TOS PROTOCOL AND PROCEDURE: MEASUREMENT OF VEGETATION STRUCTURE

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See configuration management system for approval history.

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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 40m x 40m Tower plots.
F	02/25/2015	ECO-02537	Update of TOS protocol based on 2014 field experience and budget analysis.

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1 OVERVIEW

1.1 Background

The measurement of vegetation structure, as well as the mapping of free-standing woody stems, is an important complement to data streams generated by the NEON Airborne Observation Platform (AOP) and Terrestrial Instrument System (TIS). 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 carbon flux data, vegetation structure data will facilitate understanding how biomass in different plant growth forms contributes to ecosystem level carbon flux.

This protocol is designed to measure key aspects of vegetation structure that are directly comparable to airborne LiDAR observations, as well as additional structural metrics that enable estimation of per stem and per plot plant biomass and productivity. These measurements include: stem diameter(s), canopy diameter(s), stem height, stem location (for stems that meet certain criteria), stem species identification, and stem status (i.e. healthy, dead, or damaged).

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.

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.

2 RELATED DOCUMENTS AND ACRONYMS

2.1 Applicable Documents

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

AD[01]	NEON.DOC.004300	EHS Safety Policy and Program Manual
AD[02]	NEON.DOC.004316	Operations Field Safety and Security Plan
AD[03]	NEON.DOC.000724	Domain Chemical Hygiene Plan and Biosafety Manual
AD[04]	NEON.DOC.001155	NEON Training Plan
AD[05]	NEON.DOC.050005	Field Operations Job Instruction Training Plan
AD[06]	NEON.DOC.000914	NEON Science Design for Plant Biomass, Productivity, and Leaf Area Index
AD[07]	NEON.DOC.014051	Field Audit Plan
AD[08]	NEON.DOC.000824	Data and Data Product Quality Assurance and Control 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.005003	NEON Scientific Data Products Catalog
RD[04]	NEON.DOC.001271	TOS Protocol and Procedure: Manual Data Transcription
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

2.3 Acronyms

Acronym	Definition
DBH	Diameter at breast height; breast height = 130 cm above the ground
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 further defining trees, saplings and shrubs is available in AD[06]. Parenthesis following the terms in the list below indicate the 3-letter code used for classifying particular defined growth forms.

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, tends toward the canopy, and supports lateral branches. An individual may be considered to have >1 bole if the split occurs below 130 cm from the ground – i.e., the split is below breast height.

Lianas (lia): Non-self-supporting woody stems with DBH ≥ 1 cm. Lianas are not mapped, but the ID number of the tagged, mapped support tree is recorded (if rooted in the plot) during the data collection process.

Multi-bole Tree (mbt): A self-supporting individual with multiple boles ≥ 10 cm diameter at breast height.

Overstory: The overstory is typically formed by the tallest individuals in the plot, and we often wish to map overstory individuals visible to AOP remote sensing instruments. In a closed canopy forest, the overstory is clearly comprised of those tall trees that make up the canopy, and these individuals are mapped, while shorter shrubs in the understory are not mapped. In the Great Basin, it is possible for shrubs like *Artemisia tridentata* to make up the overstory in plots lacking trees, and here, these shrubs ARE mapped. Savannah ecosystems are a mixture of the previous two examples, with trees forming the overstory in some parts of the plot and shrubs/herbaceous plants forming the "overstory" in other parts of the plot. However, for simplicity we only consider individuals with DBH ≥ 10 cm to be the overstory in savannah-like plots: even though individuals with DBH < 10 cm may be visible to remote-sensing instruments throughout much of the plot, these individuals with DBH < 10 cm are NOT mapped if individuals with DBH ≥ 10 cm form an overstory in any part of the plot.

Primary stem: A stem that supports smaller stems, 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 criteria for a given growth form.

Sapling (sap): A self-supporting individual with a single primary stem; diameter at breast height is < 1 cm or total height is < 130 cm, and diameter 10 cm above the ground (ddh) is ≥ 1 cm.

Shrub Group: Shrub Groups are defined as two or more individuals in contact, such that it is difficult 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 are mapped as polygons.

Single Shrub (sis): A self-supporting individual with multiple primary stems; diameter of more than one stem at breast height meet the criteria 1 cm ≤ DBH < 10 cm.

Single-bole Tree (sbt): A self-supporting individual with a single bole ≥ 10 cm diameter at breast height.

Small Shrub (sms): A self-supporting individual with multiple primary stems; diameter of all stems at breast height is < 1 cm or total height is < 130 cm. Diameter 10 cm above the ground (ddh) of at least one stem is ≥ 1 cm. Individuals with no stems ≥ 1 cm ddh are not measured with this protocol, and will be measured as part of the herbaceous plant sampling effort.

Small Tree (smt): A self-supporting individual with a single primary stem; diameter at breast height meets the criteria 1 cm ≤ DBH < 10 cm.

Understory: Small-stature vegetation, either woody stemmed or herbaceous, that exists in the presence of an overstory.

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

A combination of NEON Distributed, Gradient, and Tower Plots will be used for collecting vegetation structure data (Figure 1 and Figure 2). These ground datasets will enable calibration and validation of annually generated LiDAR datasets, and in conjunction with the AOP data, will form the basis for LiDAR-derived data products at the site and regional scales (e.g. site and regional LAI and plant biomass estimates).

In forested systems, vegetation structure data collected in the Tower Plots will constitute an important component of biomass and productivity estimation within the NEON Tower footprint, and will allow researchers to understand how tower-based NEE and NEP measurements correspond with field-based assessment of NPP. Because field-collected vegetation structure data are integrated with other measurement platforms (i.e. the NEON AOP and TIS), it is very important that the mapping and measurement of woody stems is performed with care, and in a repeatable fashion.

This field procedure is designed to generate data that elucidate the structure, spatial location, and biomass of the woody-stemmed plant community, including tree, sapling/shrub, liana, and other growth forms. Stem mapping activities and the collection of vegetation structure data will take place in Distributed and Tower Plots, and may also take place in Gradient Plots if Gradient Plots are required at a given site. If required, Gradient Plot sampling will not take place until the field season after the first AOP overflight of a site has occurred. The procedure provides detailed guidelines for measuring the following key parameters: diameter at breast height (DBH), diameter at decimeter height (ddh), total stem height, canopy diameter, species ID, stem status (i.e. healthy, snag, damaged, etc.), and the location of measured stems. Parameters such as DBH, ddh, canopy diameter and total stem height can then be used to estimate aboveground biomass and carbon (C) density values, on both a per stem and a per unit area basis.

