estimated using general allometric equations developed for trees (e.g., Jenkins et al. 2003, Jenkins et al. 2004).

Example 2: An *Acer rubrum* individual has four boles with the following diameters at 130 cm along each bole: 12 cm, 9 cm, 4 cm, and 3.5 cm. This individual is classified as a multi-bole tree growth form because the largest bole is ≥ 10 cm DBH, and there are two secondary boles with diameters ≥ 1/3 the diameter of the largest bole. The smallest bole with DBH = 3.5 cm is not tagged and measured because its diameter is not 1/3 that of the largest bole.

Example 3*: Rhododendron spp.* may grow large enough that one or more stems have DBH ≥ 10 cm. If only DBH and stem count are considered, **Figure 4** on its own would have large *Rhododendron* individuals classified either as a single-bole tree (multiple stems, but DBH of only one bole ≥ 10 cm) or a multi-bole tree (more than one bole with DBH ≥ 10 cm). However, considering *Rhododendron spp.* are usually < 4 – 5 meters height, these large individuals are classified as single shrub (sis).

Example 4*:* A young Interior Live Oak (*Quercus wislizenii*) may split below 130 cm into multiple boles with 10 cm > DBH ≥ 1 cm. Because this species routinely achieves single- and multi-bole tree status, smaller individuals are classified as 'small tree', rather than 'single shrub' (see dashed arrow in **Figure 4**).

Example 5*:* A Big Sagebrush individual (*Artemisia tridentata*) has multiple emergent boles / stems, with only one such emergent stem having 10 cm > DBH ≥ 1 cm; all others have DBH < 1 cm or are < 130 cm height. This species never attains single- or multi-bole tree status, and this individual is classified as a 'single shrub,' rather than a 'small tree.'

Example 6*:* Species information may not be informative with respect to assigning growth form. For example, *Toxicodendron* spp. commonly exist as lianas, small shrubs, and shrub groups.

Below, **Figure 3** provides high-level classification information, and **Figure 4** indicates how low-level growth form classifications are informed by structural and taxonomic data. To make a correct classification, use the flow charts in combination with the definitions in **Table 10**, and use knowledge of species-level growth habits at a site.

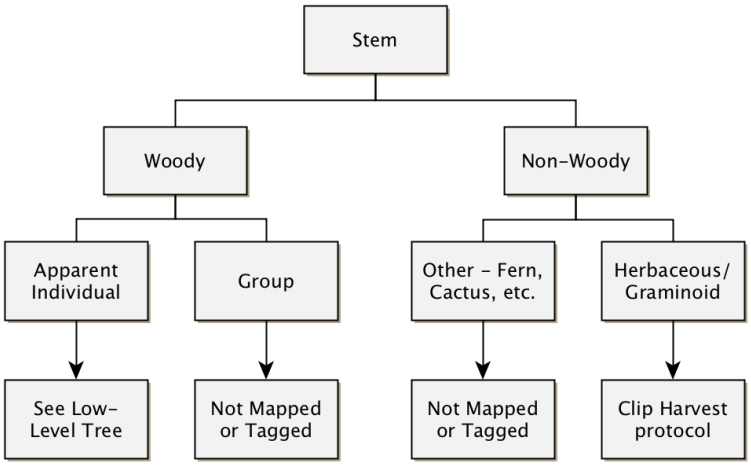


Figure 3. High-level classification tree for assigning vegetation to growth form, and assigning the correct protocol.

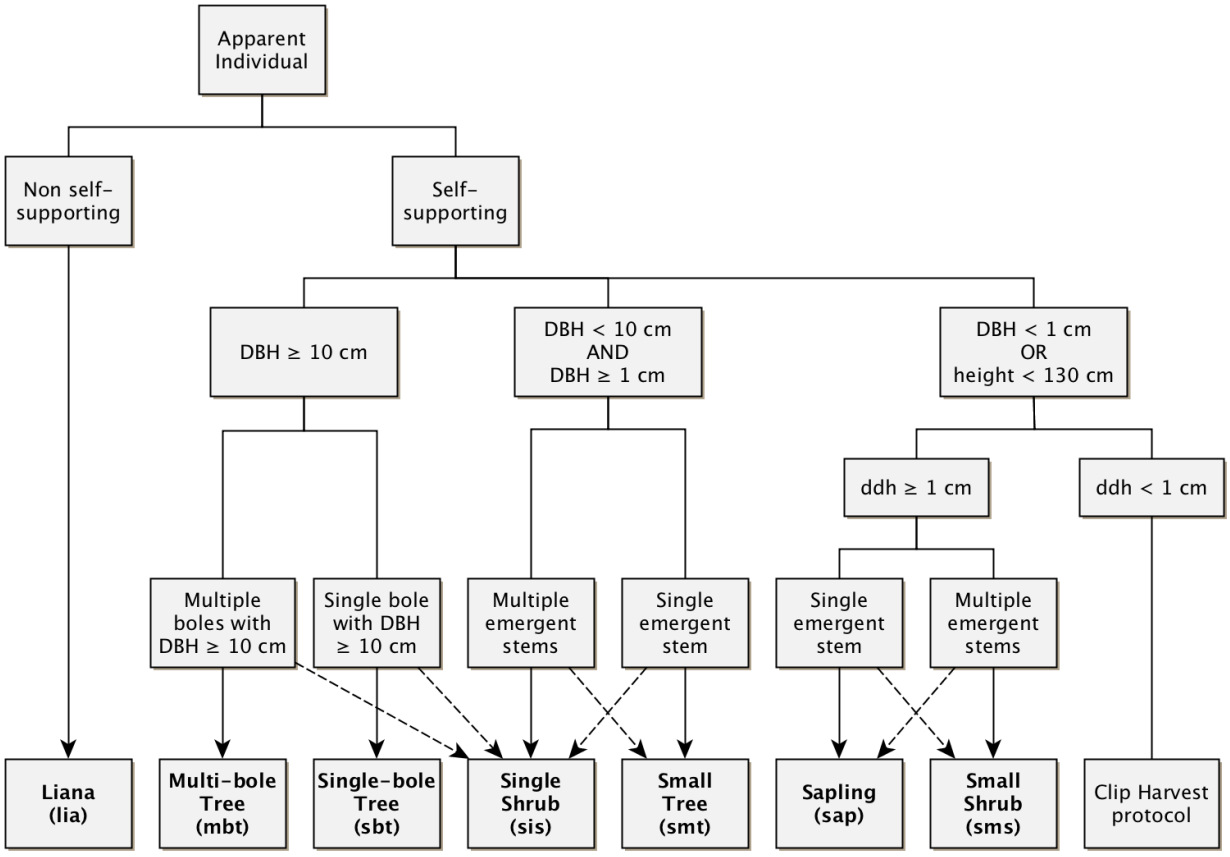


Figure 4. Low-level classification tree indicating how structural observations and stem diameter data inform the classification of apparent individuals to growth form. Dashed lines call out points where growth form classification may change after considering height and species-specific information.

IMPORTANT

SOP B.1 provides generalized definitions and guidance for determining growth forms. However, not every possible situation can be addressed in this generalized format. For example, the line between a multi-bole apparent individual and a shrub group can be difficult to clearly define, especially for clonal species. Following this protocol may lead technicians in different domains to different conclusions. Therefore, we recommend creating site-specific or species-specific materials within each Domain to maintain consistency through time with respect to how decisions are made to resolve common problem situations. Science may review documents and facilitate sharing between Domains.

B.2 Nested Subplot Dimensions and Guidelines

Saplings, small trees, shrubs, lianas, and many other woody and non-woody species with DBH < 10 cm sampled via this protocol can attain very high stem densities, even within a single subplot. A nested subplot approach may therefore be employed to standardize the sampling effort across plots. Subplot and nested subplot sizes are shown in **Figure 2**. To ensure sampling effort consistency:

- On a per plot basis, nested subplot size may be chosen independently for:
  - Lianas,
  - The sum of '***smt + sap + sis + sms + shrub groups***'; and
  - Any '***other***' qualifying vegetation, including palms, yucca, ferns, etc. (see Appendix F for a full list of 'other' qualifying vegetation).
- ***For all growth forms, the chosen nested subplot size must be used for the entire plot***.

Subplot and nested subplot details are illustrated in **Figure 2**, and compiled below in **Table 11**. Nested subplots are numbered in sequence beginning with the SW corner of the subplot; SW=1, SE=2, NW=3 NE=4 (**Figure 2**).

Table 11. List of supported subplot and nested subplot dimensions that vary with plot size. The decision to use nested subplots is made on a per plot basis, and allows standardization of sampling effort across plots.

Plot Size	Plot component	Dimensions (area)	Additional Information
20 m x 20 m (400 m^2)	subplot	10 m x 10 m (100 m^2)	
	nested subplot	5 m x 5 m (25 m^2)	Nested subplots not employed for trees with DBH ≥ 10 cm; these individuals are measured throughout the entire plot.
		3.16 m x 3.16 m (10 m^2)	
		1.73 m x 1.73 m (3 m^2)	
		1 m x 1 m (1 m^2)	
40 m x 40 m (1600 m^2)	subplot	20 m x 20 m (400 m^2)	Two of the four subplots are randomly selected for sampling by Science. Lists of random subplots are provided on the NEON intranet.
	nested subplot	10 m x 10 m (100 m^2)	Nested subplots not employed for trees with DBH ≥ 10 cm; these individuals are measured throughout the selected subplots.
		5 m x 5 m (25 m^2)	
		3.16 m x 3.16 m (10 m^2)	
		1.73 m x 1.73 m (3 m^2)	
		1 m x 1 m (1 m^2)	

B.3 Selecting Nested Subplot Sizes and Recording Plot Meta-Data

Data collected as part of this SOP are recorded in the ***VST: Plot Meta-Data [PROD]*** application. Consult the 'Manual for Fulcrum Application: TOS Vegetation Structure [PROD] – All SOPs' for data entry details (RD[14]).

In the first year of sampling, the nestedSubplotArea is selected once per plot, for each of the growth forms (or groups of growth forms) listed above in SOP 0. The following guidelines apply when determining whether nested subplots can be employed:

- Visually assess the density of qualifying, apparent individuals across the whole plot for each of the three groups listed above, and estimate a nested subplot size appropriate for each group.
- A shrub group that receives a single ID is counted as 1 individual for the purpose of selecting an appropriate nested subplot size. Should a single, large shrub group span more than one nested subplot area, tally the group within each of the nested subplots in which it occurs.

Plots are assessed annually for stem density on a per growth form basis. Changes to nested subplot sizes may only be made in consultation with NEON Science following significant changes in stem density that are anticipated to be long-term in nature (e.g., increase or decrease in stems following fire, blow-down, logging, woody stem encroachment, etc.).

The *VST: Plot Meta-Data [PROD]* application ensures an accurate, detailed per plot per year report of growthForm presence / absence at the scale of the nested subplot, such that the total area sampled is clearly documented, which is critical for scaling purposes. In addition, recording Plot Meta-Data transparently indicates the completeness of the planned sampling effort to the NEON end-user community.

Steps to determine and record nested subplot size:

1. Create a record in the *VST: Plot Meta-Data [PROD]* application. Enter required information:
    a. **siteID** and **plotID**.
        i. If working in a 40m x 40m Tower Plot, the app will display **randomSubplotA** and **randomsubplotB** subplotIDs that have been selected for sampling.
    b. **Previous year's plotID**; if the plot has been measured in a prior year, the nested subplot sizes selected in the previous bout will be displayed for reference.
    c. **yearBoutBegan**; for bouts that span > 1 calendar year, enter the year in which the bout began for ALL records.
    d. **samplingProtocolVersion**; the version of the Vegetation Structure protocol used to guide sampling.

2. Assess the entire plot for the ***presence*** of qualifying woody and non-woody perennial vegetation growth forms (listed in **Table 10** and Appendix F).
    a. If qualifying vegetation for all growth forms is absent from the entire plot:
        i. Select **targetTaxaPresent** = 'No' in the *VST: Plot Meta-Data* 'presenceAbsence' section.
        ii. Save the record and proceed to the next plot.
    b. If qualifying vegetation is present in the plot:
        i. Select **targetTaxaPresent** = 'Yes' in the *VST: Plot Meta-Data* 'presenceAbsence' section.
        ii. Further indicate which growth forms are present in the entire plot. Record growth form-specific **targetTaxaPresent** = 'Yes/No' for:
            1. Trees (sbt, mbt)
            2. Shrubs (includes sum of sis, sms, smt, sap, and shrub groups).
            3. Lianas
            4. Cacti
            5. Ferns
            6. Yucca
            7. Palms
            8. Ocotillo
            9. Xerophyllum (Bear Grass)
3. For growth forms present in the plot, determine which of the growth forms listed immediately above qualify for measurement with nested subplots, and which nested subplot size may be used.
    a. ***Exception***: Never use nested subplots for trees.
    b. Avoid using the laser rangefinder for establishing 1 m^2 and 3 m^2 nested subplots unless there are no other viable options.
        i. Manufacturer's stated accuracy for the laser rangefinder is 30 cm. Although measured accuracy may be better than 30 cm, do not assume.
    c. For a plot that HAS been sampled previously: Typically the **same nested subplot size each year** in order to ensure that repeat measurements are made on tagged stems.
        i. In the *VST: Plot Meta-Data* app, select **previous year's plotID** to view previously selected nested subplot sizes.
        ii. If significant changes in stem density have occurred over time, due to succession, self-thinning, natural disturbance, or management activities, discuss with Science whether a change in nested subplot size is warranted.

d. For a plot that has NOT been measured previously: Assess per growth form vegetation density and select an optimal nested subplot size. ***Density thresholds depend on plot size***:

   i. ***In a Distributed Plot or 20m x 20m Tower Plot***: Sample a minimum of 20 individuals across the entire 20m x 20m plot.

      For individuals distributed relatively homogeneously, this is equivalent to:

      1. 5 apparent individuals per subplot, OR
      2. Approximately 2-3 apparent individuals per nested subplot.

      *Note: If nested subplots are employed, there must be a **minimum** of 20 individuals sampled across the entire plot (**see scenario in Box 2**). If fewer than 20 individuals are present within the plot, or within any available nested subplot size, sample the entire plot.*

   ii. ***In a 40m x 40m Tower Plot***: Sample a minimum of 20 apparent individuals ***for at least one*** 20m x 20m subplot.

      For individuals distributed relatively homogeneously, this is equivalent to:

      1. 10 apparent individuals per nested subplot (any size)

      *Note: In a 40m x 40m plot, one 20m x 20 m subplot must have a **minimum** of 20 individuals. **It is acceptable if only one subplot meets this threshold** and the other randomly selected subplot has fewer than 20 individuals (**see scenario in Box 3**).*

4. Record the **Nested Subplot Sampling Area** in the *VST: Plot Meta-Data* app for each growth form present in the plot that qualifies for nested subplots.

   a. **nestedSubplotArea**[**growthForm**]; If a nested subplot is not used for a growth form present in the plot, choose 'noneSelected'.

   b. 'noneSelected' is also auto-populated for growth forms not present in the plot.

5. Populate **Absence Lists** to demonstrate and record that all subplots/nested subplots have been surveyed for all growth forms present.

   a. For each growth form present in the plot, select any subplots or nested subplots that were surveyed and did NOT contain individuals of that growth form.

   b. Select 'presentInAll' if the growth form was present in all nested subplots surveyed.

6. Review auto-calculated **Total Area Sampled** values to ensure a match between what is recorded and what was sampled in the field.

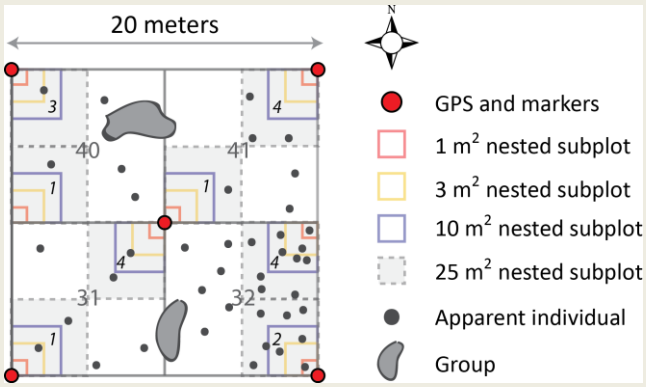
    a. Update Nested Subplot Sampling Area to match actual sampling effort if necessary.

7. Save the record.

Box 2. *Guidelines for selecting nested subplot size in a 20 m x 20 m base plot with heterogeneously distributed vegetation.*

In this scenario, we consider whether nested subplots might be appropriate for measuring individuals with DBH < 10 cm that are heterogenously distributed throughout the plot (Figure below). Remember that nested subplots are not employed for individuals with DBH ≥ 10 cm. In this plot, there are 42 apparent individuals with DBH < 10 cm, and 2 shrub groups, for a total of 44 (each shrub group is counted as n=1). We are required to measure a minimum of n=20 per plot, assuming there are at least that many present, so in this case, we should explore whether use of nested subplots can reduce the sampling effort while maintaining a sample size of n ≥ 20. We assess the number of individuals sampled across the entire plot for each nested subplot size, working upwards from the smallest nested subplot size to the largest:

- 1 m^2: 2 apparent individuals sampled → insufficient sample size
- 10 m^2: 12 apparent individuals sampled → insufficient sample size
- 25 m^2: 28 apparent individuals sampled → sufficient sampling effort, use 25 m^2 nested subplots throughout the entire plot.