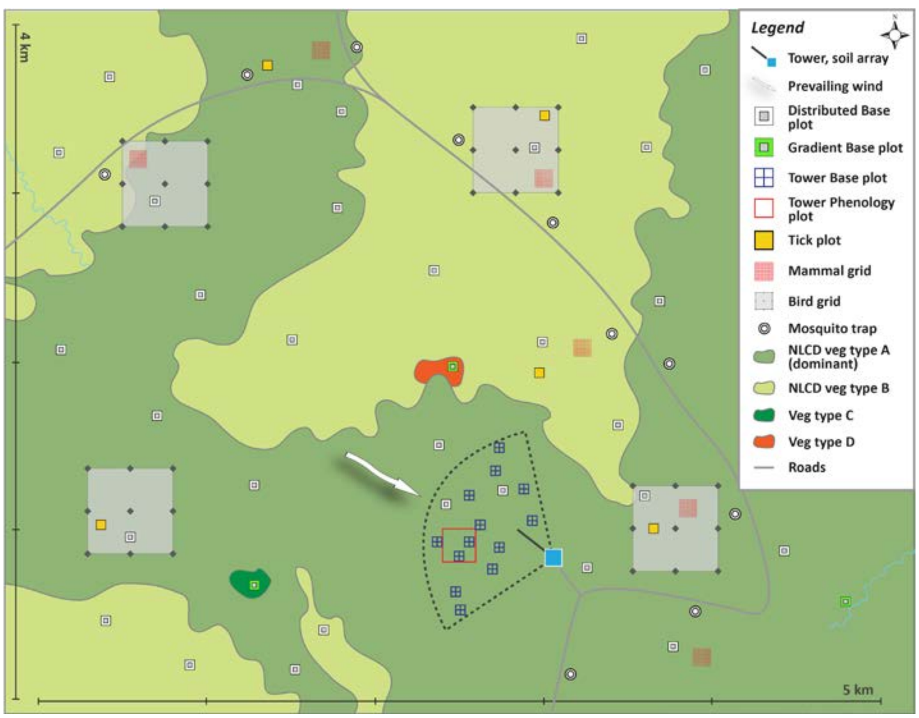


Figure 1. Generalized TOS sampling schematic, showing the placement of Distributed, Tower, and Gradient Plots

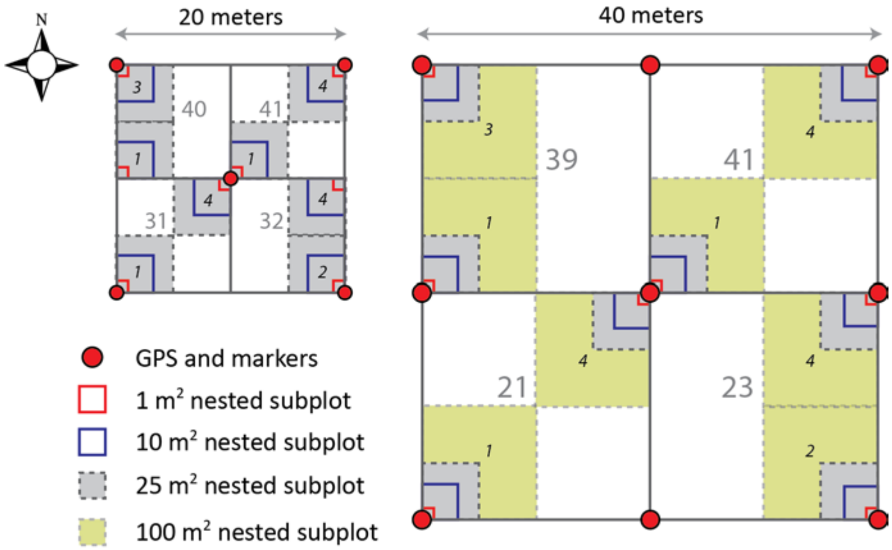


Figure 2. Illustration of a 20 m × 20 m base plot (left; larger destructive sampling portion of the plot not shown), a 40 m × 40 m base plot (right), and associated nested subplots used for measuring woody stem vegetation. The 20m x 20m plot size may be used for either Distributed or Tower plots, and 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 F.

Additional data will be collected from herbaceous plants, as described in RD[06] and RD[07]. All of the data collected according to this Vegetation Structure protocol are acquired with hand-held tools in the field, and there is no laboratory component to the work.

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 JIRA 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 JIRA problem tracking system.

The procedures described in this protocol will be audited according to the Field Audit Plan (AD[07]). Additional quality assurance will be performed on data collected via these procedures according to the NEON Data and Data Product Quality Assurance and Control Plan (AD[08]).

4 SAMPLING SCHEDULE

4.1 Sampling Frequency and Timing

Frequency: At each site, the sampling frequency for trees, saplings/shrubs, lianas, and 'other' growth forms depends on plot type:

- Distributed plots: 1X per year, 3-year sampling interval (i.e. 1 site per domain per year)
- Tower plots: 1X per year, annual sampling interval

Timing: Estimated sampling windows, including estimated sampling onset and cessation dates, are provided on a per site basis in Appendix G. 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 vegetation phenophase. Measurement of woody stemmed individuals (i.e. trees, shrubs, lianas) should ideally be coincident with measurement of species classified as 'other' (i.e. ferns, cacti). To enable a single sampling effort per year for vegetation structure work, ferns do not need to be measured at peak greenness. They do need to be measured before leaves and stems begin to break apart for those species, like Bracken Fern (*Pteridium aquilinum*), that senesce aboveground completely every yearannually. Additionally, ferns do not need to be measured at Distributed plots unless they constitute 50% or more of the total plot area as viewed by the Airborne Observation Platform (these are the same guidelines that trigger implementation of the herbaceous clip harvest protocol in Distributed plots).

4.2 Criteria for Determining Onset and Cessation of Sampling

Sampling onset: The onset of sampling should coincide with the end-of-growing-season onset of the senescence phenophase for deciduous and herbaceous plants. The guiding principle is that vegetation structure measurements should begin after the majority of annual growth in a given growing season has completed.

- For systems dominated by evergreen trees and shrubs, begin sampling when herbaceous plants begin to senesce.
- Approximately 50% of deciduous or herbaceous vegetation should have begun senescing before Vegetation Structure sampling begins.
- Use the dates in Appendix G as a guide for when to begin monitoring the vegetation for senescence, but bear in mind that individual years may deviate significantly from the average dates provided.
- At sites with pronounced wet/dry seasonality – e.g., D17 San Joaquin – structural measurements should begin once the dry season has begun and growth rates are minimal.

- 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 before the onset of the next growing season, i.e. before bud break.

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

4.3 Sampling Timing Contingencies

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

Table 1. 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 sub-plot 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 or more 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.

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. As with any laser device, however, reasonable precautions should be taken in its operation. It is recommended that you avoid staring into the transmit aperture while firing the laser.
- Never attempt to view the sun through the scope. Looking at the sun through the scope may permanently damage the eyes.

6 PERSONNEL AND EQUIPMENT

A team 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. 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 2. Equipment list – Preparing for Sampling

Item No.	R/S	Description	Purpose	Quantity*	Special Handling
Durable Items					
MX100703	R	GPS receiver, recreational accuracy	Navigate to sampling location	1	N
MX100322	R	Laser Rangefinder, ½ foot accuracy	Map stems; measure stem height and canopy diameters. Mapping; measuring stems > 2 m height	1	N
	R	USB Cable	Transfer data to GPS unit.	1	N
Consumable items					
MX103942	R	All weather copy paper	Print datasheets	As needed	N

R/S=Required/Suggested

Table 3. Equipment list – Mapping and Tagging

Item No.	R/S	Description	Purpose	Quantity*	Special Handling
Durable Items					
MX103214	S	Cardboard ventilator	Press collected individuals for identification		N
MX104361	R	Chaining pins or other suitable anchor	Anchor measuring tapes	4	N
MX100320	S	Compass with mirror and declination adjustment	Determine nested subplot boundary	1	N
	S	Cooler	Chill perishable samples in field	1	N
MX106349	R	DBH tape, 200 cm	Measure stem diameter. Stems present with diameter > 64 cm	1	N
MX106348	R	DBH tape, 64 cm	Measure stem diameter. Stems present with 5 cm < diameter < 64 cm	1	N
	S	Field guide, regional flora reference guide and/or key	Identify unknown species	1	N
MX103218	R	Foliage filter	Allow laser rangefinder use in dense vegetation	1	N
MX100703	S	GPS receiver, recreational accuracy	Navigate to sampling location	1	N

Item No.	R/S	Description	Purpose	Quantity*	Special Handling
	R	Hammer	Label blank tags	1	N
MX103480	R	Hand stamp steel die set	Label blank tags	1 set	N
	R	Handheld caliper, 0.1 cm precision	Measure stem diameter < 5 cm; lianas prevent accurate diameter measurement with tape	1	N
MX100358	S	Ice pack	Chill perishable samples in field	As needed	N
MX100322	S	Laser Rangefinder, ½ foot accuracy	Determine nested subplot boundary; map stems; measure stem height and canopy diameter. Individuals with relatively large canopies; plots with slopes > 20%	1	N
MX104369	R	Measuring tape, minimum 50 m	Determine nested subplot, subplot boundary	2	N
MX100312	S	Paper blotters	Press collected individuals for identification	As needed	N
MX100316	S	Plant press	Press collected individuals for identification	As needed	N
MX104381	S	Tripod , non-magnetic	Hold laser rangefinder directly over plot marker	1	N
MX104359	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

Item No.	R/S	Description	Purpose	Quantity*	Special Handling
Consumable items					
	R	AA battery	Spare battery for GPS receiver	4	N
MX103224	R	Aluminum nail	Affix tag to stems with DBH ≥ 5 cm	As needed	N
MX107336	R	Aluminum wire, 20 gauge	Affix tag to stems with DBH ≥ 5 cm	1 spool	N
	R	CR123A battery	Spare battery for laser rangefinder	2	N
MX103940	S	Flagging tape	Temporarily mark stems after measurement	2	N
MX104546	R	Fluorescent lumber crayon	Mark DBH measurement location on stem	1	N
MX100592	S	Resealable plastic bag, 1 gal	Collect voucher specimens	20	N
MX103478	R	Round numbered aluminum tag, silver; 0001-6000 and 8001-9999	Tag qualifying stems	As needed	N
MX103481	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

Item No.	R/S	Description	Purpose	Quantity*	Special Handling
Resources					
	R	Field datasheet	Record data		N

R/S=Required/Suggested

Table 4. Equipment list – Biomass/productivity measurements*

Item No.	R/S	Description	Purpose	Quantity*	Special Handling
Durable Items					
MX103214	S	Cardboard ventilator	Press collected individuals for identification		
MX104361	R	Chaining pins or other suitable anchor	Anchor measuring tapes	4	N
	S	Cooler	Chill perishable samples in field	1	N
MX106349	R	DBH tape, 200 cm	Measure stem diameter. Stems present with diameter > 64 cm	1	N
MX106348	R	DBH tape, 64 cm	Measure stem diameter. Stems present with 5 cm < diameter < 64 cm	1	N

Item No.	R/S	Description	Purpose	Quantity*	Special Handling
	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
	S	Field guide, regional flora reference guide and/or key	Identify unknown species	1	N
MX103218	R	Foliage filter	Allow laser rangefinder use in dense vegetation	1	N
MX100703	S	GPS receiver, recreational accuracy	Navigate to sampling location	1	N
	R	Hammer	Label blank tags	1	N
MX103480	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
MX100358	S	Ice pack	Chill perishable samples in field	As needed	N
MX100322	R	Laser Rangefinder, ½ foot accuracy	Map stems recruited into the minimum size class; measure stem height, canopy diameter. Brushy; trees with relatively large canopy diameters; slopes ≥ 20%	1	N
MX105823	R	Measuring stick, 2 m folding	Measure heights of small-stature woody vegetation	1	N