A 20 m x 20 m plot with heterogenously distributed vegetation. Grey numbers indicate subplot IDs, and black italic numbers indicate nested subplot IDs.

Box 3: *Guidelines for selecting nested subplot size in a 40 m x 40 m base plot with heterogeneously distributed vegetation.*

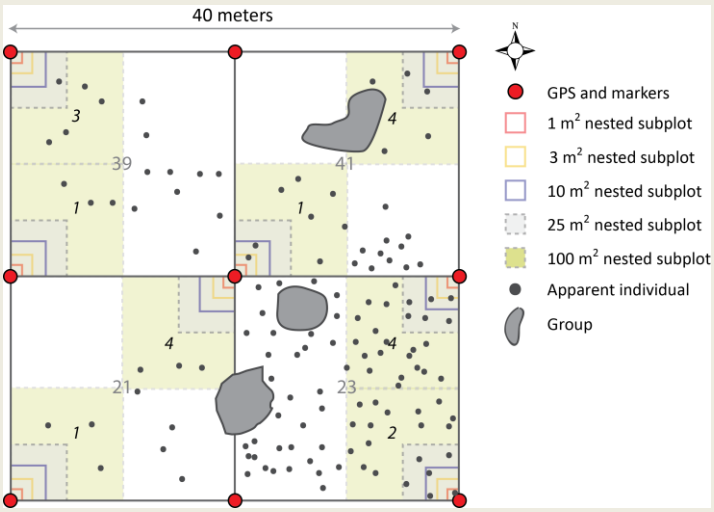
In this scenario, we again consider whether nested subplots might be employed for measuring individuals with DBH < 10 cm that are heterogeneously distributed throughout the plot (Figure below). Here, assume subplots 23 and 41 are prescribed for sampling, so we do not consider subplots 21 and 39 further. An initial visual survey of the plot indicates that qualifying individuals are relatively dense in subplot 23 (n=81, including 2 groups), and are significantly less dense in subplot 41 (n=25, including 1 group). The critical difference here, compared to Scenario 1, is that we are required to sample n ≥ 20 individuals ***for at least one of the two subplots randomly selected for sampling; the other subplot does not need to meet the n ≥ 20 requirement***. Because stem density in subplot 23 is relatively high, we begin by assessing whether there is a nested subplot size that will give us n ≥ 20 individuals for subplot 23:

- 1 m^2: 1 apparent individual sampled → insufficient sample size
- 10 m^2: 5 apparent individuals sampled → insufficient sample size
- 25 m^2: 12 apparent individuals sampled → insufficient sample size
- 100 m^2: 45 apparent individuals sampled → sufficient sampling effort, use 100 m^2 nested subplots throughout the entire plot.

Using the 100 m^2 nested subplot for both of the two randomly selected subplots, our sampling effort looks like this:

- subplot 23, n=45
- subplot 41, n=13. We must also measure the portion of the group that overlaps nested subplot 4

******Note***: If subplot = 23 had NOT been randomly selected, the selected nested subplot size would be different for this example plot.



A 40 m x 40 m plot with heterogeneously distributed vegetation. Grey numbers indicate

B.4 Mapping and tagging requirements by growth form

Mapping and tagging requirements are guided by the principle that qualifying woody stems visible to AOP remote sensing instruments are mapped within NEON TOS plots. However, due to logistical constraints, mapping efforts within a given ecosystem are targeted toward those individuals in an ecosystem with the greatest biomass AND that are visible to remote sensing instruments. The following are examples of how this strategy is executed in three common ecosystem types:

- *Closed canopy forest*: The overstory is typically comprised of trees with DBH ≥ 10 cm, and individuals that meet this DBH criterion are mapped. Small trees, saplings, shrubs, etc. in the understory with DBH < 10 cm are not mapped.
- *Rangeland shrub, Pinyon / Juniper, Scrub Oak, short-stature woodlands*: In these systems, it is possible for shrubs like *Artemisia tridentata* or *Prosopis spp*. (mesquite) to make up the overstory in plots that lack trees with DBH ≥ 10 cm. Here, these smaller stature individuals with DBH < 10 cm ARE mapped.
- *Savannah ecosystems:* These systems are a mixture of the previous two examples; trees with DBH ≥ 10 cm form the overstory in some parts of the plot, and shrubs/herbaceous plants form the "overstory" in other parts of the plot. For simplicity only individuals with DBH ≥ 10 cm are considered the overstory in savannah-like plots because these larger individuals comprise the majority of the plot biomass. Even though individuals with DBH < 10 cm may be visible to remote-sensing instruments throughout much of the plot, these individuals are NOT mapped if there are individuals with DBH ≥ 10 cm in any part of the plot prescribed for measurement.

Mapping and tagging requirements also vary by growth form:

- *Apparent Individuals*:
    - May be mapped as points; growth form specific mapping and tagging requirements are provided in **Table 12**.
    - Are tagged with a unique aluminum ID tag for repeat measurements.
    - Mapping and tagging data are recorded in the ***VST: Mapping and Tagging [PROD]*** application.
    - 'Other' non-woody individuals are measured like Apparent Individuals, but are typically not mapped and tagged (except for tree palms).
- *Shrub Groups:* The locations of shrub groups are mapped relative to the plot with polygons and graph paper (SOP C.2), and location data are NOT entered into the NEON database. Individual stems within the group are not tagged.

Table 12. Summary of mapping and tagging requirements for each growth form.

Growth Form	Map	Stem Diameter Measurement Location	Tag type, location, and method	Additional required data
Single bole tree (sbt)	Record **stemDistance** and **stemAzimuth** relative to pointID (plot marker)	130 cm along the bole; see Appendix D for complex cases	- Unique # - 10 cm above stemDiameter measurement location - Aluminum nail	- taxonID - identificationQualifier
Multi-bole tree (mbt)	Record **stemDistance** and **stemAzimuth** of largest bole relative to pointID (plot marker)	- 130 cm along qualifying boles if pith intersection occurs below 30 cm - See Appendix D if pith intersection is > 30 cm along stem	- Unique # on largest stem; tag largest live stem if possible - A,B,C... on all additional qualifying stems; record additional tagIDs as '1234a' - 10 cm above stemDiameter measurement location - Aluminum nail	- taxonID - identificationQualifier
Small tree (smt)	Record **stemDistance** and **stemAzimuth** relative to pointID if no overstory is present in the plot*	- 130 cm along qualifying boles - See Appendix D if multi-bole and pith intersection is > 30 cm along stem	- Unique # - 10 cm above stemDiameter measurement location **OR** a consistent, visible location - Loose aluminum wire	- taxonID - identificationQualifier - nestedSubplotArea
Sapling (sap)	Not mapped	10 cm along stem	- Unique # - Consistent, visible location - Loose aluminum wire	- taxonID - identificationQualifier - nestedSubplotArea
Single shrub (sis)	Record **stemDistance** and **stemAzimuth** of shrub center relative to pointID if no overstory is present in the plot*	For each qualifying emergent bole: - 10 cm along the stem (if possible), AND - 130 cm along the stem on largest diameter fork of each emergent bole - See Appendix D for complex cases	- Unique # on largest emergent bole; tag largest live stem if possible - no tag on additional qualifying boles; mark secondary emergent boles with lumber crayon - 10 cm above stemDiameter measurement location (nail) **OR** ground level (wire) -Aluminum nail or loose wire as appropriate	- taxonID - identificationQualifier - nestedSubplotArea

Growth Form	Map	Stem Diameter Measurement Location	Tag type, location, and method	Additional required data
Small shrub (sms)	Record **stemDistance** and **stemAzimuth** of shrub center relative to pointID if no overstory is present in the plot*	10 cm along each qualifying stem	- Unique # - Consistent, visible location - Loose aluminum wire	- taxonID - identificationQualifier - nestedSubplotArea
Shrub group (sgr)	Graph paper method used to calculate area only; location not recorded in NEON database	N/A	Not tagged, unique ID assigned per bout (may be tracked internally from year-to-year to facilitate re-measurement if desired)	- nestedSubplotArea
Liana (lia)	Not mapped, but supporting stem tagID is recorded when applicable	130 cm along the stem; see Appendix E for complex cases	- Unique # - 10 cm above stemDiameter measurement location - Loose aluminum wire, only one tag for each apparent individual despite branching	- supporting stem tagID - taxonID - identificationQualifier - nestedSubplotArea
Ferns (frn)	Not mapped	Species dependent; see Appendix F	Not tagged	- taxonID - identificationQualifier - nestedSubplotArea
Palm (plm)	*Tree palms:* Record **stemDistance** and **stemAzimuth** relative to pointID (plot marker) *Other palms:* Relative position if no overstory is present in the plot	Species dependent; see Appendix F	- Unique # - 10 cm above stemDiameter measurement location (nail) **OR** ground level (wire) - Aluminum nail or loose wire as appropriate	- taxonID - identificationQualifier - nestedSubplotArea
Yucca (yuc)	Not mapped	N/A	Not tagged	- taxonID - identificationQualifier - nestedSubplotArea

* For mapping and tagging, 'overstory' is defined as the presence of at least one individual in the plot or selected subplots with DBH ≥ 10 cm.

SOP B.4.1 Exceptions and Special Considerations

There are numerous instances in which the generalized guidelines provided above in **Table 12** are insufficient when it comes to deciding on an appropriate measurementHeight and tagging location. Complex and non-standard individuals that require special consideration, are summarized in **Table 13**, and illustrated in detail in Appendix D. Site-specific modifications are described in Appendix I.

Table 13. Guidelines for determining the appropriate measurement and tagging location for situations not covered in Table 9.

Measurement location and tagging guidelines for complex woody stems	
Stem/Site Characteristics	**measurementHeight and tag location**
Growing on sloped or uneven terrain	Measure stem diameter 130 cm from uphill side, tag 10 cm above measurementHeight.
Thickened base	Measure stem diameter 50 cm above the point where stem becomes 'regular' again.
Leaning or twisted stems	Measure stemDiameter 130 cm along the underside of the stem; diameter measurement is perpendicular to the direction of stem growth, not parallel to ground. Tag 10 cm above measurementHeight.
Stems with anomalies at 130 cm (e.g., bulge, node/branch, or minor, localized damage).	Measure above the anomaly where stem becomes 'regular' again. Tag 10 cm above measurementHeight. When damage is a major feature of the stem, do not move the measurementHeight and tag location.
Deep litter/duff layer heaped around bole base	The measurementHeight and tagging location are determined from ground level, not the top of the duff layer.
Bole / stem is broken	• For break points ≥ 130 cm height, follow standard measurementHeight and tagging guidelines. • For 'sbt', 'mbt' and 'smt', ignore live or dead broken boles < 130 cm height, but follow guidelines for resprouts if present (see below). • For 'sap' and 'sms', broken stems < 30 cm length are ignored (live and dead, see Appendix D). Tag largest, live qualifying stem.
Multi-bole tree with mix of live and dead stems (includes stump ≥ 130 cm height and DBH ≥ 10 cm w/ re-sprouts)	• Location of measurementHeight and tag depends on where pith of resprout intersects with pith of main bole. See Appendix D. • Broken boles, either dead or alive, must be > 130 cm height to qualify for tagging. • Resprouts NOT required to be ⅓ diameter of main bole when main bole is dead.
Downed live, with vertically growing resprouts	Measurement and tagging strategy depends on whether the pith of the downed bole is above or below the forest floor. See Appendix D.

Measurement location and tagging guidelines for complex woody stems	
Stem/Site Characteristics	**measurementHeight and tag location**
Standing dead	• For standing dead ≥ 130 cm length, follow standard measurementHeight and tagging guidelines. • For 'sbt', 'mbt', 'smt' and 'sis', dead boles < 130 cm length are ignored. • For 'sap' and 'sms', dead stems < 30 cm length are ignored and not tagged (see Appendix D).
Leaning dead	• If lean is < 45° off vertical, measure and tag same as standing dead; height measured is total height above the ground, NOT total stem length; • If lean is ≥ 45°, ignore stem, will be assessed as Coarse Downed Wood (except in the case of decumbent growth forms such as manzanita species).
Plot burned since previous bout	Do not change measurement strategy. Do not need to search for fallen, tagged individuals for re-measurement.

B.5 Mapping and Tagging Apparent Individuals

This section describes: a) the tagging procedure for qualifying woody and non-woody perennial individuals; and b) the offset mapping procedure for qualifying trees and shrubs. See **Table 12** for mapping and tagging requirements by growth form.

Data collected as part of this SOP are recorded in the ***VST: Mapping and Tagging [PROD]*** application. Consult the 'Manual for Fulcrum Application: TOS Vegetation Structure [PROD] – All SOPs' for data entry details (RD[14]).

If structure measurements (SOP C) are made at the same time as 'Mapping and Tagging' data are collected, record structure data in the ***VST: Apparent Individuals [PROD]*** application.

This SOP is implemented every time the Vegetation Structure protocol is implemented in order to account for recruitment of new qualifying individuals.

- The procedure described here applies to apparent individuals only.
- Stems must be ≥ 50% rooted in the plot in order to be considered 'in' and included in long term monitoring.
- Dead individuals are tagged and mapped if they are leaning < 45° from vertical (but note this criterion does not apply to decumbent growth forms).
- The mapping procedure will be completed for:
    - Single bole trees **stemDiameter** ≥ 10 cm
    - Multi-bole trees with **stemDiameter** ≥ 10 cm for at least one bole
    - Single shrubs (only if no trees with DBH ≥ 10 cm are present in the entire plot)
    - Small trees (only if no trees with DBH ≥ 10 cm are present in the entire plot)
    - Small shrubs (only if no trees with DBH ≥ 10 cm are present in the entire plot)

Note: Stem mapping and tagging do not need to occur sequentially on a per stem basis. That is, depending on the system, it may be more efficient to ID and tag all individuals in the plot, and then map all of these individuals. Use the work flow that is optimal for your plots.

MAPPING TOOLS

The steps below assume the use of a laser rangefinder; however, a meter tape and declination-corrected compass may be used on slopes < 20% if the tape is not prevented from being stretched straight by understory vegetation. Training is required to properly set declination and accurately use a compass.

To determine taxonID, tag, and map, qualifying vegetation:

1. Delineate the plot or subplot(s). Use existing plot markers, tapes, and chaining pins to carefully delineate the plot and subplots. In this case, it is not necessary to pay attention to whether the plot is sloped or flat: the tape is used only to help determine which stems are "in" versus "out" of the plot.
    - To be considered "in," an individual must be ≥ 50% rooted within the plot. For multi-stemmed individuals, ≥ 50% of the emergent stems must originate from within the plot.
    - If shrub thickets prevent stretching tape, a rangefinder may also be used for "in" versus "out" determination.
2. Choose a plot marker with high-resolution GPS coordinates that can be used for offset mapping.

    - ***Only pointIDs shown in red in Figure 2 may be used for offset mapping.***
    - Avoid using pointID = 41 unless absolutely necessary. Mapping from this pointID leads to trampling of nested subplots used for Plant Diversity sampling.
3. Mount the laser rangefinder on the non-magnetic tripod and position the body of the rangefinder directly over the selected plot marker.
    - Use of a tripod ensures the rangefinder is centered over the plot marker.
    - Hand-holding the rangefinder may result in swinging the unit from side-to-side, introducing errors in azimuth (primarily) and distance (secondarily).
    - Care should be taken to avoid placing tripod legs within nested subplots used for Plant Diversity measurements.
4. For each individual that requires a tag, create a record in the *VST: Mapping and Tagging* app. See **Table 12** for tagging criteria. Enter the following:
    a. **Foliar Canopy Sampling Tag** status; select 'Yes' if the individual is specifically tagged for Canopy Foliar Sampling and is not otherwise measured for Vegetation Structure.
    b. **domainID** and **siteID**; these fields narrow the list of plotIDs.
    c. **plotID**; the list of available plotIDs is populated by records created in the *VST: Plot Meta-Data* app. Create Plot Meta-Data records prior to Mapping and Tagging records.
    d. **yearBoutBegan** and **date**; typically the former is part of the latter, but may be different if the bout began in a previous year and continued over the Dec 31st to Jan 1st transition.
    e. **samplingProtocolVersion**; the version of the Vegetation Structure protocol used to guide sampling.
    f. **activity**; select 'mapping and tagging' if the individual will be mapped, otherwise select 'tag'.

5. Determine the **measurementHeight** using **Table 12**, **Table 13**, and Appendix D. Attach a pre-numbered aluminum tag according to guidelines in **Table 12**; this number is the **tagID**. When emergent boles/stems are in close proximity, it is best to treat each qualifying emergent bole/stem as an individual.

    a. Mark the measurementHeight on the qualifying stem(s) using lumber crayon or equivalent.

    b. ***TIP:*** It is helpful to mark trees you have just tagged, mapped, and/or measured with a small length of flagging in order to track work progress. All temporary flagging must be removed once data have been collected from all trees within a given subplot.