Item No.	R/S	Description	Purpose	Quantity*	Special Handling
MX104369	R	Measuring tape, minimum 50 m	Determine nested subplot, subplot boundary	2	N
MX100312	S	Paper blotters	Press collected individuals for identification	As needed	N
MX100316	S	Plant press	Press collected individuals for identification	1	N
MX104359	S	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
Consumable items					
	S	AA battery	Spare battery for GPS receiver		N
MX103224	R	Aluminum nail	Affix tag to stems with DBH ≥ 5 cm	As needed	N
MX107336	R	Aluminum wire, 20 gauge	Affix tag to stems with DBH ≥ 5 cm	1 spool	N
	R	CR123A battery	Spare battery for laser rangefinder	2	N
MX103940	S	Flagging tape	Temporarily mark stems after measurement	2	N
MX104546	R	Fluorescent lumber crayon	Mark DBH measurement location on stem	1	N
	S	Graph paper	Estimate area of shrub groups	As needed	N

Item No.	R/S	Description	Purpose	Quantity*	Special Handling
MX103478 MX103477 MX103479 MX108192 MX108193 MX108194 MX108197 MX108198	R	Round numbered aluminum tag, silver; 0001-6000 and 8001-9999	Tag new qualifying stems	As needed	N
MX103481	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
	R	QA/QC 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 5. Equipment and materials required for a team of two to minimize exposure to toxic oils from *Toxicodendron spp.*

Item No.	R/S	Description	Purpose	Quantity*	Special Handling
Durable Items					
	S	Haglof Mantax Black calipers, 95 cm	Measure supporting stem diameters up to 95 cm when Toxicodendron are attached; labeled for use with toxicodendrons to minimize spread of oils to other equipment. Accurate enough to also measure Toxicodenron diameter.	1	N
	S	Haglof Mantax Black calipers, 50 cm	Measure supporting stem diameters up to 50 cm when Toxicodendron are attached; labeled for use with toxicodendrons to minimize spread of oils to other equipment.	1	N
	R	Handheld caliper, 0.1 cm precision	Labeled for use with toxicodendrons to minimize spread of oils to other equipment	1	N
	R	Pruning shear	Labeled for use with toxicodendrons to minimize spread of oils to other equipment. Used to gain access to woody stems surrounded by Toxicodendron.	1	N

Item No.	R/S	Description	Purpose	Quantity*	Special Handling
Consumable items					
MX107108	R	Cleanser, urushiol-specific, Tecnu or equivalent	Clean equipment after use with Toxicodendrons	1	N
	R	Nitrile gloves, powderless	Prevent oil contact with skin	Box of 12	N
	R	PPE outer-wear	Prevent oil contact with skin, normal clothing	Case of 24	N
	R	Trash bag	Dispose of used gloves and PPE to minimize toxic oil transfer	Box	N

R/S=Required/Suggested

6.2 Training Requirements

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

Technicians must be trained in the proper care of the laser rangefinder. 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.

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 regionally-specific 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 timeframe provided below is an estimate based on completion of a task by a skilled two-person team (i.e., not the time it takes at the beginning of the field season). Use this estimate as framework for assessing progress. If a task is taking significantly longer than the estimated time, a problem ticket should be submitted.

An experienced two-person team may complete mapping and tagging of woody stems in 6-12 hours per plot. Annual measurement of large stems and other woody vegetation components within a forested 40 m x 40 m Tower plot may require up to 16 hours to complete. 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:

- Decision tree for defining vegetation classifications based on morphology
- Summary table of which vegetation structure measurements are required for each vegetation class
- Instructions for mapping individuals relative to plot markers, and details for how to tag mapped trees, shrubs and lianas.

SOP C: Measuring Vegetation Structure in the Field. The procedures for making vegetation structure measurements are described in detail.

SOP D: Field Campaign Follow-up. Describes steps necessary to complete data transcription and replenishment of field supplies.

SOP A Preparing for Sampling

A.1 Office tasks

1. Transfer all required files containing plot marker locations to the recreational accuracy handheld GPS receiver.

A.2 Checking the TruPulse 360R laser rangefinder

1. 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.
2. Declination changes with time at each site, and should be looked up annually at http://www.ngdc.noaa.gov/geomag-web/
3. *TruPulse Declination Offset.* Check the current declination against what is entered in the TruPulse. See RD[09] for details.
4. *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. See RD[09] for details.
5. *Compass Calibration.* The compass should be calibrated after the batteries are changed. Be aware that interference from local magnetic fields can prevent accurate calibration, and can cause the calibration routine to fail.

SOP B Classification, Mapping, and Tagging

Mapping and tagging of qualifying individuals occurs in both Distributed and Tower plots.

- In 20m x 20m Distributed and Tower plots, the entire plot is assessed for qualifying individuals.
- In 40m x 40m Tower plots, two randomly selected 20m x 20m subplots are assessed for qualifying individuals. Lists of randomly selected subplots are provided by Science Operations. No mapping or measurements will take place in those 20m x 20m subplots that are **not** selected, including for trees with DBH ≥ 10cm.

B.1 Defining Vegetation Classification

Assess each individual separately; growth form is not tied to species for this protocol:

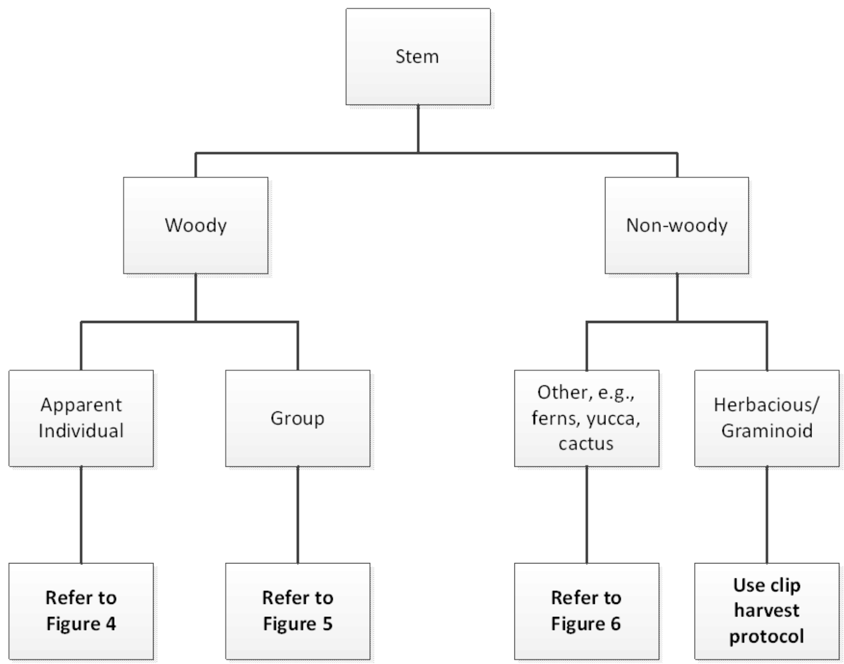


Figure 3. Decision tree for defining growth forms. Apparent Individual, Group and Other decision trees are detailed in Figures 4-6.

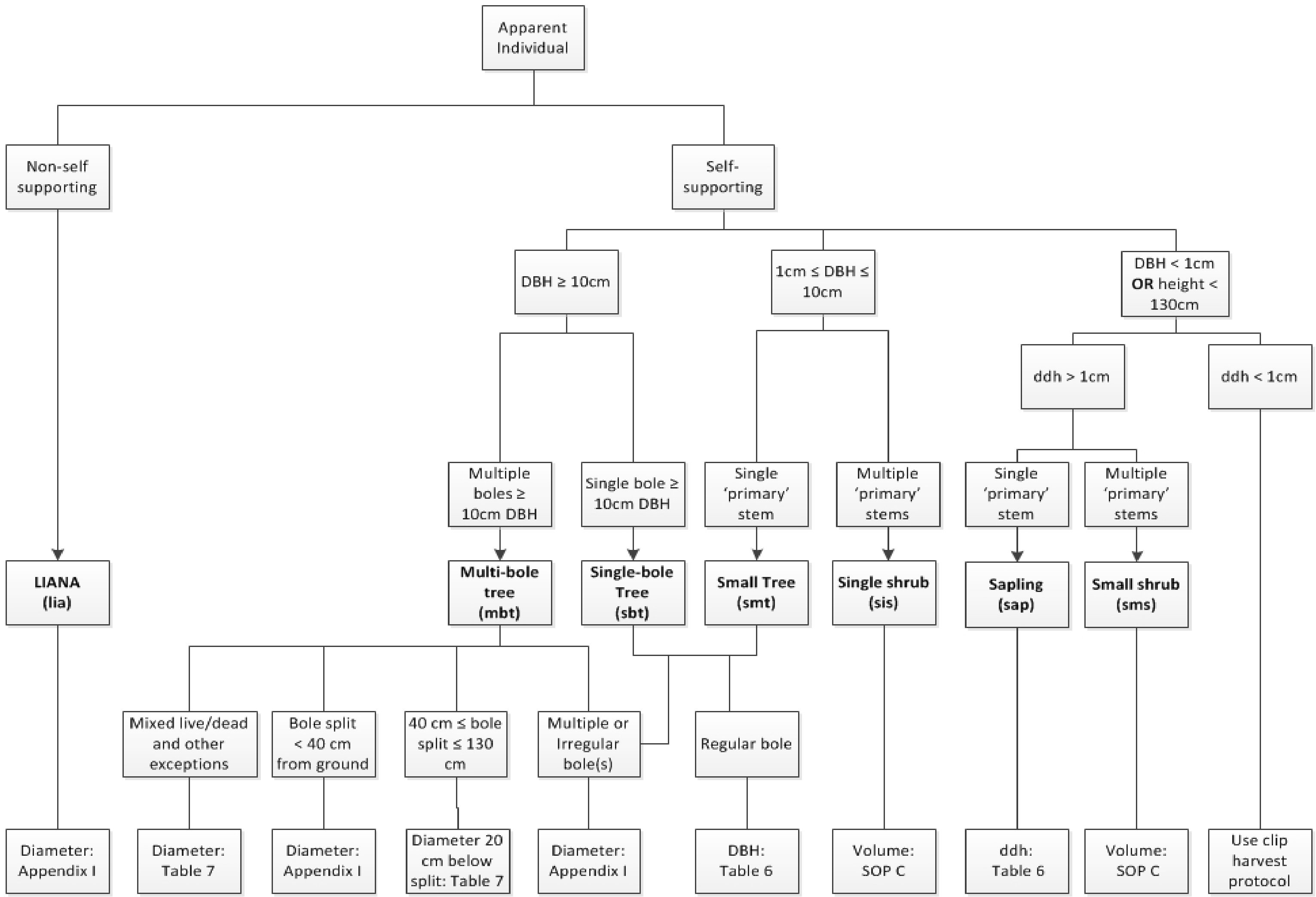


Figure 4. Decision tree for defining growth forms for apparent individuals. Note: Individuals may change classification from one year to the next, for example due to a gain of qualifying stems, an individual may move from "small tree" to "single shrub". Growth form classification is not tied to species.