6. Record required **Stem Data** for the individual:

    a. **subplotID**; select the subplot in which the individual is rooted. Helps to relocate individuals in subsequent bouts.

    b. **nestedSubplotID**; select if rooted within a nested subplot. Helps to relocate individuals in subsequent bouts; may be left NULL for many trees (sbt, mbt).

    c. **tagID**; the numeric identifier for the individual. Should be unique within a domain.

    d. **supportingStemTagID**; required for the liana (lia) growth form only.

    e. **previouslyTaggedAs**; enter the previous, incorrect identifier if an individual was previously tagged in the field and associated with an incorrect tagID value in the database.

        i. The correct tagID value is recorded in the **tagID** field.

    f. **taxonID**; select from the NEON master list of USDA plant species codes for species present within the domain. Identify to the greatest taxonomic resolution possible.

        i. Record the USDA plants code rather than the scientific name.

        ii. If **taxonID** is unknown and the stem is alive, assign a morphospecies ID as indicated in steps below, obtain leaf, bark, and/or reproductive part samples (e.g., cones, nuts), and bring back to the lab to identify.

        iii. When stem **plantStatus =** 2 (standing dead), assign to species if possible. If the species cannot be determined, assign to genus, family, unknown hardwood or unknown softwood, in that order of preference.

g. **identificationQualifier**; select the appropriate qualifier when identification below a given taxonomic rank (e.g., family or genus) cannot be made (**Table 14**).

i. An qualifier is used in combination with a 'sp.' or 'spp.' in the scientific name. The 'sp.' indicates only one unknown species is involved; the 'spp.' indicates multiple unknown species in the same genus.

ii. If the genus of a specimen is obvious, and the specimen is one of up to 3 species, assign the specimen to the best matched species, and then assign 'identificationQualifier = CS'.

iii. When a genus- or family-level code is selected, an identification qualifier is not needed, unless for example, the genus is uncertain.

Example: If you record **taxonID =** 'PINUS', do NOT record **idQ** = 'cf. species'; it is already clear that you do not know the species based on the fact that a Genus-level code was reported in **taxonID**.

Table 14. identificationQualifier codes for species ID. Leave this field blank if technician is confident in the genus and species ID.

idQ code	identificationQualifier description
CS	*cf. species*: roughly equals but "not sure" about the species
AS	*aff. species*: similar to, but is not the species
CG	*cf. genus*: roughly equals but "not sure" about the genus
AG	*aff. genus*: similar to, but is not the genus
CF	*cf. family*: roughly equals but "not sure" about the family
AF	*aff. family*: similar to, but is not the family
CV	*cf. variety:* roughly equals but "not sure" about the variety
AV	*aff. variety:* similar to, but is not the variety

7. Map the individual if it qualifies for mapping (see **Table 12** for criteria; skip this step if the individual is only tagged):

a. Make sure **activity** = 'mapping and tagging' in the *VST: Mapping and Tagging* app.

b. Record the **pointID**; this is the plot marker number over which the laser rangefinder is positioned.

i. Refer to Appendix G if plot markers are not numbered.

c. Record the **stemDistance;** nearest 0.1 m. This is the horizontal distance from the plot marker to the base of the main stem, or the center of a shrub.

   i. See RD[09] for rangefinder operation instructions.

   ii. Note that tapes are preferred for measuring distances < 3 m due to rangefinder accuracy.

d. Record the **stemAzimuth;** nearest 0.1 degree. This is the angle relative to True North from the chosen plot marker to the base of the main stem or center of shrub.

   i. The angle should be preceded by a "**d**" indicating that declination has been set for the laser rangefinder at your current location. See RD[09] for details.

8. Record additional Stem Data for the individual:

   a. **identificationReferences**; for unknown species that must be keyed out, record the references used (e.g., dichotomous keys, regional flora guides) on a per individual basis the first time the species is encountered. It is not necessary to record the identificationReferences the next time the species is encountered.

      i. Only required when a species at a site has been keyed out with that reference for the first time. Consult with the lead Field Ecologist if you are unsure.

   b. **morphospeciesID**; enter a concise, descriptive ID that will be possible to link to this species at a later time – e.g., 'hirsute palmate decumbent' instead of 'green fuzzy'.

      i. Record the **taxonID** to the best of your ability IN ADDITION to the morphospeciesID.

      ii. If domain staff are not able to identify a given morphospecies prior to data entry, the morphospecies ID must be recorded in the morphospecies ID list (found in the 'morphospeciesTracking' folder of the FOPS / TOS Sharepoint library).

      iii. *Cryptic species:* To aid in identifying cryptic species at a site, members of cryptic pairs or groups should be added to NEON master taxon lists. New pairs / groups may be entered in the 'crypticSpeciesGroups' spreadsheet in the 'taxonTables' folder of the 'Sampling Support Documentation' Sharepoint library.

9. Enter optional **Plant Voucher or Genetic Archive Data** if:

   a. Adding the sample to a domain-specific reference collection would be helpful (see RD[07] for procedure), or

   b. If collecting a specimen from the individual for Genetic Archive (see RD[07]).

10. Save the *VST: Mapping and Tagging* record and proceed to the next individual.

B.6 Mapping QA/QC

- Ensuring that mapping data are accurate is important because:
    - Mapping data are used by the external community to link ground-based measurements with airborne remote-sensing data.
    - Mapping data reveal whether larger trees are accurately classified 'in' or 'out' of the plot. This can be particularly useful in steep terrain or dense brushy vegetation when it is difficult to determine plot boundaries. Making consistent, accurate in/out classification is essential for scaling biomass estimates to the plot-level.
- Use the VST Mapper application to view stem mapping results on a plot-by-plot basis as soon as the data records are entered into Fulcrum. The '***About***' tab of the VST Mapper describes app functionality. Pay particular attention to:
    - Mapped stems that appear to reside outside of plot boundaries. Mapping data for these individuals require verification in the field.
    - Mapped stems that appear to be located in a different part of the plot than where you remember the rooting point. Mapping data for these individuals require verification in the field.
    - The Mapper is only available within the NEON network (and via VPN) in order to prevent external access to raw L0 data that have not been QA/QC'd by the NEON data ingest pipeline.

SOP C Measuring Vegetation Structure

Overview

Woody stemmed vegetation may exhibit numerous growth forms – from single, straight boles to multiple curved, branched stems, to stems with adventitious roots that emerge some distance from the ground. The measurement strategy for woody individuals depends on growth form because allometric equations vary according to growth form with respect to required input data. With some modifications, this protocol adopts guidelines established by the U.S. Forest Service (2012) for measuring tree species. Shrubs are measured according to Lutz et al. (2014), and liana measurement guidelines are derived from Gerwing et al. (2006) and Schnitzer et al. (2008). Unless otherwise noted, diameter measurements are taken at a standard height of 130 cm (breast height, DBH) and/or at 10 cm above the ground (ddh).

In this SOP, we describe field techniques for measuring stem diameter, height, crown diameters, canopy area, and methods specific to unique growth forms such as ferns. To determine which measurements are required for a specific growth form refer to **Table 15**. Vegetation structure data are collected systematically from qualifying apparent individuals, groups, and portions of groups rooted inside each plot.

Goals

1. Make accurate growth form classifications, and thoroughly assess each plot for the presence of qualifying growth forms.
    a. Review current bout ***VST: Plot Meta-Data [PROD]*** records for each plot and update if any qualifying growth forms were missed during the initial survey (see SOP B.3).
    b. Communicate with Science if changes to nested subplot size are required.
2. Map, measure, and tag new stems that now meet mapping and tagging requirements (see SOP B.4 and SOP B.5).
    a. Collect new mapping and tagging data in the ***VST: Mapping and Tagging [PROD]*** app.
3. Determine which structure measurements are required for each qualifying individual in the plot, and collect repeatable data from consistent locations on stems.
    a. Check for changes in required measurements based on changes in growth form through time – e.g., ‘sap’ grows to ‘smt’.
    b. Collect data from all individuals with DBH ≥ 10 cm, regardless of stem density – i.e., do NOT use nested subplots for trees (‘sbt’ or ‘mbt’).
    c. Record data in the ***VST: Apparent Individuals [PROD]*** and ***VST: Shrub Groups [PROD]*** applications.

C.1 Measuring Apparent Individuals

Data collected as part of this section are recorded in the ***VST: Apparent Individuals [PROD]*** application. Consult the 'Manual for Fulcrum Application: TOS Vegetation Structure [PROD] – All SOPs' for data entry details (RD[14]). The measurements required for an individual are dependent on the assigned **growthForm** (**Table 15**).

Table 15. Summary of required measurements for each growth form; it is assumed that required taxonomic data are recorded *VST: Mapping and Tagging* app as part of SOP B implementation. Note that individuals may change growthForm from one year to the next, potentially necessitating different measurements (e.g., a change from 'sapling' to 'small tree').

Growth Form	Stem Diameter	Height	Crown Diameter	Additional Measurements
Liana (lia)	- stemDiameter (DBH) - measurementHeight - see D.6 for complex cases	Not measured	Not measured	- plantStatus
Single bole tree (sbt)	- stemDiameter (DBH) - measurementHeight - See **Table 13** and Appendix D.1 for complex cases	- vdApexHeight = Maximum height above observer - vdBaseHeight = Height from observer to base of tree (typically a negative number)	- Distributed Plots only - Maximum diameter - Perpendicular to max	- plantStatus - canopyPosition (Distributed Plots only)
Multi-bole tree (mbt)	- stemDiameter (DBH, per bole) - See Appendix D.2 to determine correct measurementHeight	Measure per individual, not per bole. - vdApexHeight = Maximum height of tallest bole above observer (not per bole) - vdBaseHeight = Height from observer to base of tree (typically a negative number)	- Distributed Plots only - Per individual, not per bole - Maximum diameter - Perpendicular to max	- plantStatus (per bole) - canopyPosition (not per bole, Distributed Plots only)
Small tree (smt)	- stemDiameter (DBH) - measurementHeight - See **Table 13** and Appendix D for complex cases - Measure multiple boles if applicable (**Figure 4**)	Measure per individual (not per bole). - vdApexHeight (top) and vdBaseHeight (ground) - Record vdBaseHeight = 0 if total height is measured from the ground with a collapsible ruler	- Distributed Plots with no overstory only - Per individual, not per bole - Maximum diameter - Perpendicular to max	- plantStatus (per emergent bole, if applicable)

Growth Form	Stem Diameter	Height	Crown Diameter	Additional Measurements
Sapling (sap)	- basalStemDiameter (ddh) - measurementHeight - Measure multiple emergent boles if present (Appendix D.6)	Measure per individual, not per stem. - vdApexHeight = Maximum height - Record vdBaseHeight = 0 if total height is measured from the ground with a collapsible ruler	Not measured	- plantStatus (per emergent stem, if applicable)
Single shrub (sis)	- basalStemDiameter (ddh, (per qualifying emergent bole) - stemDiameter (DBH, (only on largest diameter fork per emergent bole) - ddh and DBH measurementHeight - See Appendix D.5 for complex cases	Measure per individual, not per bole. - vdApexHeight = Maximum height - Record vdBaseHeight = 0 if total height is measured from the ground with a collapsible ruler	- Per individual, not per bole. - Maximum diameter - Perpendicular to max	- plantStatus (per emergent bole) - shape - If shape=icn: maxBaseCrownDiameter, and ninetyBaseCrownDiameter - If shape=elp: height to crown base
Small shrub (sms)	- basalStemDiameter (ddh, (per qualifying emergent stem) - measurementHeight - Measure multiple emergent stems if present (Appendix D.6) - Broken emergent stems must be ≥ 30 cm height (or stem length) to qualify for measurement (Appendix D.6).	Measure per individual, not per stem. - vdApexHeight = Maximum height - Record vdBaseHeight = 0 if total height is measured from the ground with a collapsible ruler	- Per individual, not per stem - Maximum diameter - Perpendicular to max	- plantStatus (per emergent stem) - If shape=icn: maxBaseCrownDiameter, and ninetyBaseCrownDiameter - If shape=sph: height to canopy base
Shrub group (sgr)	Not measured	- Five points that best represent overall height of the group	Crown area; graph paper method	- % contribution to total volume (per species) - % live (per species) - % dead (per species)
Fern (frn)	- Species dependent; see Appendix F	- Tree ferns only - Maximum height - Record vdBaseHeight = 0 if total height is measured from the ground with a collapsible ruler	Not measured	- plantStatus - Species dependent; see Appendix F

Growth Form	Stem Diameter	Height	Crown Diameter	Additional Measurements
Palm (plm)	- stemDiameter (DBH, (tree palms only) - If present, record 'DBH contains leaf base' in **remarks** field - See Appendix F	- Maximum height - For tree palms, typically measure vdApexHeight (top) and vdBaseHeight (ground) - Record vdBaseHeight = 0 if total height is measured from the ground with a collapsible ruler	Species dependent; see Appendix F	- plantStatus - Species dependent; see Appendix F
Yucca (yuc)	Not measured	- Maximum height - Record vdBaseHeight = 0 if total height is measured from the ground with a collapsible ruler	- Maximum diameter - Perpendicular to max	- plantStatus
Bear Grass (xer)	- basalStemDiameter (per flowering stem)	Not measured	Not measured	- meanLeafLength
Ocotillo (oco)	Not measured	- Measure per individual, not per stem. - Maximum height - Record vdBaseHeight = 0 if total height is measured from the ground with a collapsible ruler	- maxBase CrownDiameter - ninetyBase CrownDiameter	- stemNumber

SOP C.1.1 Plot Delineation and Assessment

1. **Check the *VST: Plot Meta-Data* application to determine whether a plot has been measured before, and if so, which nested subplot area is recommended for each growth form.**
    a. Survey the plot, and record required Plot Meta-Data for the current year: Be alert for growth forms that may not have been present in the past.
    b. *If a plot has been measured before*, it is ideal to use the same subplot size each year, unless a change in nested subplot size has been discussed with Science.
    c. *If a plot has NOT been measured before:*
        i. Return to SOP B to assign nested subplots (if required), and record required information in the *VST: Plot Meta-Data* application. Be sure to record the nested subplot size for each growth form present in the plot.
        ii. Perform speciesID, and mapping and tagging activities, and record required information in the *VST: Mapping and Tagging* application.
        iii. Individuals must exist in *VST: Mapping and Tagging* before measurements can be recorded in *VST: Apparent Individuals*.
2. Delineate the plot or subplot. Use existing plot markers, meter tapes, and chaining pins to carefully delineate the plot / subplot boundaries.
    - It is not necessary to pay attention to whether the plot is sloped or flat: the tape is used only to help determine which stems are 'in' versus 'out' of the plot.
    - Individuals are only measured when ≥ 50% of the individual (or ≥ 50% of the stems, for a multi-stemmed individual) are rooted within the measurement area.
    - Refer to the Plot Establishment Protocol (RD[08]) for a review of tape wrapping techniques that can be used to delineate modules or subplots.
3. Delineate nested subplots, if required. The one-sided length of the nested subplots are listed in Section 0, **Table 11**.
4. Survey the plot to identify individuals previously not measured that now qualify as one of the growth forms listed in **Table 10**.
    a. For new recruits, return to SOP B, and record required data in the *VST: Mapping and Tagging* application.

SOP C.1.2 Collecting Apparent Individual Structure Data

- Bring per plot checklists of previously tagged individuals to the field to ensure that repeat measurements are obtained for as many apparent individuals as possible (SOP A.3).
- It is helpful to mark trees that have been measured with a small length of flagging to track work progress. All temporary flagging must be removed once data have been collected.

For each qualifying apparent individual:

1. Determine the **measurementHeight**(s) for each of the qualifying stems of the individual – i.e., the distance along the bole(s) at which the **stemDiameter** is measured, beginning from where the bole emerges from the ground (see **Table 12** and Appendix D).
    a. The measurementHeight is determined independently for multiple emergent boles that are part of the same individual.
    b. In many cases, the measurement location will already be marked with lumber crayon following the 'Mapping and Tagging' activity (SOP B.4).
    c. Re-use previously measured **measurementHeight** values if within ± 5 cm of the observed height in the current year.
2. Mark (or re-mark) the stem at the desired measurementHeight with lumber crayon to enable repeat measurements at the exact same location.
    a. Mark stems with DBH ≥ 30 cm at multiple points around the bole to ensure accurate re-measurement.
    b. Re-mark the stem if the lumber crayon is faded or difficult to discern.
3. Assess whether a diameter tape or calipers should be used to measure stem diameter.
    a. ***Use a diameter tape for***: Self-supporting stems with DBH ≥ 5 cm, AND that do NOT have lianas that will interfere with accurate diameter measurement.
    b. ***Use calipers for***:
        i. Self-supporting stems with DBH < 5 cm; use calipers to measure the stem at its widest point, and perpendicular to its widest point. Calculate the average, and record. Diameter tapes are less accurate for small stems.
        ii. Self-supporting stems with DBH ≥ 5 cm that DO have lianas that will interfere with accurate diameter measurement; use calipers to measure the stem at its widest point (excluding lianas), and perpendicular to its widest point. Calculate the average, and record.
        iii. Lianas.

4. Create a record in the *VST: Apparent Individuals* app. Enter the following:
    a. **domainID** and **siteID**; these fields narrow the list of plotIDs.
    b. **plotID**; the list of available plotIDs is populated by records created in the *VST: Plot Meta-Data* app. Create *VST: Plot Meta-Data* records prior to *VST: Apparent Individuals* records.
    c. **Go To Mapping & Tagging App**; click 'New' if the individual has not yet been tagged and there is no prior *VST: Mapping and Tagging* record. A *VST: Mapping and Tagging* record must exist prior to creating a *VST: Apparent Individuals* record.
        i. **If *VST: Mapping and Tagging* data exist but are incorrect**: Navigate manually to the *VST: Mapping and Tagging* app (do not click the 'Select' or 'New' button within the *VST: Apparent Individuals* app), and:
            1. If 'LOAD_STATUS' = LOADED: Create a new Mapping and Tagging record.
            2. Else: Edit existing Mapping and Tagging record, update with correct information, and save.
            3. Return to the *VST: Apparent Individuals* workflow.
    d. **tagID**; select the tagID value from the list of previously created *VST: Mapping and Tagging* records. Verify that the taxonID associated with the tagID is correct.
    e. **tagStatus**; select from the following options:
        i. **ok**; select if:
            1. Previously attached tag exists, is legible, and value is consistent with previously entered value, OR
            2. A new tag has been attached because the individual did not previously qualify for measurement, OR
            3. A new tag has been attached because the previous tagID value could not be determined with ≥ 90% certainty and the previous tagID was swapped for a new tagID.
        ii. **replaced**; tag no longer attached, readable, etc., and the previously recorded tagID value can be surmised with ≥ 90% certainty (via VST Mapper, process of elimination, or other means). Tag has been re-made with previous number.
        iii. **notRequired**; applicable to ferns, yucca, many cactus (see **Table 12**).
    f. **taxonID**; for reference only. Update in *VST: Mapping and Tagging* if corrections are required.