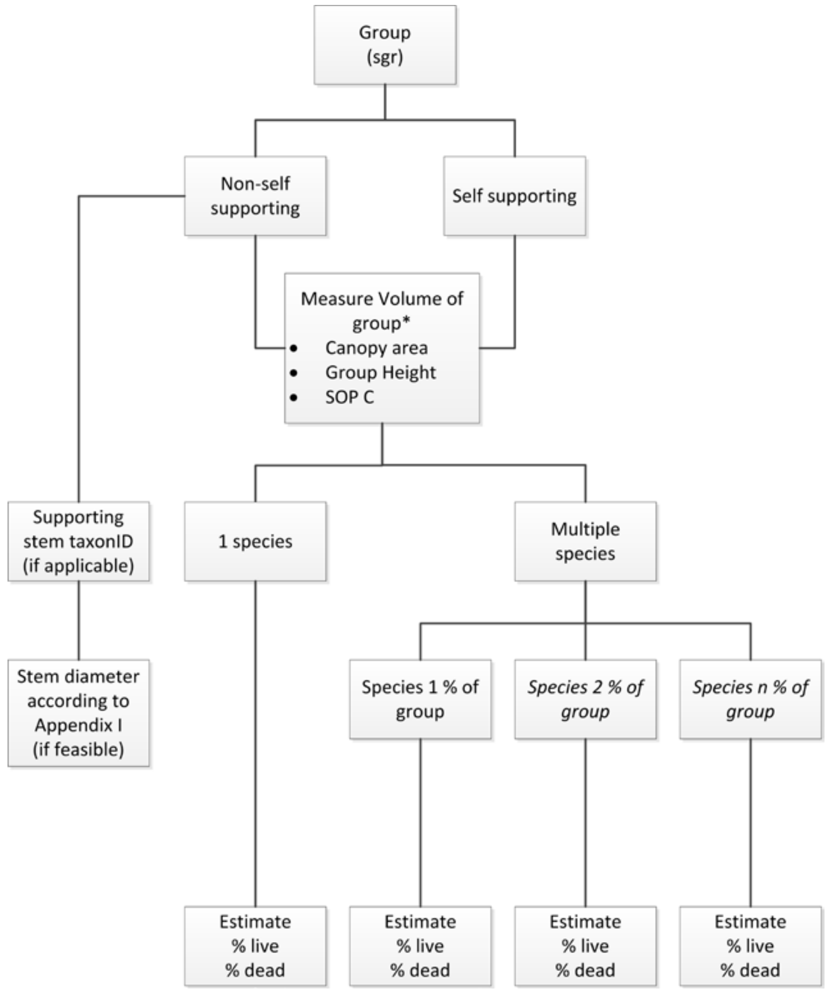


Figure 5. Decision tree for groups of shrubs and/or liana in which it is not possible to distinguish apparent individuals.

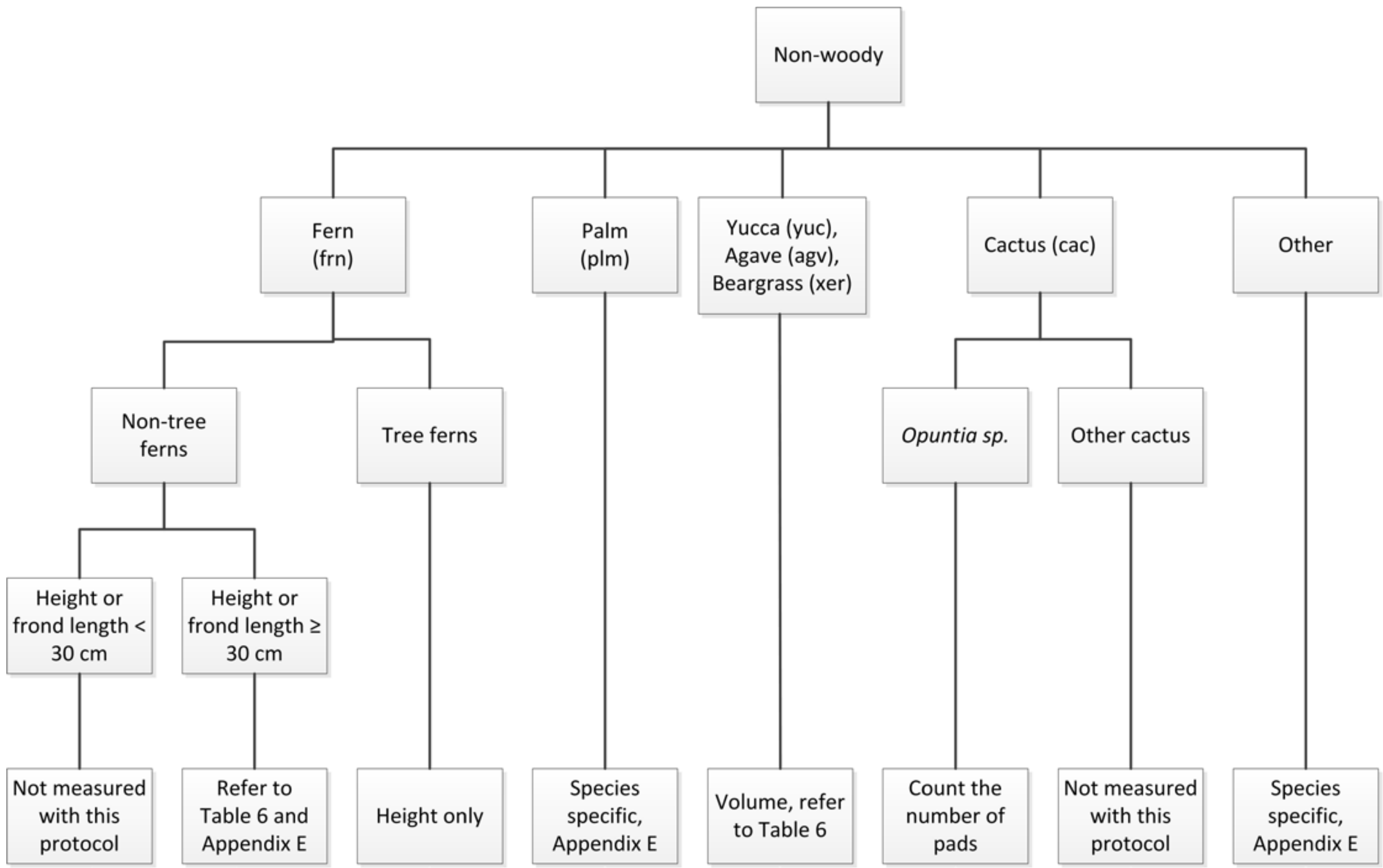


Figure 6. Decision tree for structure measurements of non-woody perennial species.

B.2 Summary of required measurements

Table 6. Summary of biomass measurements required for each growth form. There are limited, non-herbaceous perennial growth forms listed in this table; these growth forms are not tagged or mapped, refer to Appendix D for additional measurement details. Note: Species may change classification from one year to the next, for example due to a gain of qualifying stems, an individual may move from "small tree" to "single shrub".