5. Assess and record the **plantStatus** for each qualifying stem (see definitions in **Table 16**).
    a. See Appendix D.4 for guidance for multi-bole individuals with mixed plantStatus.
6. Determine and record the **growthForm** for the individual (see definitions in **Table 10**).
    a. Values of **stemDiameter** (DBH or ddh), measured below, may help guide classification.
    b. Remember that **growthForm** values may change from year to year (e.g., 'sap' to 'smt').

Table 16. List of plantStatus codes and their definitions.

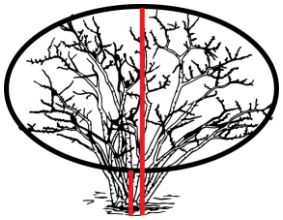
Code	Description
1	**Live** – any live Apparent Individual (new, re-measured or ingrowth) that is of typical healthy status for the ecosystem in question. E.g., if trace amounts of insect damage or foliar disease are typical on the majority of individuals, use this code rather than code 4 or 5 below.
2	**Standing dead –** any dead individual, or standing dead bole within a multi-bole individual, regardless of cause of death. The entire tree or bole must be dead, and the main bole is NOT broken. For dead, broken boles see additional code below. Indicate factors associated with death in order of importance in the **remarks** field. Potential causes of death include: • Biotic: Suppression, animal damage, mistletoe • Disease: Blister rust, rot, canker, other (specify), unknown • Insect: Bark, defoliating, other; specify insect species if possible • Physical: Crown damage, crushed, lightning, other (specify if possible) • Fire: Crown scorch, crown combustion, bole/stem scorch, bole/stem combustion, burned through at base (for small trees, due to litter & duff burning around base), other (describe). • Unknown: A last resort category; may be applicable if individual is long dead.
3	**Removed** – an individual that has been cut and removed by direct human activity related to harvesting, silviculture or land clearing (re-measurement plots only). If the individual is a species that may resprout and eventually qualify again for measurement record 'no longer qualifies' rather than 'removed'.
4	**Live, insect damaged** – Visible damage caused by insects that exceeds trace amounts that may be present on typically healthy trees; note 'crown' or 'bole' damage in **remarks**, and indicate type of insect causing damage if possible (e.g., Mountain Pine Beetle, Gypsy Moth, etc.)
5	**Live, disease damaged** – Visible damage caused by disease that exceeds trace amounts that may be present on typically healthy trees; note 'crown' or 'bole' damage in **remarks**, and indicate type of disease causing damage if possible (e.g., Blister Rust, rot, canker, other (specify), unknown.
6	**Live, physically damaged** – Visible damage not caused by insects or disease, but of known origin; note 'crown' or 'bole' damage in **remarks**, and indicate type of physical damage (e.g., bole scar, girdling, snow/ice damage, crushed, lightning, crown scorch, bole scorch, ungulate herbivory, human damage)
7	**Live, other damage** – Visible damage of other origin, e.g. biotic suppression; note 'crown' or 'bole' damage in **remarks**, and note cause of damage if possible.
8	**No longer qualifies** – note reason in **remarks**; record in multiple years if individual is still alive and may qualify in the future**.** Reasons for not measuring include: Individual no longer qualifies (e.g., standing dead has fallen down), complete consumption by fire, etc.
9	**Live, broken bole/stem** – individual with broken top, with broken main bole and ascending leaders (that may or may not be taller than the break point), or that is broken and dead at top but live below, etc. Indicate factors that may have caused the break and other damage in order of importance in the **remarks** field. When damage does not result in a clean break in the bole/stem, record 'Live, physically damaged'.

10	**Dead, broken bole/stem** –all parts of the broken bole or stem are dead; may have broken spike top, or dead leaders ascending beyond the break point. Indicate factors associated with death and the source of damage in order of importance in the **remarks** field.
11	**Lost, burned –** A previously measured individual that is not measured in the current bout because the plot has been burned, and the individual could not be re-located for measurement. Cause of loss is presumed to be fire.
12	**Lost, herbivory –** A previously measured individual that is not measured in the current bout because the individual could not be re-located for measurement. Cause of loss is presumed to be herbivory.
13	**Lost, presumed dead** – A previously measured individual that is not measured in the current bout because it could not be re-located for measurement. The individual is presumed dead based on evidence within the plot. Note presumed cause of death in the **remarks** field (e.g., blowdown event).
14	**Lost, fate unknown** – A previously measured individual that is not measured in the current bout because the individual could not be re-located.
15	**Downed –** A previously measured individual that is not measured in the current bout because it is > 45˚ from vertical.

7. Determine the **shape** of the individual (***only required for growthForm = 'sis' and 'sms'***; see **Table 17**). Shrub crown dimensions and height will be used to calculate volume according to idealized shapes.

Table 17. Idealized shapes for shrub volume estimation.

Shape	Example	Additional measurements
Half-sphere (hsp)*		None
Oblate half sphere (ohs)*		None
Cone (cne)		None
Inverted cone* (icn)		**aDatum** = baseCrown MaximumDiameter (red line), **bDatum** = baseCrown NinetyDiameter

Shape	Example	Additional measurements
Cylinder (cyl)		None
Ellipsoid or sphere (elp)		**aDatum** = baseCrownHeight (short red line); **height** (long red line) is already recorded

* Images from Ludwig et al. (1975)

a. Not all shrubs match an idealized shape: Choose the best fit, and consider the stems and branches as they emerge from the ground level, not just the leafy crown.

b. There will not necessarily be a 'correct' shape to assign for a given shrub; that is, more than one shape can conceivably apply.

i. Shape may be relatively consistent from year-to-year, so use the previous year's **shape** as a starting point (if available).

ii. Calibrate your judgement as a team prior to beginning work to enable consistent data collection through time and across teams.

8. Measure the **stemDiameter** at the required **measurementHeight**(s). See **Table 15** for growth-form-dependent requirements (DBH, ddh or both). All diameter cutoffs that determine measurements are hard cutoffs – do not round.

a. Place the diameter tape or calipers directly over the marking(s) from step (2).

i. Take care to avoid sloughing bark when collecting data. Negative growth can be perceived due to bark loss.

ii. For large boles, the tape must not slip above or below the desired measurementHeight.

b. Record in the *VST: Apparent Individuals* app:

i. **stemDiameter** (growthForm dependent): The diameter of the bole perpendicular to the pith, typically 130 cm along the bole for DBH; nearest 0.1 cm. Not recorded when growthForm = 'sap' or 'sms'.

ii. **basalStemDiameter** (growthForm dependent): The basal diameter of the bole, typically 10 cm above the ground; nearest 0.1 cm. Recorded only when growthForm = 'sap', 'sis', or 'sms'.

iii. **measurementHeight**(s): Distance along the bole at which the **stemDiameter** or **basalStemDiameter** is actually measured; nearest 1 cm. Both DBH and ddh are required for 'sis' individuals.

1. If the desired measurementHeight is out of reach for all but the tallest foresters, adjust downward to ensure that repeat measurements can be made by the average person (see Appendix D.2, Case B for how to deal with compound splits that often lead to this situation).

iv. To create records for individuals with multiple qualifying stems/boles:

1. For multi-bole trees (mbt): Create one record per each uniquely identified qualifying bole. Each unique tagID will have a corresponding record in the *VST: Mapping and Tagging [PROD]* app.

2. For all other growth forms: Create one record for each qualifying stem/bole, and ***use the same tagID for each stem.*** Only one record exists in *VST: Mapping and Tagging [PROD]* for the individual.

9. Measure the **height** (if required). See **Table 15** for growth-form-dependent requirements. Record in the *VST: Apparent Individuals* app:

a. **vdApexHeight**; the definition depends on the measurement method:

i. *Rangefinder:* The vertical distance between the top of the canopy and the rangefinder (typically a positive number); nearest 0.1 m

ii. *Collapsible ruler, surveyor level rod, measuring stick, or equivalent*: The vertical distance between the top of the canopy and the ground; nearest 0.1 m

b. **vdBaseHeight**; the definition depends on the measurement method:

i. *Rangefinder:* The vertical distance between the rangefinder and the tree base where it emerges from the ground (typically a negative number); nearest 0.1 m

ii. *Collapsible ruler or equivalent*: Enter '0', since **vdApexHeight** already represents total **height** above ground when measured with a collapsible ruler. ***Do NOT leave blank!***

c. *See SOP C.1.3 for strategies to deal with broken individuals.*

10. Measure **crown** dimensions (if required). See **Table 15** for growth-form-dependent requirements. Crown dimensions can be measured via either of the two techniques in RD[09]. The **crown** dimensions may include live and dead material from intact boles / stems. However, do not include broken boles in measured **crown** dimensions.

    Record in the *VST: Apparent Individuals* app:

    a. **maxCrownDiameter**; The maximum extent of the crown; nearest 0.1 m.

    b. **ninetyCrownDiameter**; The diameter at 90˚ to maxCrownDiameter; nearest 0.1 m.

11. Record additional growthForm dependent shrub data (if required). See **Table 15** for growth-form-dependent requirements.

    a. For **shape** = 'inverted cone' (icn):

        i. **maxBaseCrownDiameter**; nearest 1 cm. The maximum diameter of the base of the crown (red line in **Table 17** above), always measured at ground level. (Use **aDatum** field on paper data sheet). For a perfect inverted cone, this diameter is the diameter of the stem.

        ii. **ninetyBaseCrownDiameter**; nearest 1 cm. The diameter at the crown base that is perpendicular to maxBaseCrownDiameter. (Use **bDatum** field on paper data sheet).

    The **crown** diameter measurements may be made using any of the methods below; use the technique that works best given the constraints imposed by the vegetation:

    - Large calipers
    - Rigid collapsible meter stick
    - Meter tape
    - Laser rangefinder

    b. For **shape** = 'ellipsoid' (elp)

        i. **baseCrownHeight**; nearest 1 cm. Use a rigid, collapsible meter stick to measure the average height above the ground for the lowest portion of the crown (short red line in **Table 17** above; use **aDatum** on paper data sheet, **bDatum** = null).

12. Assess and record the **canopyPosition** (***required for 'sbt' and 'mbt' in Distributed Plots***). See **Table 18** for canopyPosition codes and definitions.

    a. The canopyPosition data are ***critical*** for selecting representative individuals visible to remote sensing for sampling via the NEON TOS Canopy Foliar Chemistry protocol.

    b. *Example*: A closed canopy, nothern hardwood forest. A young Red Oak (*Quercus rubra*) with DBH = 12.2 is growing at the center of a narrow gap in the canopy caused by a blow-down that occurred some years before. Assign canopyPosition = 3, based on the fact that the top of the tree's crown is dominating a small canopy gap, and receiving direct sun. The sides receive little direct light, since the gap is narrow.

Table 18. Canopy position definitions. Modified from USFS Forest Inventory Analysis program Crown Class definitions to emphasize an individual's visibility to AOP remote-sensing instruments (U.S. Forest Service 2012).

Code	canopyPosition description
1	**Open Grown** – Full sun, not touching other plants, with crowns that have received full light from above and from all sides throughout most of its life, particularly during its early developmental period.
2	**Full sun** – crowns receiving full light from above and partly from the sides. Their crown form or shape appears to be free of influence from neighboring plants.
3	**Partially shaded** – crowns receive full light from above but little direct sunlight penetrates their sides.
4	**Mostly shaded –** individuals that receive little direct light from above and none from the sides.
5	**Full shade** – individuals that receive no direct sunlight either from above or the sides.

13. Review all ***VST: Apparent Individuals [PROD]*** record fields for completeness and accuracy. Save the record and repeat steps for additional qualifying individuals.

    a. It is valuable to spend a minute to identify missing data or errors while still in the field where the individual can be checked against measurement requirements (see **Table 15**, **Table 17**).

    b. Collecting missing data at a later date and / or correcting errors without access to the measured individual is time-consuming and costly.

SOP C.1.3 Measuring Broken Individuals

I. Broken boles: sbt

When either live or dead broken 'sbt' individuals > 130 cm height are encountered:

- Record **plantStatus** = 9 or 10 (see **Table 16**).
- Skip step (13) below, and do NOT record **crown diameter** data.
- Record: **breakDiameter, vdApexBreakHeight** and **vdBaseBreakHeight.**
    - If using paper data sheets, record on the next row of the data sheet as **remarks.**
    - If leader branches ascend higher than the break height, **vdApexHeight** will be larger than **vdApexBreakHeight**.
    - If the break height is the highest point, the value recorded for **vdApexBreakHeight** will be the same as that recorded for **vdApexHeight**.
    - **vdBaseBreakHeight**; often the same as **vdBaseHeight** but may be different for a broken 'mbt' bole growing on a slope.

a. *If the broken top of the bole can be found nearby on the ground:*

    i. Search for the top of the bole, which should be nearby on the ground.

    ii. Measure the **breakDiameter** of the fallen bole as near the break point as possible. Measure two diameters with calipers and record the average if a diameter tape cannot be used.

b. *If the broken top cannot be found,* or it cannot be determined which broken top matches the broken bole of interest: Two people may use calipers to estimate the diameter at the breakpoint.

    i. Person 1: Stand away from the broken bole at a sufficient distance such that you can see the breakpoint AND the base of the bole (i.e., the same distance required for measuring the height of the break).

    ii. Person 2: Stand in front of the broken bole with the caliper jaws open and pointing up.

    iii. Person 2 directs Person 1 to open the calipers until the jaw gap appears to match the diameter at the breakpoint (squinting may help).

II. Broken boles: mbt

When either live or dead broken boles > 130 cm height are part of a multi-bole tree:

a. *If a subset of the boles are broken:*

   i. Record **plantStatus** individually for each bole (see **Table 16**).

   ii. Record **crown diameter** measurements once for the intact bole(s) (step 13 below). Record these values as the crown diameter entries for the largest, unbroken bole.

   iii. Measure and record **breakDiameter**, **vdApexBreakHeight**, and **vdBaseBreakHeight** for the broken bole(s) on separate rows of the data sheet as described above for broken 'sbt.'

b. *If all of the boles are broken:*

   i. Record **plantStatus** individually for each bole (see **Table 16**).

   ii. Skip step (13) below and do NOT record **crown diameter** data.

   iii. Measure and record **breakDiameter**, **vdApexBreakHeight**, and **vdBaseBreakHeight** for each broken bole on separate rows of the data sheet as describe above for broken 'sbt.'

III. Broken boles: smt

a. When a single-bole 'smt' has broken, or all boles of a multi-bole 'smt' have broken, and height is now < 130 cm:

   i. Assign **plantStatus** = 8 (no longer qualifies), and do not measure in the current year.

   ii. Continue to monitor in future years, as individual may again qualify for measurement.

   iii. If no prior measurements exist or the tag cannot be found, treat the individual as a 'sap' and measure accordingly.

b. When one or more boles of a small multi-bole 'smt' have broken, and are now < 130 cm height:

   i. For broken boles that do not qualify, assign status = 8 as above for single-bole 'smt'.

   ii. Continue to measure qualifying emergent boles as normal.

   iii. Measurement of **crown** diameter does not include broken boles.

c. When one or more boles of a small multi-bole 'smt' have broken, and are now ≥ 130 cm height:

   i. Record **plantStatus** = 9 or 10 for each broken bole.

   ii. Measure **crown** diameter for intact boles; do not include broken boles in diameter measurement.

   iii. Measure **breakDiameter** as for 'sbt', above.

IV. Broken boles: multi-stem sap and sms

a. When an emergent stem has ddh ≥ 1 cm, and is broken and < 30 cm height (or stem length):

   i. If all qualifying emergent stems are broken and < 30 cm height, no measurements are made. Otherwise,

   ii. Do not measure ddh.

   iii. Measure **crown** diameter for intact stems; do not include broken stems in diameter measurement.

b. When an emergent stem has ddh ≥ 1 cm, and is broken and ≥ 30 cm height (or stem length):

   i. Assign **plantStatus** = 9 or 10

   ii. Measure ddh.

   iii. Measure **crown** diameter for intact stems; do not include broken stems in diameter measurement.

   iv. If all qualifying emergent stems are broken and ≥ 30 cm height, no **crown** measurements are made.

V. Broken boles: sis

a. When an emergent bole is broken and is < 130 cm height:

   i. Assign **plantStatus** = 8, and do not measure in the current year.

   ii. **basalStemDiameter** = do not measure.

   iii. Measure **crown** diameter for intact boles; do not include broken boles in diameter measurement.

b. When an emergent bole is broken and is ≥ 130 cm height:

   i. Record **plantStatus** = 9 or 10 for each broken bole.

   ii. Measure **crown** diameter for intact boles; do not include broken boles in diameter measurement.

c. When all previously qualifying emergent boles are broken, and are < 130 cm height:

   i. Assign **plantStatus** = 8 for each bole.

   ii. Do not measure **crown** diameter, unless broken individual has transitioned to 'sms' growth form.