Growth Form[1]	Map	Tag type, location, and method[3]	Stem Diameter Measurement Location	Height	Canopy Diameter	Additional Measurements
Liana (lia)	N/A	- Unique # - 140 cm along stem - Aluminum nail or loose wire, only one tag for each apparent individual despite branching	130 cm above ground; see Appendix H for complex cases	N/A	N/A	- nestedSubplotArea - taxonID - identificationQualifier - supporting stem stemID
Single bole tree (sbt)[2]	relative position	- Unique # - DBH + 10 cm - Aluminum nail	130 cm above ground	Maximum height, 2-shot TruPulse routine	Distributed Plots only: Maximum diameter and perpendicular to max	- taxonID - identificationQualifier - status - canopyPosition (Distributed plots only)

Growth Form[1]	Map	Tag type, location, and method[3]	Stem Diameter Measurement Location	Height	Canopy Diameter	Additional Measurements
Multi-bole tree (mbt)[2]	relative position of largest stem	- Unique # on largest stem - A,B,C... on all secondary qualifying stems ; record secondary stem tagID as 1234a (on the datasheet) - Measurement Height + 10 cm - Aluminum nail	20 cm below the split when possible, otherwise measure each qualifying bole; see Appendix H, cases C and G	Maximum height, 2-shot TruPulse routine	- Distributed Plots only: Maximum diameter and perpendicular to max - Record measurement for canopy from all boles in row associated with largest stem, field is left blank for additional qualifying boles.	- taxonID - identificationQualifier - status - canopyPosition (Distributed plots only)
Small shrub (sms)	N/A	- Unique #, - Ground level - Loose aluminum wire	ddh of all stems ≥ 1 cm @ 10 cm above ground	Maximum height, meter tape or collapsible ruler	Maximum diameter and perpendicular to max	- nestedSubplotArea - taxonID - identificationQualifier - shape

Growth Form[1]	Map	Tag type, location, and method[3]	Stem Diameter Measurement Location	Height	Canopy Diameter	Additional Measurements
Single shrub (sis)	relative position of center if no overstory is present in the plot	- Unique # on main stem, no tag on additional qualifying stems; mark secondary stems with lumber crayon - DBH + 10 cm on primary stem (nail) **Or** Ground level (wire) -Aluminum nail or loose wire as appropriate	- Measure 20 cm below the split when possible, otherwise measure each qualifying stem	Maximum height; laser rangefinder if height > 2 meters, meter tape or collapsible ruler for < 2 m	Maximum diameter and perpendicular to max	- nestedSubplotArea - taxonID - identificationQualifier - status - canopyPosition (Distributed plots only) - shape
Shrub group (sgr)	Graph paper method	No tag, unique ID assigned annually	N/A	5 tallest points within group	Canopy area; graph paper	- nestedSubplotArea - Species estimate of % contribution to total volume - % live per species - % dead per species
Small tree (smt)	relative position if no overstory is present in the plot	- Unique # - DBH +10 cm - Aluminum nail or loose wire as appropriate	130 cm above ground	Maximum height, 2-shot TruPulse routine or meter tape	Distributed Plots with no overstory only: Maximum diameter and perpendicular to max	- nestedSubplotArea - scientificName - status

Growth Form[1]	Map	Tag type, location, and method[3]	Stem Diameter Measurement Location	Height	Canopy Diameter	Additional Measurements
Sapling (sap)	N/A	- Unique # - Ground level - Loose aluminum wire	ddh; 10 cm above ground	Maximum height, 2-shot TruPulse routine or meter tape	N/A	- nestedSubplotArea - taxonID - identificationQualifier - status
Ferns[4] (frn)	N/A	N/A	N/A	Tree ferns only; Maximum height, 2-shot TruPulse routine	N/A	- nestedSubplotArea - taxonID - identificationQualifier - status - Average frond length - number of fronds - basal stem diameter - See Appendix E
Palm (plm)	relative position if no overstory is present in the plot	N/A	N/A	Maximum height, 2-shot TruPulselaser rangefinder routine or meter tape	N/A	- nestedSubplotArea - scientificName - See Appendix E
Yucca (yuc) Agave (agv)	N/A	N/A	N/A	Maximum height, meter tape	Maximum diameter and perpendicular to max	- nestedSubplotArea - scientificName - status - See Appendix E

[1] assess each individual separately; growth form is not tied to species for this protocol
[2] measure height of both single bole and multi-bole trees, regardless of status (i.e. measure snags/stumps as well)
[3] Measurement guidelines for unusual conditions are addressed in section B.3
[4] Ferns may be ignored when sampling Distributed plots if aerial cover of ferns is < 50% of the entire plot area as seen by AOP.

B.3 Exceptions and special considerations

Table 7. Rules for determining the appropriate measurement location for situations not covered by generalized rules in Figures 3-6 and **Table 6**

Measurement guidelines for stems with diameter ≥ 1 cm	
Stem/Site Characteristics	**Measurement strategy**
Growing on slope or uneven terrain	Measure DBH 130 cm from uphill side.
Leaning or twisted stems	Measure 130 cm along stem (not perpendicular to ground). Diameter measurement is at an angle (i.e., perpendicular to the direction of stem growth at measurement height, not parallel to ground).
Stems with anomalies at 130 cm (e.g., big bulge, node/branch, or damage.	• Measure DBH 5 cm below the anomaly where stem becomes “normal” again. • Record the alternate measurement height in **measurementHeight** field on data sheet.
Stems that split into multiple boles below 130 cm.	• Measure DBH 20 cm below the split point where the stem is regular. • Record the alternate measurement height in **measurementHeight** field on data sheet.
Deep duff layer present	Measure DBH 130 cm from ground level, not the top of the duff layer
Top of tree is broken	• Measure DBH 130 cm from ground level • Measure height of break • Measure diameter at break point.
Multi-bole tree with mix of live and dead stems (includes stump ≥ 130 cm height and DBH ≥ 10 cm w/ re-sprouts)	Growth form = multi-bole tree but diameter is not measured according to Appendix I. • Measure all qualifying stems, record **stemStatus**. • Measure height and diameter at break point for dead boles. (see additional guidelines in **Box 1**)
Standing dead	• Measure DBH, status=dead. If top is broken, measure the height of the break and the diameter at the break point. • Measure diameter at the break at first ‘normal’ point below splintered sections. • Standing dead < 130 cm height is ignored.

Measurement guidelines for stems with diameter ≥ 1 cm	
Stem/Site Characteristics	**Measurement strategy**
Leaning dead	If lean is < 45° off vertical, measure same as standing dead If lean is ≥ 45°, ignore stem, will be included as Coarse Downed Wood.
Plot burned since previous bout	Do not change measurement strategy. Do not need to search for fallen, untagged individuals for re-measurement.