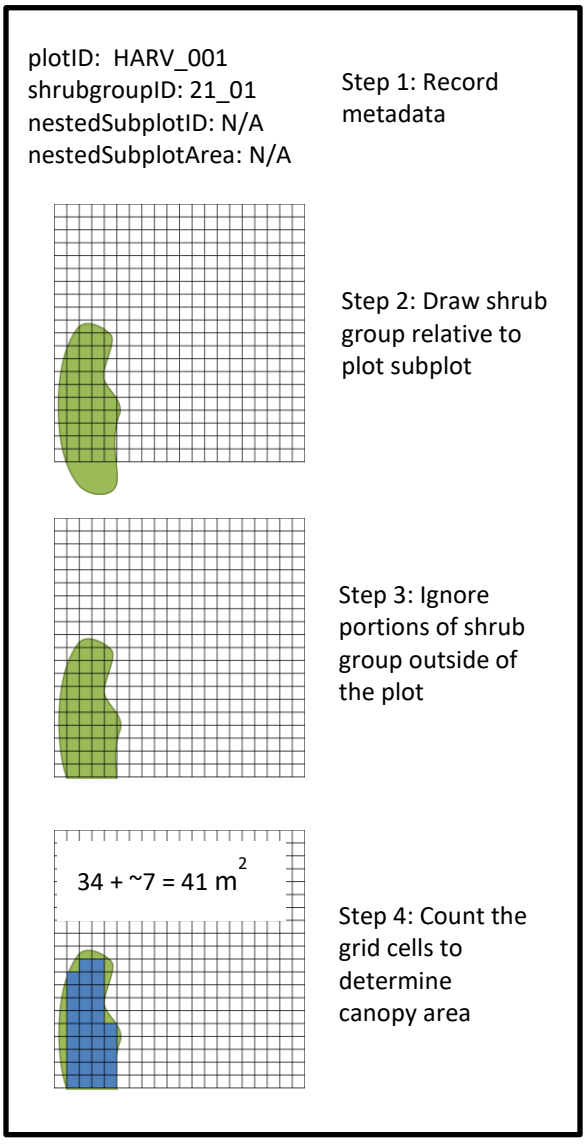
   iii. Continue to monitor in future years, as individual may again qualify for measurement.

   iv. If no prior measurements exist or the tag cannot be found, treat the individual as a 'sms' and measure accordingly.

C.2 Measuring Shrub Groups and Liana Groups

Data collected as part of this section are recorded in the ***VST: Shrub Groups [PROD]*** application. Consult the 'Manual for Fulcrum Application: TOS Vegetation Structure [PROD] – All SOPs' for data entry details (RD[14]).

Classifying vegetation as a 'group' is a measure of last resort, as group measurements are the least useful with respect to allometric biomass estimation (see SOP B for explanation and classification guidelines). Shrub and Liana groups are not mapped relative to a plot marker, and it is not required that they be tagged; however, you may tag shrub groups to better enable repeat measurements if you wish. Groups are measured so that the volume of the group may be estimated as 'canopy area' x 'average height'. Canopy area is estimated using the graph paper mapping technique, with the area covered by the group determined by counting the number of graph squares within the group (**Figure 5**).



Each group receives a unique **groupID** that is unique within the plot. This number is not necessarily a permanent assignment; it is a temporary uniqueID used, in part, to group data related to multi-species groups.

Figure 5. Example of graph paper method for determining shrub group area within a 20 m x 20 m subplot. In this example, **canopyArea** = 41.

For each Shrub or Liana Group:

1. Assess the % cover of the group relative to the measurement area:
    a. Do not map the group if cover is 100% for a given subplot or nested subplot - i.e., stems are very dense, and a more-or-less continuous group covers the entire measurement area. When this occurs, record the nestedSubplotArea in the canopyArea field. E.g., if the nestedSubplotArea = 25 m^2 and cover is 100%, record canopyArea = 25.
    b. If the group covers <100% of the measurement area, map the area of the group using the graph paper methods described below and shown in Figure 5. Example of graph paper method for determining shrub group area within a 20 m x 20 m subplot. In this example, **canopyArea** = 41.
    c. .
2. Measure Shrub or Liana Group **canopyArea** with the graph paper method:
    a. Label plotID, subplotID, nestedSubplotID, nestedSubplotArea on the graph paper.
    b. Draw the measurement area boundaries, (1 cm^2 = 1 $m^{2,}$).
    c. Draw the shape of the shrub group to scale within the measurement area.
    d. Count the number of grid cells contained within the sketched group, begin with whole cells then add up partial cells: the sum is the **canopyArea** for the group.
3. Measure Shrub Group average height:
    a. Use either the laser rangefinder (> 2 m), a meter tape (< 2 m) or collapsible ruler (< 2 m).
    b. Measure the height at 5 locations (**aGroupHeight**, **bGroupHeight**, etc.); nearest 0.1 m.
        i. Choose heights that you feel best represent the average maximum height of the shrub group. Bear in mind that the goal is to estimate the volume of the entire group as accurately as possible.
        ii. For groups that include lianas, measure height for the majority of the group, do not account for climbing stems extending to the canopy.
4. Create a record in the *VST: Shrub Groups [PROD]* application. Enter the following:
    a. **siteID** and **plotID**; select a plotID from the list generated by the *VST: Plot Meta-Data* app. Return to *VST: Plot Meta-Data* and create record for the current bout if one does not yet exist.
    b. **Date**; enter the correct date, *YYYY-MM-DD* format.
    c. **subplotID** and **nestedSubplotID**; the subplot in which the shrub group is located, and if applicable, the nestedSubplotID within the subplot. These data can aid in re-finding shrub groups in future bouts.

d. **eventID**; a unique identifier for the sampling event, '*vst_SITE_YYYY*' format, where *YYYY* is the year the bout began. If an auto-populated value is incorrect, return to *VST: Plot Meta-Data* and update the record.

e. **samplingProtocolVersion**; the version of the Vegetation Structure protocol used to guide sampling.

f. **groupID**; unique identifier *within a plot* for the shrub group, using the form '*XX_YY*' where *XX* is the subplotID, and *YY* is an incremental number (01, 02, 03…) assigned in the field, starting over for each plot.

g. **canopyArea**; the area of the shrub group, nearest 1 square meter.

h. **aGroupHeight, bGroupHeight, etc**.; enter 5 representative height measurements, nearest 0.1 meter.

5. Assess the shrub group to determine taxonomic composition and per taxon live/dead status.

a. Determine the % contribution by volume (ocular estimation) of each species within the shrub group (sum of live + dead biomass).

b. For each species present, assess the % live and % dead within the total shrub group volume. The sum of % live and % dead should = 100 for each taxonID.

c. Create a child record in the *VST: Shrub Groups* app for each taxonID within the shrub group and record:

i. **taxonID**; select from the NEON master list of USDA plant species codes for species present within the domain. Identify to the greatest taxonomic resolution possible.

1. If **taxonID** is unknown and the stem is alive, assign a morphospecies ID as indicated in steps below, obtain leaf, bark, and/or reproductive part samples (e.g., cones, nuts), and bring back to the lab to identify.

ii. **identificationReferences**; for unknown species that must be keyed out, record the references used (e.g., dichotomous keys, regional flora guides) on a per individual basis the first time the species is encountered. It is not necessary to record the identificationReferences the next time the species is encountered.

iii. **identificationQualifier**; select the appropriate qualifier when identification below a given taxonomic rank (e.g., family or genus) cannot be made (**Table 14**).

iv. **morphospeciesID** (if applicable); enter a concise, descriptive ID that will be possible to link to this species at a later time. Follow all guidance in SOP B.5.

v. **volumePercent**; visually estimated % volume of the shrub group for a taxonID, nearest 10%. If a taxonID is < 5% of total shrub group volume, record volumePercent = 1%

vi. **livePercent**; the estimated percent of the biomass that is alive for a taxonID in the shrub group, nearest 10%.

vii. **deadPercent**; the estimated percent of the biomass that is dead for a taxonID in the shrub group, nearest 10%. Sum of livePercent + deadPercent must = 100%.

d. Save the child record, and repeat for additional taxa present in the shrub group. The sum of the % volume contributions from all taxa must equal 100%.

6. Save the parent shrub group record and proceed to the next shrub group.

C.3 Measuring 'Other' growth forms

SOP C.3.1 Ferns and Fern Allies

Ferns and fern allies are one of the most common 'other' growth forms encountered across the Observatory. As a group, ferns and fern allies have a range of shapes and sizes. However, there are a limited number of fern allometries available for estimating biomass for this group. Measurements required for common fern species are provided in Appendix F. If a fern species is not explicitly listed in Appendix F, measure according to the last row of **Table 19** (below).

For Distributed Plots: Ferns may be ignored when sampling Distributed plots if visually estimated aerial cover of ferns is < 50% of the entire plot area. That is, visually estimate the fern cover as seen by AOP.

For Tower Plots: Sampling ferns within Tower Plots is determined by Science, and is based on analysis of Site Characterization data.

To measure Ferns and fern allies:

1. Determine the appropriate measurement area.
    - All non-woody, 'other' growth forms are grouped when determining the appropriate nested subplot size. That is, if ferns are present with additional 'other' growth forms, the appropriate measurement area should be determined considering ferns + any additional 'other' growth forms.
2. Ignore all individuals with a height OR average frond length < 30 cm
    - *Note: This will likely disqualify many fern allies from consideration for this protocol*
3. Determine morphology group (see **Table 19**), and measure accordingly.
4. For densely clustered ferns that form an impenetrable mass (e.g., some D20 PUUM species):
    - Consider dense patches as 'groups' similar to Shrub Groups (SOP C.2).
    - Groups count as '1' when determining the correct nested subplot size.

Table 19. Fern and fern ally morphology groups, and associated required measurements.

Morphology	Required measurement(s)
Tree fern or similar	Height, stemDiameter or basalStemDiameter (see next section)
Bracken Fern (*Pteridium sp.)* or similar	basalStemDiameter
Other fern types	Refer to Appendix F for species-specific measurements
Not listed here or in Appendix F	• Average frond length (select representative frond to measure) • Number of total fronds

SOP C.3.2 Tree Ferns

1. Select a nested subplot area as per standard woody tree growth forms:
    a. Tree ferns with DBH ≥ 10 cm: Do NOT use nested subplots. Measure these individuals throughout the plot.
    b. For tree ferns with DBH < 10 cm and with ddh ≥ 1 cm, use nested subplots as per woody growth forms.
2. Mapping tree ferns:
    a. Map all individuals with DBH ≥ 10 cm.
    b. Map the root point, not the crown.
3. Determine the **measurementHeight**:
    a. Measure diameter 130 cm along the stem from the 'root collar' or 'root point'.
        i. For downed individuals that are still growing, find the rooting point, and measure 130 cm along the downed stem to find the measurement location.
        ii. For individuals with pedestals, define the zero point as the top of the pedestal, then measure 130 cm along the stem from the top of the pedestal.
    b. For individuals with the frond attachment point at 130 cm (or close to it):
        i. Move the measurement location down the stem until the stem is regular.
        ii. Record the modified measurementHeight.
    c. Guidance in Appendix D.1 may help with other complex situations.
4. Measure the **stemDiameter**:
    a. Use calipers when boles are extremely furrowed, moss-covered, or there are other irregularities like roots / shrubs / lianas that prevent accurate use of tapes.
    b. Avoid sloughing off bark to ensure repeat measurements do not yield negative changes in stemDiameter.
5. Measure **vdApexHeight** and **vdBaseHeight**:
    a. Record **vdApexHeight** at the point where woody parts stop and fronds emerge.
        i. The point at which woody material stops and fronds emerge is often obscured. When possible, probe by hand to determine where woody parts stop.
        ii. For very tall individuals for which manual probing is not possible, use experience with shorter individuals to consistently visually estimate the correct vdApexHeight.
    b. Use a measuring stick or a rangefinder to measure the required heights.

SOP C.3.3 Additional 'Other' Growth Forms

'Other' growth forms that are also measured according to this protocol are listed below. Required measurements are unique to each growth form, and are listed in Appendix F.

- Palm trees. Distinct measurements are required for:
  - 'shrub'-type palms (e.g., *Serenoa repens*); ignore individuals with < 30 cm mean total leaf length.
  - 'tree'-type palms (e.g., *Butia capitata*)
- *Cactaceae* species:
  - The Cactus SOP is implemented concurrently with this protocol. Measurement of Cactaceae species is described in the companion Cactus SOP (RD[11]).
- Yucca species
  - Include agave species with yucca-like growth form in this group.
- Xerophyllum species (i.e., Bear Grass)

SOP D Field Campaign Follow-up

D.1 Sample preservation

- Place plastic bags with leaf samples from unknown species in a refrigerator until they are identified and/or placed in a plant press and dried for identification at a later date.
- **Specimens should not be left in the refrigerator for more than two days.**
- Identification often requires a variety of dichotomous keys, a dissecting microscope, a dissecting kit, and a herbarium with voucher specimens for verification.

D.2 Refreshing the sampling kit

- Recharge batteries on the GPS unit.
- Make sure there are either 1) adequate supplies of fresh replacement batteries for the TruPulse 360R (type CR123A); or 2) rechargeable batteries are re-charged.
- Check that supplies of lens tissue are adequate.
- Check that supplies of consumable materials are adequate, particularly data sheets.

D.3 Equipment maintenance, cleaning, and storage

- If necessary, clean the lenses on the laser rangefinder with a lens cloth or lens tissue.
- Remove plot location information that is no longer needed from the GPS unit.

SOP E Data Entry and Verification

Mobile applications are the preferred mechanism for data entry. Data should be entered into the protocol-specific application as they are being collected, whenever possible, to minimize data transcription and improve data quality. For detailed instructions on protocol-specific data entry into mobile devices, see the Fulcrum Manual (RD[14]) on the internal NEON Sampling Support Library. Mobile devices should be synced at the end of each field day, where possible; alternatively, devices should be synced immediately upon return to the Domain Support Facility.

However, given the potential for mobile devices to fail under field conditions, it is imperative that paper datasheets are always available to record data. Paper datasheets should be carried along with the mobile devices to sampling locations at all times. As a best practice, field data collected on paper datasheets should be digitally transcribed within 7 days of collection or the end of a sampling bout (where applicable). However, given logistical constraints, the maximum timeline for entering data is within 1 month of collection or the end of a sampling bout (where applicable). See RD[04] for complete instructions regarding manual data transcription.

E.1 Digital Data Workflow

The 'Manual for Fulcrum Application: TOS Vegetation Structure [PROD] – All SOPs' provides a detailed description and illustration of the workflow (RD[14]). A summary is provided here.

1. ***VST: Plot Meta-Data***
    a. Records created here inform which plots are subsequently available in all downstream apps for selection in **plotID** fields for the current bout.
    b. All growth forms measured in downstream applications must be documented here first.
2. ***VST: Mapping and Tagging***
    a. Records created here inform which **tagID**s are available for measurement in *VST: Apparent Individuals*.
    b. All **tagIDs** that will be measured must be entered here first.
    c. Published taxonID values for Apparent Individuals on the Data Portal are derived from this application.
    d. Verify mapping and tagging efforts immediately after field work is complete using the VST Mapper application.

3. ***VST: Apparent Individuals***
    a. Records created here rely on previously created **plotID** and **tagID** records in upstream applications – *VST: Plot Meta-Data* and *VST: Mapping and Tagging*, respectively.
4. ***VST: Shrub Groups***
    a. Records created here rely on previously created **plotID** records in the upstream *VST: Plot Meta-Data* application.
    b. The **groupID** does NOT need to be created first in *VST: Mapping and Tagging*.

E.2 Field Data Sheets

Paper data sheets for Vegetation Structure data collection may be used if the mobile application ingest platform is unavailable or compromised.

1. Transcribe data from the 'Plot Meta-Data' data sheet into the *VST: Plot Meta-Data [PROD]* app.
2. Transcribe data from the 'Mapping and Tagging' data sheet into the *VST: Mapping and Tagging [PROD]* app.
3. Transcribe data from the 'Apparent Individuals,' 'Other non-cactus,' and 'Cactus' data sheets into the *VST: Apparent Individuals [PROD]* app.
4. Transcribe data from the 'Shrub Groups' data sheet into the *VST: Shrub Groups [PROD]* app.

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APPENDIX A DATASHEETS

The following datasheets are associated with this protocol:

Table 20. Datasheets associated with this protocol

NEON Doc. #	Title
A.1 NEON.DOC.001573	A.2 Datasheets for TOS Protocol and Procedure: Measurement of Vegetation Structure

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

APPENDIX B QUICK REFERENCES

B.1 Quick Reference: Making Quality Measurements of Woody Vegetation Structure

Step 1 – Calibrate laser rangefinder compass.

Step 2 – Delineate measurement area.

Step 3 – Assess need for subplots (typically for new plots only).

Step 4 – Tag and identify species of each qualifying individual (new plots and as needed in existing plots). See summary tables on next page for location and method of tagging.

Step 5 – Record metadata on data sheets (Plot ID, Subplot # and nestedSubplotSize).

Step 6 – Take and record measurements

Step 7 – Remove temporary flagging.

For directions on using the laser rangefinder, see TOS Standard Operating Procedure: TruPulse Rangefinder Use and Calibration (RD[09]).

APPENDIX C REMINDERS

Making quality measurements of vegetation structure

Measurement Area: Make sure to know…

- ☑ Size of plot and subplots.
- ☑ Number of subplots in the plot.
- ☑ Size of nested subplots (if any) for plots previously measured.
- ☑ How to determine whether nested subplots are needed for new plots.

Taking Measurements: Remember to…

- ☑ Include stem in tally if > 50% of the individual (or > 50% of stems for multi-stemmed plants) are rooted in the measurement area.
- ☑ Use temporary flagging to distinguish measured and unmeasured stems.
- ☑ Carefully record all metadata, measurements, and observations on data sheet.
- ☑ Mark, map, and tag new individuals that meet minimum size cutoff.
- ☑ Identify previously tagged stems that have died since last measurement.
- ☑ Remove temporary flagging when measurements are completed

Using the laser rangefinder: Pay close attention to…

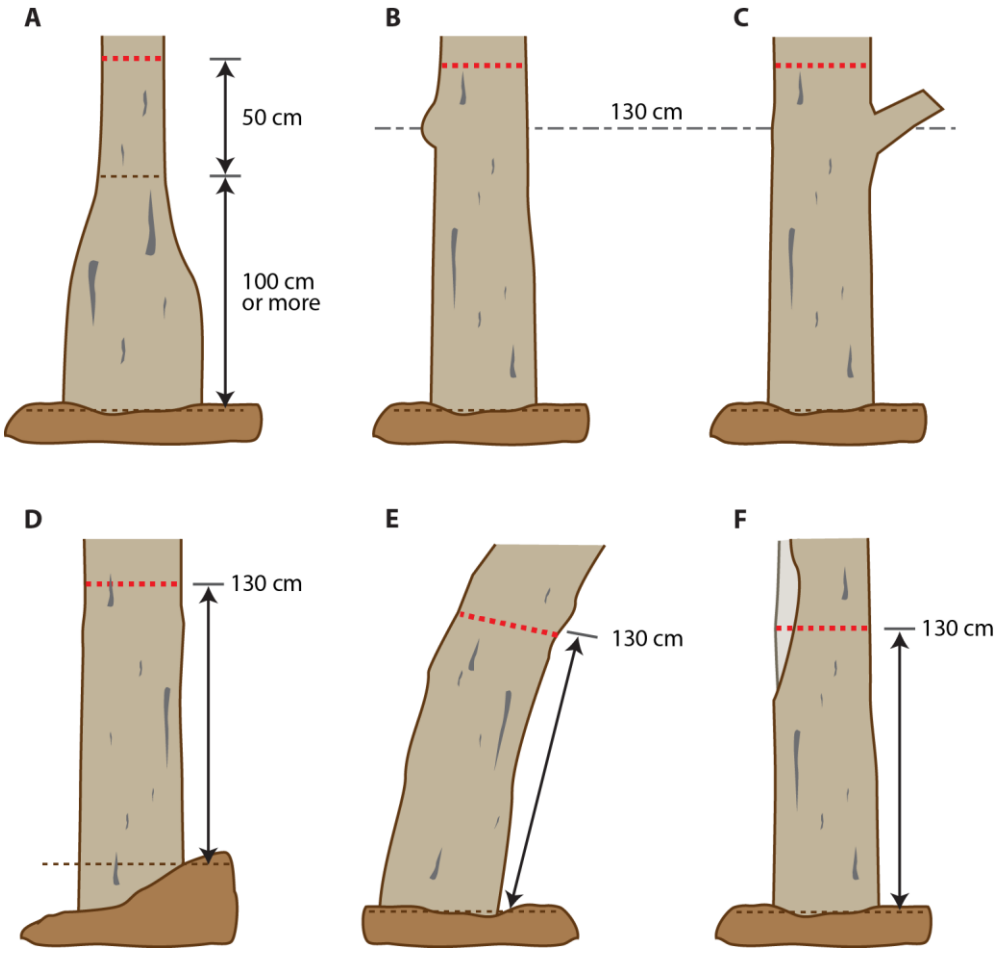
- ☑ Declination – Is it set for your current location?
- ☑ Selection choices in drop-down menu.
- ☑ Battery charge – Replace when low-charge indicated.
- ☑ Transcription of measurements onto data sheet.
- ☑ Metal objects – Keep them at least 2 feet away from instrument when using internal compass.

Directions for the laser rangefinder are in TOS Standard Operating Procedure: TruPulse Rangefinder Use and Calibration (RD[09]).

APPENDIX D WOODY STEM MEASUREMENT GUIDELINES

In the sections below, guidelines for tree measurement were adapted from the U.S. Forest Service Forest Inventory and Analysis National Core Field Guide (U.S. Forest Service 2012). The approach for measuring shrubs was developed in collaboration with researchers from the Smithsonian "Mega-Plot" network (SIGEO)(Lutz et al. 2014).

D.1 Irregular Boles



The lowest dashed line represents ground level from which the desired measurement height is referenced. The thick dashed red line shows the desired measurement height above ground level. Place tags 10 cm above the measurement height.

(A) ***Pronounced thickening near the base.*** If the point at which swelling returns to normal is ≥ 100 cm above the ground (top dashed line), **measurementHeight** for bole diameter is 50 cm above this point.

(B) ***Irregularities at breast height.*** If swelling, bumps, depressions or other irregularities occur at breast height, move the measurementHeight above the irregularity to a point where the bole becomes regular again.

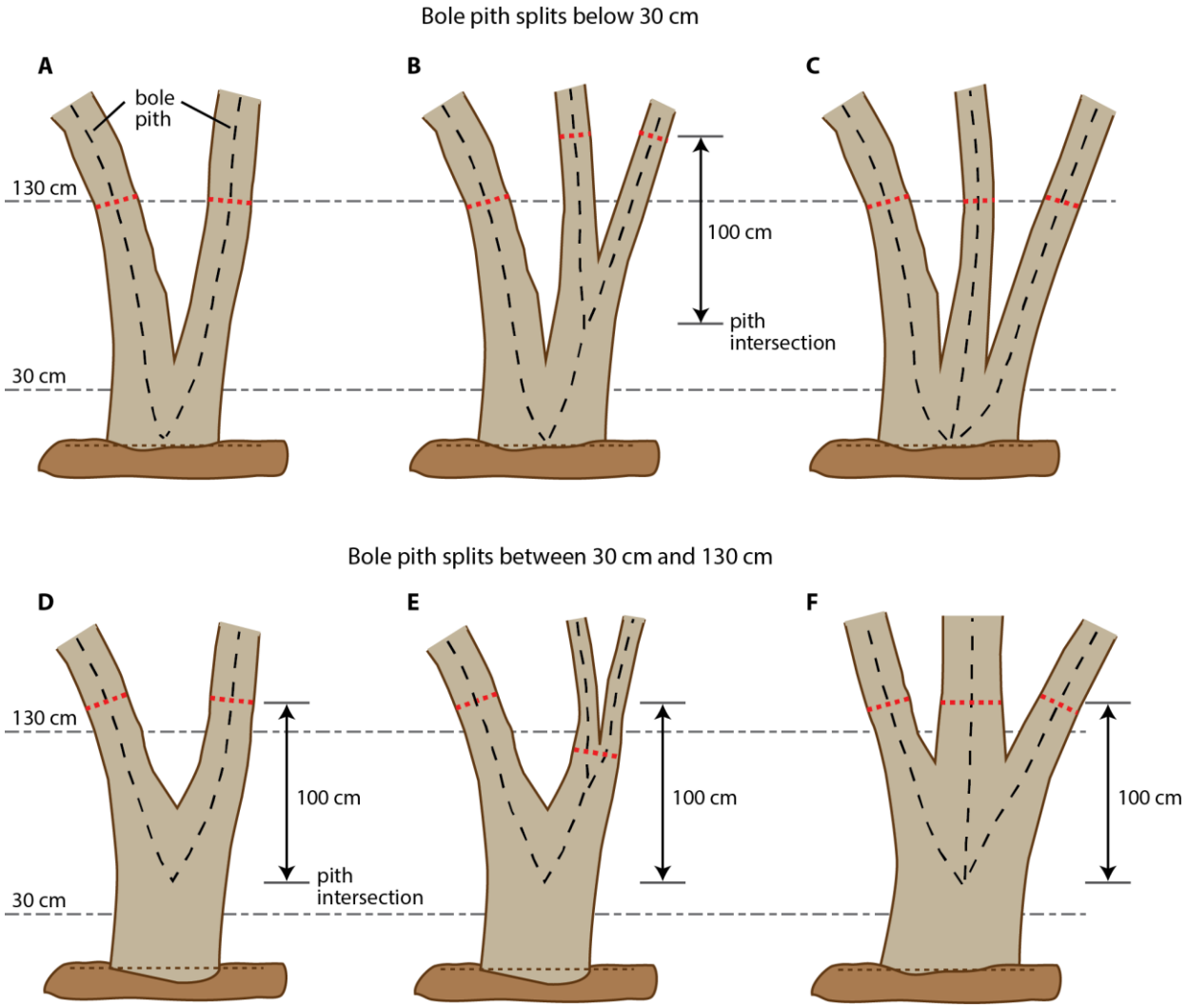
(C) ***Branches at breast height.*** Similar to **(B)**, move the measurementHeight above the branch to a point where the branch no longer affects bole diameter and the bole is "regular."

(D) ***Sloped ground.*** Consider ground level to be the uphill side of the bole, and measure DBH 130 cm above this point.

(E) ***Leaning tree.*** Measure diameter 130 cm along the bole on the underside face. If a tree grows on a slope and leans downhill, this rule is waived in favor of **(D)** above.

(F) ***Missing wood or bark.*** If a tree is missing substantial wood or bark at the desired measurementHeight (light grey indicates exposed wood and missing bark), do not attempt to reconstruct the diameter as it would appear without the damage. Measure the DBH of the wood and bark that is present. However, if the damage is localized, treat it as an irregularity, and measure as in **(B)**.

D.2 Multi-bole Individuals and Stem Diameter Measurement



In the figure above, all individuals are either 'mbt' or multi-bole 'smt' growthForms. Furthermore:

- The lowest, finely dashed line represents ground level from which the 30 cm and 130 cm reference heights are drawn (multi-dashed background lines).
- The thick dashed red line shows the desired measurement height above ground level.
- If the bole is not growing vertically, measure 130 cm along the bole, rather than 130 cm above ground. Diameter is measured perpendicular to the pith.
- Large dashed black lines indicate the pith of each bole.
- Tag 10 cm above the measurementHeight.
- To qualify as a split, or fork, the stem in question must be at least ⅓ the diameter of the main bole, and must branch out from the main bole at an angle of < 45˚.
    - ***Exception:*** Forks that are < 2.5 cm diameter are ignored and NOT measured, even if they meet the ⅓ diameter requirement. This exception holds for 'mbt' and multi-bole 'smt' individuals.
- Forks originate at the point on the bole at which the piths intersect.

(A) ***Simple split***. Piths intersect ≤ 30 cm above the ground. Measure stemDiameter on each bole 130 cm above the ground, or 130 cm along the stem if curved.

(B) ***Compound split.*** Primary piths intersect ≤ 30 cm above the ground. Because each of the two main boles are measured separately, stemDiameter on the left bole is measured 130 cm above the ground. However, the right bole forms a secondary split between 30 cm and 130 cm. Here, the stemDiameter of the secondary splits are measured 100 cm above the point of the secondary pith intersection.

In the event the pith intersection for the secondary fork on the right occurs close to 130 cm, the resulting desired measurement location may be out of reach for all but the tallest foresters. Adjust the measurementHeight downward, if necessary, to ensure that repeat measurements can be made by the average person. Repeatability through time is more important that reaching exactly 100 cm above the fork in the pith.

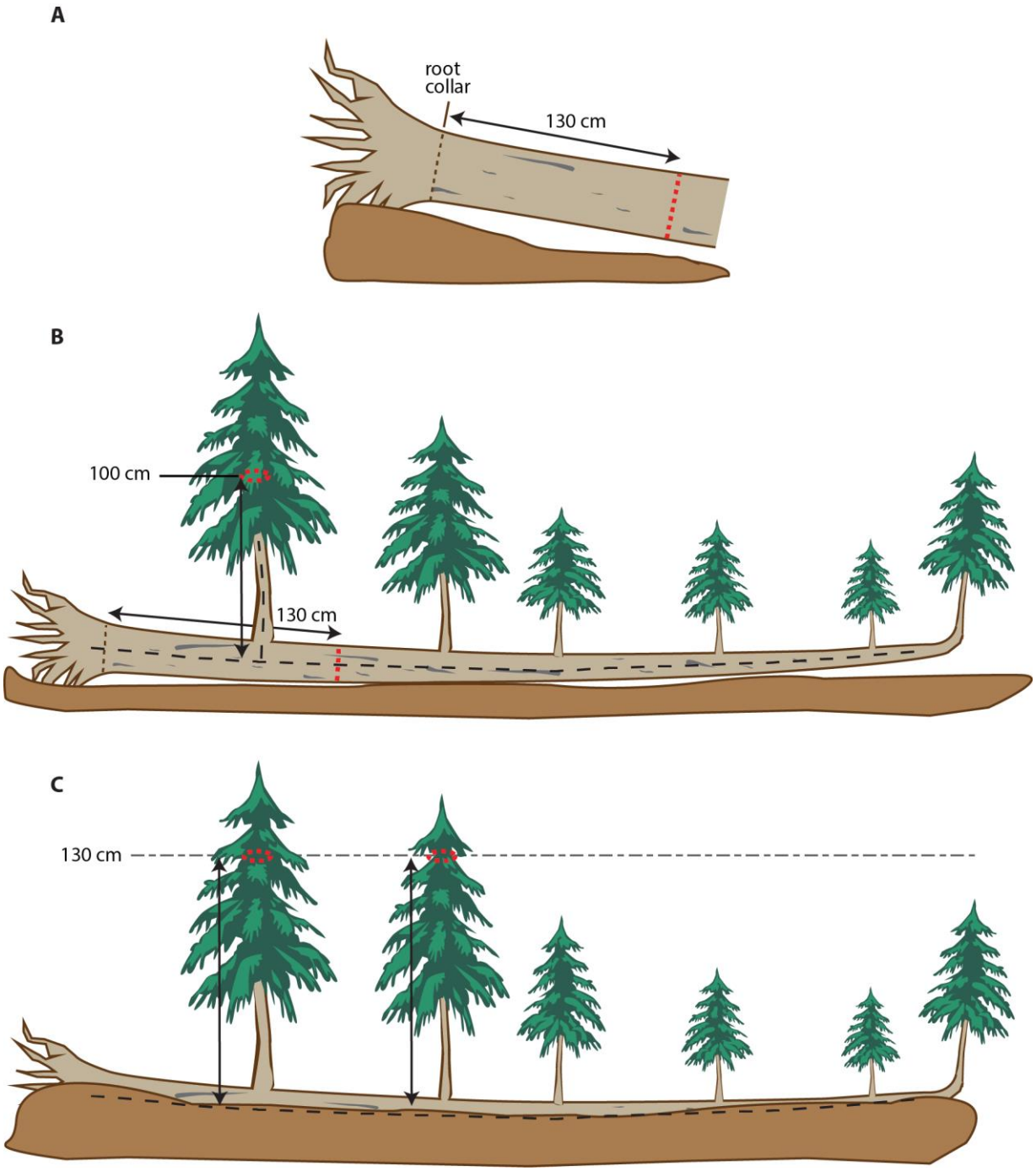
(C) ***Multiple boles.*** Multiple piths originate from the same point ≤ 30 cm above the ground. Measure stemDiameter on each bole 130 cm above the ground, or 130 cm along the stem if curved.

(D) ***Elevated simple split.*** Simple split with piths intersecting > 30 cm and ≤ 130 cm above the ground. Forks originating between 30 cm and 130 cm are measured 100 cm above the pith intersection point.

(E) ***Elevated compound split.*** Primary piths intersect > 30 cm and ≤ 130 cm above the ground. The left primary fork is assessed independently from the right one. On the left, stemDiameter is measured 100 cm above the primary pith intersection point. The right bole forms a secondary split between 30 cm and 130 cm; in this case, once a stem is tallied as a fork originating from a primary split between 30 cm and 130 cm, ignore any additional forks, and measure just below the base of stem separation. That is, do not measure stemDiameter the full 100 cm above the primary pith intersection point.

(F) ***Elevated multiple boles.*** Multiple piths originate from the same point > 30 cm and ≤ 130 cm above the ground. To qualify, multiple boles must originate from roughly the same point along the main bole. Each bole is assessed as an independent tree, and stemDiameter is measured 100 cm above the pith intersection point.

D.3 Live Downed Trees



(A) ***Live windthrown tree.*** Measure 130 cm along the bole from the top of the root collar. Tag 10 cm above the measurement location.

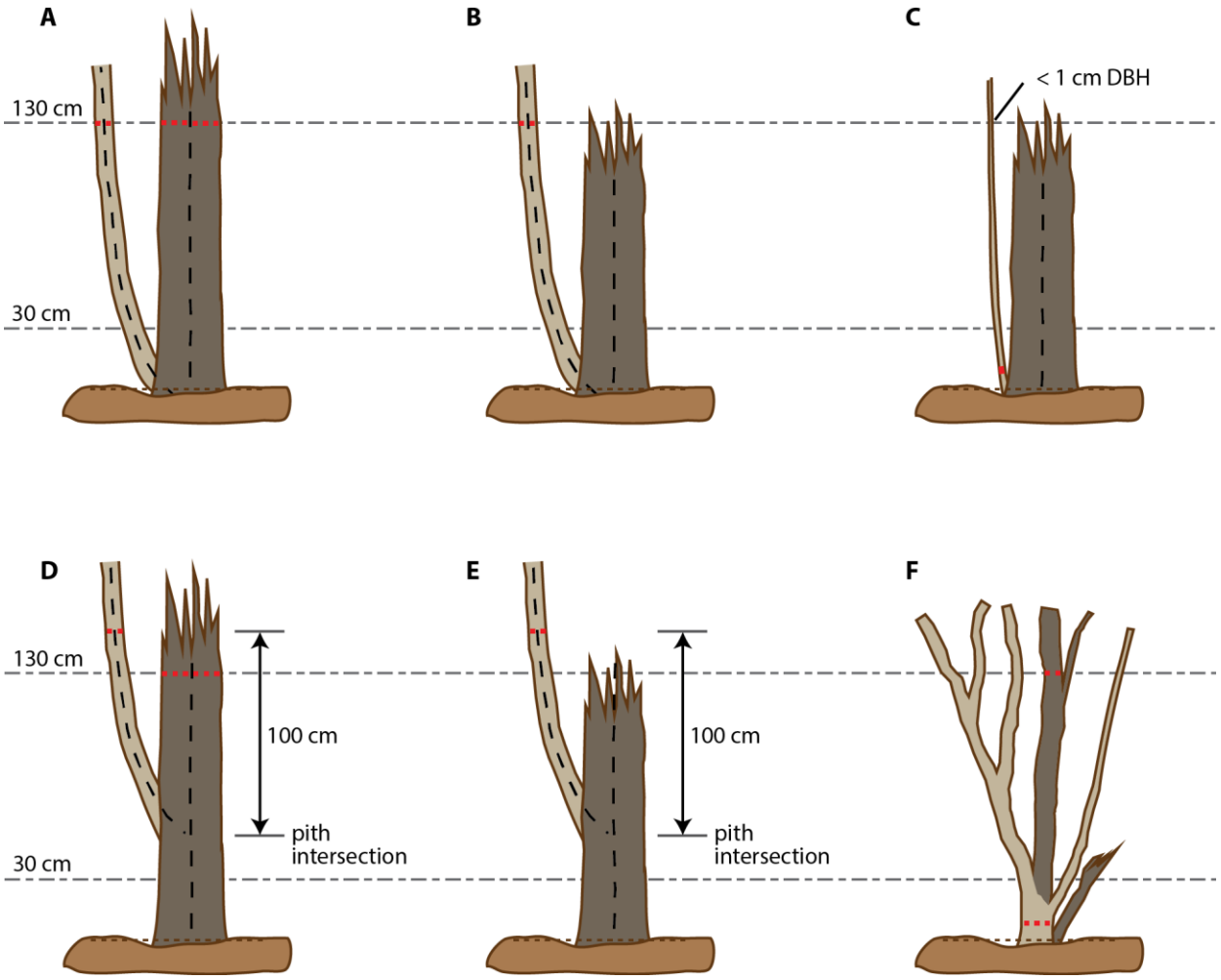
For **(B)** and **(C)**, consider a downed live tree, touching the ground, with tree-like branches that originate from the main bole, AND are less than 45˚ off the vertical. If the pith of the main bole

(black dashed line) is above the duff layer, assess according to **(B)**, and if the pith is below the duff layer, assess according to **(C)**.

(B) ***Pith above duff.*** Use the same forking rules specified for a forked tree, and measure and tag accordingly. If the intersection between the main downed bole and the tree-like branch is > 130 cm along the main bole, treat that branch as part of main bole – i.e., ignore it.

(C) ***Pith below duff.*** Ignore the main bole of the tree, and assess each tree-like branch individually to determine whether it qualifies for measurement. In the figure, the two left-most tree-like branches are ≥ 10 cm DBH, and are measured 130 cm above the ground (not necessarily equal to measuring from the top of the main downed bole). The other, smaller tree-like branches may qualify for measurement if they lie within the desired measurement area (i.e., nested subplot size).

D.4 Mixed Status Individuals



The figure above deals with trees **(A – E)** and shrubs **(F)** that have both living (light brown) and dead (dark brown) boles or portions of stems. The lowest, finely dashed line represents ground level from which the desired measurement height is referenced. The thick dashed red line shows the stemDiameter measurement location. For **(A – E):**

- Stump sprouts originate between ground level and 130 cm above the ground.
- Measure stump sprouts the required distance along the bole if it is growing off the vertical.
- Stump sprouts are handled the same as forked trees, with the exception that the diameter of the sprout is **NOT** required to be ⅓ the diameter of the main bole, and there is no 2.5 cm minimum diameter.
- For multi-stemmed woodland species, treat all new sprouts as part of the same new tree.

(A) ***Resprout with dead main bole that is > 130 cm height.*** The pith of the resprout intersects with the main dead bole somewhere below the ground. Growth form is a multi-bole tree (mbt). Similar to when both boles are alive, measure the diameter of each bole 130 cm

above the ground. For the dead bole on the right, measure the diameter of the break point as well as DBH, and also record the height of the break point.

(B) ***Resprout ≥ 1 cm DBH with dead main bole that is < 130 cm height.*** Measure the DBH of the resprout 130 cm above the ground, and ignore the dead main bole. The diameter of the resprout determines the growth form (sbt or smt); if growthForm = smt, only measure if the individual falls within the desired measurement area.

(C) ***Resprout < 1 cm DBH with dead main bole that is < 130 cm height.*** Measure the diameter of the resprout 10 cm above the ground (ddh), and ignore the dead main bole. The growthForm = sap, and the individual is only measured if it falls within the desired measurement area. If the main dead bole is > 130 cm height as in **(A)**, then measure the dead bole as in **(A)**.

(D) ***Resprout ≥ 1 cm DBH with pith intersecting that of the main bole between 30 cm – 130 cm above the ground.*** Growth form is a multi-bole tree (mbt). Similar to when both boles are alive, measure the diameter of the resprout 100 cm above the pith intersection point. Measure the dead bole as in **(A)**.

(E) ***Resprout ≥ 1 cm DBH with pith intersecting main dead bole ≥ 30 cm above the ground, and the latter is < 130 cm height.*** Measure the DBH of the resprout 100 cm above the pith intersection point, and ignore the main dead bole. The growthForm = sbt or smt.

(F) ***Shrub with plantStatus = dead for largest split, and broken dead stems.*** plantStatus = live for the entire individual, even though the largest split is dead. If the individual has multiple qualifying emergent stems > 130 cm height (or total length) with different status, DO record status separately for each emergent stem. Measure DBH at 130 cm on largest split, and measure ddh. Ignore broken dead emergent stems that are < 130 cm height (or total length if growing off the vertical).

D.5 Shrubs

The brown dashed line represents ground level. The thick dashed red line shows the desired stemDiameter measurement height above ground level. Simple dashed black lines represent stem piths. Light brown shows live tissue, and dark brown indicates dead.

(A) ***Simple shrub with unified base.*** Measure DBH at 130 cm (or along the pith for decumbent growth forms) on *the thickest fork only*, and measure diameter at decimeter height (ddh).

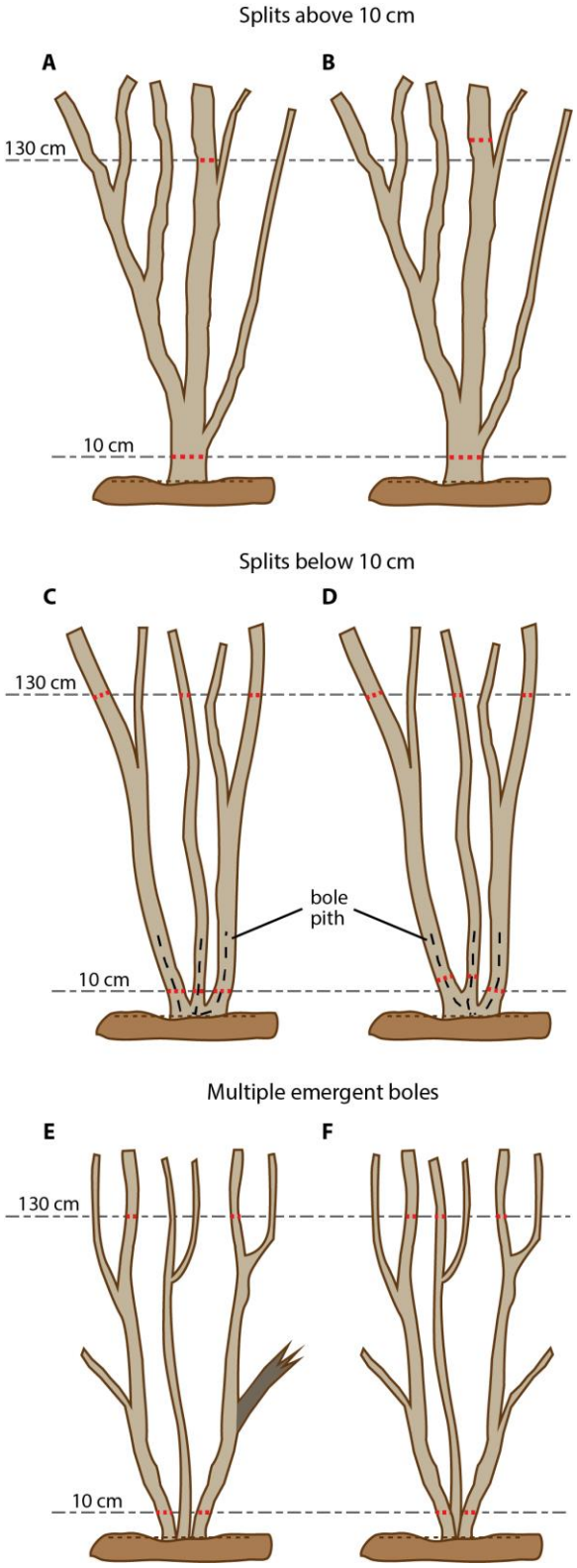
(B) ***Irregular at DBH.*** Similar to **(A)**, but with a branch point at 130 cm on the largest fork. Move the measurement height up on the largest fork so the DBH is not influenced by the branch.

(C) ***Multiple stems connected above ground.*** Piths intersect below 10 cm and originate from a visible root collar. Consider emergent stems separately for stemDiameter, and intact stems together for crown diameter(s). Measure DBH at 130 cm *on the thickest fork of each emergent stem,* and measure ddh for each emergent stem with qualifying DBH.

(D) ***Irregular at ddh.*** Similar to **(C)**, but the base of stem separation for the left two stems occurs right at 10 cm above ground. Because the piths intersect below 10 cm, the left two stems are still considered separately, but the stemDiameter is measured higher where the diameters are not affected by the fork.

(E) ***Multiple stems connected below ground.*** If stems emerge independently from a buried root collar, consider each emergent stem separately for stemDiameter. Measure DBH *on the thickest fork of each emergent stem at 130 cm height;* the thickest fork on the right stem is dead/broken and ignored because it does not reach 130 cm. Measure ddh for each emergent stem with qualifying DBH; center stem does not qualify for DBH and is not measured for ddh.

(F) ***Access denied.*** Similar to **(E)**, but middle stem now qualifies at DBH, and desired ddh measurement height is no longer accessible. For the middle stem, DBH is measured and ddh is not measured if a measurement location cannot be accessed within the first 30 cm along the stem.



D.6 Saplings and Small Shrubs

Saplings and small shrubs have no qualifying DBH. The brown dashed line represents ground level. The dashed red line shows the stemDiameter measurement height relative to ground. Light brown shows live, and dark brown indicates dead. For all cases, consider emergent stems separately for basal stem diameter measurements, and consider all intact stems together when measuring crown diameter(s).

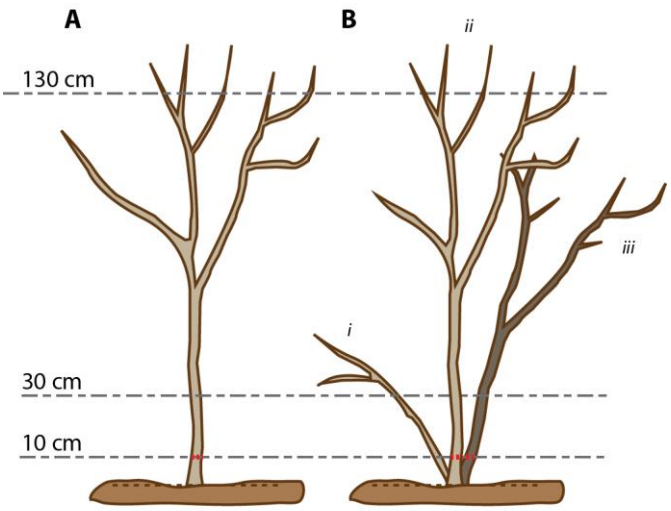
(A) ***Simple sapling or small shrub with unified base.*** Measure ddh 10 cm above the ground, or 10 cm along the stem for decumbent growth forms.

(B) ***Multiple intact stems connected below ground.*** *(i)* Ignored: ddh < 1 cm; *(ii)* Measure ddh, plantStatus = live; *(iii)* Measure ddh, plantStatus = dead.

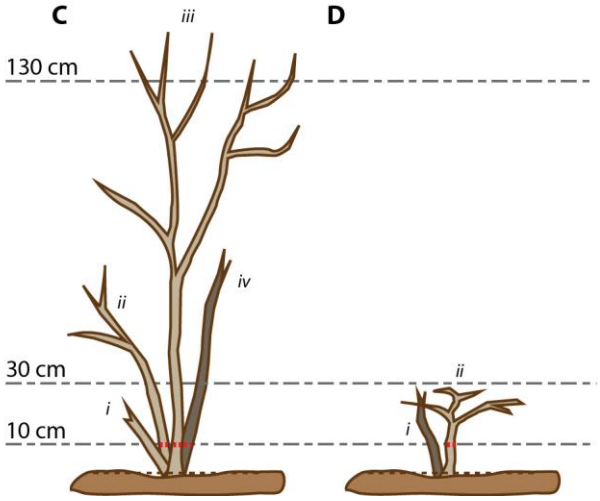
(C) ***Multiple intact and broken stems, connected below ground.*** *(i)* Ignored: ddh ≥ 1 cm, but broken, and total length < 30 cm; *(ii)* Measure ddh, plantStatus = live; *(iii)* Measure ddh, plantStatus = live; *(iv)* Measure ddh: broken, but total length ≥ 30 cm, plantStatus = 10 (dead, broken).

(D) **Mixed status dwarf small shrub.** *(i)* Ignored: ddh ≥ 1 cm, but broken, and total length < 30 cm; *(ii)* Measure ddh for live stems < 30 cm length if stem meets qualifying diameter and is not broken.

Intact Saplings and Small Shrubs



Broken Saplings and Small Shrubs



APPENDIX E LIANA MEASUREMENT GUIDELINES

The guidelines below ensure consistent measurement of complex liana growth forms (adapted from Schnitzer et al. 2008). Although originally conceived with respect to lianas, these guidelines should also be used to consistently determine the measurement location for other types of woody stems that are similarly complex.

Figure 6. Guidelines for determining where to measure liana stem diameter (red line) across a variety of complex growth forms. Different growth forms correspond to capital letters, and are described more fully below. Cases A-G (top panel) are commonly encountered, and cases H-R (bottom panel) are less common.

(A) Individuals that simply ascend into the canopy are measured 130 cm along the stem from the main rooting point.

(B) Twining individuals are measured 130 cm along the stem from the rooting point, including all twists and curves.

(C) Individuals that split below 130 cm from the rooting point are measured 20 cm below the branching point:

- **(1)** If the branch point is less than 40 cm from the ground, measure half-way between the branch point and the ground, where the stem is regular.
- **(2)** If the stem is not regular anywhere between the branch point and the ground, measure according to **(G)** below.

(D) Individuals that loop to the ground and root again before ascending to the canopy are measured 130 cm from the last rooting point.

(E) Like **(D)**, but the loops have branches that ascend to the canopy. Each rooted ascending stem with a leafy canopy branch is recorded separately as part of a multi-bole individual.

(F) Individuals with rooted adventitious roots further than 80 cm from the main rooting point are measured 50 cm past the last root.

(G) Individuals that branch below 130 cm, but have a very irregular main stem or branch close to the ground. Measure branches separately at 130 cm, and record as part of a multi-bole individual.

(H) Ignore branches < 1 cm diameter, and measure the principal stem 130 cm from the roots.

(I) Exclude individuals that branch below 130 cm from the roots if none of the stems are ≥ 1 cm diameter at 130 cm above the roots.

(J) Similar to **(G)** above.

(K) Multiple rooting points in a small area: Measure each branch ≥ 1 cm diameter 130 cm from the roots of the most proximal rooting point.

(L) Exclude "ground-to-ground" individuals that loop from one rooting point to another and do not ascend to the canopy. Also exclude those individuals that are prostrate on the soil, even if they are ≥ 1 cm in diameter.

(M) Include "ground-to-ground" individuals if they have a resprout or branch, even if the branch is < 1 cm diameter. If the branch is < 1 cm, measure the principal stem 130 cm from the roots, ignoring the branch. If the branch is ≥ 1 cm diameter, and within 130 cm of the roots, the point of measurement should be on the ascending branch.

(N) Exclude individuals growing prostrate on the soil if they do not have a stem ≥ 1 cm diameter ascending towards the canopy.

(O) Exclude multiple branches that originate within 130 cm of the main roots if they are smaller than 1 cm diameter.

(P) Measure 50 cm above the last aerial root if that root attaches to the principal stem > 80 cm above where the principal stem is rooted in the soil.

(Q) If the stem is anomalous and not uniform below 130 cm from the root, measure 20 cm above the point where it becomes uniform; if there is no uniform area within reach, measure the stem 130 cm from the roots.

(R) If the stem is flat and wide, include the individual if the mean of its wide and narrow axes is ≥ 1 cm diameter.

APPENDIX F GUIDELINES FOR MEASURING 'OTHER' VEGETATION

Growth Form	taxonID	leafNumber/ stemCount	maxCrown Diameter	ninetyCrown Diameter	height	stem Diameter	meanPetiole Length	meanBlade Length	meanLeaf Length	Reference
Ferns[1] (frn)	*Athyrium filix-femina*	leaf							x	Gholz et al. (1979)
	Blechnum spicant	leaf							x	Gholz et al. (1979)
	Dryopteris austriaca	leaf							x	Gholz et al. (1979)
	Polystichum munitum	leaf							x	Gholz et al. (1979)
	Pteridium aquilinum					basal[2]				Gholz et al. (1979)
Tree Ferns (tfn)	*Cibotium spp.*				x	DBH or basal				Ostertag et al. (2014) Selmants et al. (2014)
	Cyathea spp.				x	DBH or basal				Alves et al. (2010)
Palms (plm)	*Serenoa repens*		crown	crown	x		x	x		Gholz et al. (1999)
	Sabal etonia	leaf	crown	crown	x					Schafer and Mack (2014)
	Arecaceae spp. (i.e., tree palms)				x	DBH				Morel et al. (2011)
Fouquieria splendens – Ocotillo (oco)		stem	basal[3]	basal[3]	x					Bobich and Huxman (2009)
Xerophyllum tenax – Bear Grass (xer)						basal[2]			x	Gholz et al. (1979)
Yucca sp. (yuc) *Includes agave, other species with yucca-like, large basal rosette growth form*			crown	crown	x					

[1] Fern species not mentioned in this table should be measured similarly to *Athyrium filix-femina.* In order to qualify for measurement according to this protocol, ferns must have an average frond length ≥ 30 cm.

[2] basalStemDiameter for *Pteridium aquilinum* and 'xer' is measured at the surface of the litter layer (measurementHeight = 0)

[3] See the 'icn' shrubShape in for an illustration of the maxBaseCrownDiameter and ninetyBaseCrownDiameter measurement location.

APPENDIX G PLOT MAP

Plot pointIDs are numbered according to the largest possible plot size, 80 m x 80 m, such that a plot of any size will use a consistent numbering scheme. A pointID is defined for every point on a 10 m grid within this framework; this design is used in initial plot establishment, but permanent, primary, and secondary markers are placed at 20 meter intervals. During stem mapping, technicians will only use the points that have permanent markers in place. Plot subplotIDs are determined by the pointID of the SW corner of the subplot area. Plot center will always be pointID 41.

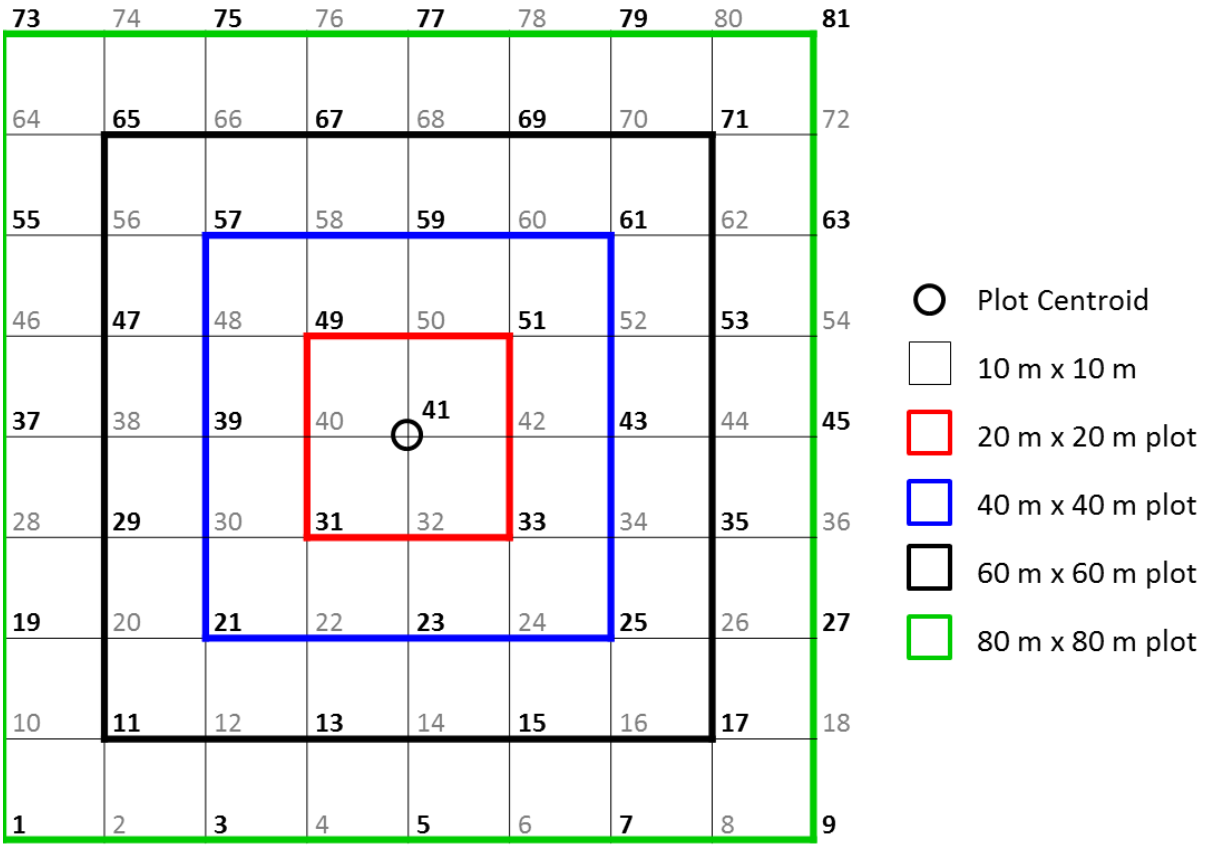


Figure 7. Plot map, illustrating how NEON base plots of various sizes are constructed from 10 m x 10 m 'modules.' The SW corner of each 'module' receives a pointID number; bold numbers indicate pointIDs that may receive physical markers and for which high-resolution GPS data may be collected.

APPENDIX H ESTIMATED DATES FOR ONSET AND CESSATION OF SAMPLING

The dates in **Table 21** below are based on historic records, and are therefore estimates for the average start and stop dates of sampling. It is essential that domain staff monitor real-time conditions to determine when to start (and stop) sampling, as described in Section 4 of this protocol.

> ***"Start Date" definition:*** Below, values in the "Start Date" field correspond to the average day of year at which greenness begins to decrease. Use these dates as a guide for when to begin monitoring for senescence. The goal is to begin vegetation structure sampling when approximately 50% of deciduous woody plants and/or herbaceous plants have begun to senesce.

"Start Date" and "End Date" fields are relevant to vegetation structure measurement windows in both Distributed and Tower plots, and represent the period of time during which vegetation photosynthetic activity is minimal following a growing season. The "Protocol Implementation" field indicates qualifying vegetation is present based on satellite imagery and on-the-ground feedback in a given plot type at the site level, and therefore the Vegetation Structure protocol should be implemented. If you feel this assessment is inaccurate for your site, please submit a problem ticket to Science Operations. It will not necessarily be possible to record vegetation structure data throughout the entire measurement window, due to snow, site access issues, etc. If provided measurement windows are not logistically feasible, changes to "Start Date" may be made in consultation with Science Operations.

All dates in **Table 21** are estimated from MODIS-EVI phenology data averaged from 2001-2009. Unless indicated otherwise, "End Date" values are in the next calendar year.

Table 21. Site-specific sampling start and end dates for vegetation structure measurements

Domain Number	Site ID	Start Date	End Date	Protocol Implementation by Plot Type	Remarks
01	BART	08/08	04/30	Dist = Yes Tower = Yes	Access problems may exist during proposed measurement window.
	HARV	08/08	04/20	Dist = Yes Tower = Yes	Access problems may exist during proposed measurement window.
02	BLAN	07/29	03/16	Dist = Yes Tower = Yes	
	SCBI	08/08	03/26	Dist = Yes Tower = Yes	
	SERC	08/08	03/21	Dist = Yes Tower = Yes	
03	DSNY	07/09	03/01	Dist = Yes Tower = No	
	JERC	08/08	03/31	Dist = Yes Tower = Yes	
	OSBS	07/09	03/11	Dist = Yes Tower = Yes	Not all Distributed plots may have qualifying stems.

Domain Number	Site ID	Start Date	End Date	Protocol Implementation by Plot Type	Remarks
04	GUAN	12/01	03/01	Dist = Yes Tower = Yes	Dates correspond to the dry season, and are derived from Ensenada precipitation data (1980-2015).
	LAJA	12/01	03/01	Dist = Yes Tower = Yes	Dates correspond to the dry season, and are derived from Ensenada precipitation data (1980-2015).
05	STEI	08/03	04/30	Dist = Yes Tower = Yes	Not all Tower plots may have qualifying stems.
	TREE	08/03	04/30	Dist = Yes Tower = Yes	
	UNDE	08/03	05/05	Dist = Yes Tower = Yes	
06	KONA	NA	NA	Dist = No Tower = No	
	KONZ	07/29	03/31	Dist = Yes Tower = Yes	Isolated stems may be encountered in Distributed plots.
	UKFS	07/29	03/16	Dist = Yes Tower = Yes	
07	GRSM	08/03	03/31	Dist = Yes Tower = Yes	
	MLBS	08/08	04/20	Dist = Yes Tower = Yes	
	ORNL	07/29	03/31	Dist = Yes Tower = Yes	
08	DELA	07/24	03/01	Dist = Yes Tower = Yes	
	LENO	07/19	03/11	Dist = Yes Tower = Yes	
	TALL	07/14	03/16	Dist = Yes Tower = Yes	
09	DCFS	07/24	04/30	Dist = Yes Tower = Yes	Isolated stems may be encountered in Distributed plots.
	NOGP	07/19	04/25	Dist = Yes Tower = No	Isolated stems may be encountered in Distributed plots.
	WOOD	07/29	04/30	Dist = Yes Tower = No	Isolated stems may be encountered in Distributed plots. Initial survey of Tower Plots → 6% woody veg cover; vst sampling not required.
10	CPER	07/29	03/31	Dist = Yes Tower = Yes	Isolated stems may be encountered in Distributed plots; Cactus SOP required for Tower Plots.

Domain Number	Site ID	Start Date	End Date	Protocol Implementation by Plot Type	Remarks
	RMNP	07/29	04/30	Dist = Yes Tower = Yes	
	STER	NA	NA	Dist = No Tower = No	
11	CLBJ	06/29	03/01	Dist = Yes Tower = Yes	MODIS-EVI may reflect herbaceous community rather than trees; adjust if necessary using on-the-ground observations.
	OAES	NA	NA	Dist = No Tower = No	
12	YELL	07/09	See Remarks	Dist = Yes Tower = Yes	For Tower Plots: Measurements must be completed before Bear Management closure.
13	MOAB	08/13	03/26	Dist = Yes Tower = Yes	Short shrubs, widely spaced; many may not be qualifying stems.
	NIWO	08/08	05/20	Dist = Yes Tower = Yes	Access problems may exist during proposed measurement window.
14	JORN	09/02	03/21	Dist = Yes Tower = Yes	
	SRER	08/28	05/31	Dist = Yes Tower = Yes	
15	ONAQ	06/19	03/16	Dist = Yes Tower = Yes	
16	ABBY	07/24	04/20	Dist = Yes Tower = Yes	Not all plots may have qualifying stems.
	WREF	07/29	04/25	Dist = Yes Tower = Yes	
17	SJER	07/01	04/30	Dist = Yes Tower = Yes	Tree senescence does not align with Mediterranean rainy season.
	SOAP	07/04	03/31	Dist = Yes Tower = Yes	
	TEAK	07/24	04/30	Dist = Yes Tower = Yes	Access problems may exist during proposed measurement window.
18	BARR	07/29	TBD	Dist = No Tower = No	Isolated qualifying stems may exist.
	TOOL	07/24	06/09	Dist = Yes Tower = No	Tower Plots: Abundant sub-shrubs that may qualify in future with climate change. Access problems may exist during proposed measurement window.
19	BONA	07/24	05/15	Dist = Yes Tower = Yes	Access problems may exist during proposed measurement window.

Domain Number	Site ID	Start Date	End Date	Protocol Implementation by Plot Type	Remarks
	DEJU	07/29	05/10	Dist = Yes Tower = Yes	Access problems may exist during proposed measurement window.
	HEAL	07/29	05/15	Dist = Yes Tower = Yes	Abundant shrub-scrub vegetation. Access problems may exist during proposed measurement window.
20	PUUM	Any	60 d after start	Dist = Yes Tower = Yes	Start Date should be consistent from year to year (± 2 weeks).

APPENDIX I SITE-SPECIFIC MODIFICATIONS

I.1 Continental Cold/Dry Sites

Site(s)	Modification Type	Modification	Standard Rule	Rationale for Change
YELL, NIWO, MOAB, SRER, JORN, ONAQ, SJER, SOAP, TEAK, WREF	Measure-ment frequency	Measure all Tower Plots on a 5 y interval.	Annual measurement of Tower Plots.	Growth rates are very slow at cold, dry sites, and annual changes in growth are too small to be detected with the standard tools NEON is using. In addition, at some sites, annual measurement results in unacceptably high disturbance to sensitive soils and biological soil crusts.

I.2 Domain 03

Site(s)	Modification Type	Modification	Standard Rule	Rationale for Change

I.3 Domain 04

Site(s)	Modification Type	Modification	Standard Rule	Rationale for Change
GUAN	Measure-ment frequency	Measure all Tower Plots on a 5 y interval; a subset of plots are measured annually: GUAN_042, GUAN_043, GUAN_044, GUAN_045, GUAN_046	Annual measurement of Tower Plots.	Measurement of all Tower Plots annually requires more resources than are available.

I.4 Domain 14

Site(s)	Modification Type	Modification	Standard Rule	Rationale for Change
SRER	Mapping guidelines	Map large-stature cacti.	Cacti are not mapped.	To speed locating individuals that require measurements, and to ensure data completeness.

I.5 Domains 18/19

Site(s)	Modification Type	Modification	Standard Rule	Rationale for Change
BONA, DEJU, HEAL, TOOL	**measure-mentHeight**	When thick bryophytes form the ground layer, the mean height of the bryophyte layer surrounding the base of the stem is used as the zero-point for determining **measurement Height**.	Mounded or heaped organic material around the base of a stem is removed, and the 'true' ground surface is exposed before determining **measurement Height**.	Bryophytes grow in a mounded, clustered manner around the base of stems, and often grow up stems 10 cm or more. It is destructive and not possible to remove bryophytes and uncover the 'true' surface of the ground because of the mat-like bryophyte growth form that slowly transitions to peat with depth. It is functionally consistent with other sites to consider the surface of the bryophyte layer the ground, and the zero-point for determining **measurementHeight**.
BARR, TOOL	Mapping requirements	Do not map 'sms' growth forms, mainly *Betula nana*, even if trees with DBH ≥ 10 cm are not present.	Map 'sis' and 'sms' if no trees with DBH ≥ 10 cm are present in the plot.	Mapping *B. nana* is not consistent with the goals of the Plant Productivity, Biomass, and Leaf Area Index Science Design.
BARR, HEAL, TOOL	Diameter cutoff	Reduce ddh cutoff from 1 cm to 0.7 cm.	For apparent individuals with no DBH, measure basal stem diameter for all individuals with ddh ≥ 1 cm.	The mean ddh of the dominant small shrubs at the site (*Betula nana*) is approximately 1 cm, with a significant number of individuals having ddh smaller than 1 cm. Using a 1 cm ddh cutoff at this site therefore arbitrarily splits the *B. nana* population such that roughly half is measured via the VST protocol, and half is measured via the HBP protocol. Reducing the ddh cutoff from 1 cm to 0.7 cm ensures that > 90% of the 'sms' individuals are measured with only the VST protocol.
BONA, DEJU, HEAL	Mapping requirements	Do not map 'sms' growth forms, mainly *Betula nana*, even if trees with DBH ≥ 10 cm are not present.	Map 'sis' and 'sms' if no trees with DBH ≥ 10 cm are present in the plot.	Black Spruce and White Spruce exist in most plots, but often do not reach DBH ≥ 10 cm, due to very slow growth rates at the latitude of these sites. Mapping Black/White Spruce is consistent with the goals of the Science Design, and mapping

Site(s)	Modification Type	Modification	Standard Rule	Rationale for Change
				B. nana is not.
BONA, DEJU, HEAL	Measure-ment frequency	*BONA*: Measure individuals every 6 y in all Distributed and Tower Plots. *DEJU, HEAL*: Measure every 6 y in all Distributed and Tower Plots, with bouts occurring a minimum of 3 times over the life of the site.	Annual measurement of apparent individuals in all Tower Plots, and every 3 y interval in Distributed Plots.	Growth rates are very slow at these cold, northerly sites, and annual changes in growth are too small to be detected with the standard tools NEON is using. Standard practice for DBH tapes/calipers, based on research experience at these sites, is to measure diameter every 5-6 y.