***** Additional guidelines for measurement location on lianas, Appendix H. Safe handling of *Toxicodendron* species provided in Appendix E.

Box 1. Guidelines for Measuring Multi-Bole Individuals with Different stemStatus

The goal is to enable estimation of the mass of dead wood in (A) and the mass of live wood in (B), while consistently applying sampling rules for established growth forms (see Figure below). Here, it does not make sense to measure one diameter at a regular point below the split between (A) and (B) due to the difference in stemStatus. The Figure shows multiple scenarios that may arise:

Left scenario:

- Stumps < 130 cm height (A) are ignored.
- If resprouts (B) grow from a stump < 130 cm height, they are assigned their own growth form and measured accordingly; if resprouts are all < 10 cm DBH, they are only measured if they fall within the selected measurement area for that growth form.

Right scenario:

- Broken boles ≥ 130 cm height and ≥ 10 cm DBH (A) are tagged and measured throughout the plot. If (B) is < 10 cm DBH, it is only measured if it falls within the selected measurement area for stems of that size class, and it is assigned its own growth form and is measured accordingly.
- If (B) is a live bole ≥ 10 cm DBH, it is tagged and measured at DBH, and the individual is a multi-bole tree (mbt). The largest bole, regardless of stemStatus receives the 'primary tag.'
- For (A), the diameter of the bole at the break is recorded in the maxCanopyDiameter field, and the canopyDiameter90 field is left blank.

Additional scenarios (not shown in the figure):

- If (A) has 1 cm ≤ DBH < 10 cm and is ≥ 130 cm tall, it is measured depending on the attributes of (B).
    - If (B) is ≥ 10 cm DBH, (A) is not measured because it is not a qualifying stem, and only (B) is tagged and measured as a single bole tree (sbt).
    - If (B) is < 10 cm DBH, the growth form is assessed by considering (A) and (B) together, and should be single shrub (sis). (A) and (B) are tagged and measured separately for diameter, due to the difference in stemStatus – i.e., do not make one measurement below the split that separates (A) from (B). However:
        - Make one set of canopy diameter measurements for the individual; do not measure the canopy diameter of dead stems and the canopy diameter of live stems.
        - Only make measurements if (A) and (B) fall within the selected measurement area for stems of that growth form.

Box 1. Guidelines for Measuring Multi-Bole Individuals with Different stemStatus (continued)

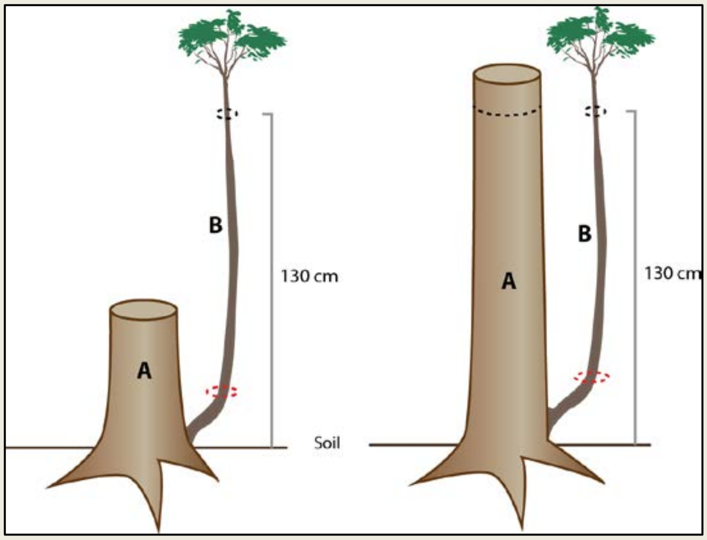


Illustration of multi-bole individuals where one bole is dead (A) and the other is alive (B). *Left:* (A) has broken off below 130 cm; *Right:* (A) has DBH ≥ 10 cm and has broken off above 130 cm. Dashed black circles indicate standard measurement heights of 130 cm for DBH; red circles indicate alternate measurement positions on (B) if DBH < 10 cm and (B) is within the selected measurement area.

B.4 Site Specific Guidelines

This protocol 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 exactly may still lead technicians 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. Science Operations will review documents and facilitate sharing between Domains.

B.5 Stem mapping

Small trees and shrubs can exist either as isolated “apparent individuals” (with either single or multiple stems), or as groups of individuals in contact with each other such that apparent individuals cannot be distinguished from neighbors (e.g. a continuous shrub thicket).

Apparent individuals may be mapped as points, depending on the growth form and other vegetation present, and are tagged with a unique aluminum ID tag for repeat measurements. The locations of groups of individuals are mapped relative to the plot with polygons and graph paper (Section C.10), but individual stems within the group are not tagged.

The procedure described here only applies to apparent individuals. Stems must be ≥ 50% rooted in the plot in order to be considered 'in' and included in long term monitoring. Dead individuals are also tagged and mapped if they are not leaning more than 45° from vertical. Data collected as part of this SOP will be recorded in the '**Mapping and tagging**' datasheet.

This procedure is for mapping trees and shrubs within a plot or subplot relative to established plot markers (see RD[08] for details). The following procedure will be completed for:

- Single bole trees >10 cm DBH
- Multi-bole trees > 10 cm DBH
- 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)

Note: Stem mapping (this section) and Tagging (Section 0) 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. Appropriate training is required to accurately use a compass.

1. Delineate the plot or subplot(s). Use existing plot markers, the 50 m 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.
2. Mount the laser rangefinder on the non-magnetic tripod.
3. Position the laser rangefinder directly over an existing plot marker for which high-resolution GPS coordinates have already been recorded.
4. Record stem map data in the **SOP B: mapping and tagging** datasheet.
5. Select a stem to map, attach a pre-numbered aluminum tag (see 'tagging' below), this number is the **stemID.**
6. Record the **pointID**. This is the plot marker number over which the laser rangefinder is positioned.
    a. Refer to Appendix F if plot markers are not numbered.
7. Record the **stemDistance** to the 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.

a. Press “Power/Fire” to turn on the TruPulse.
b. Set the unit to Target Mode = Filter. Press either the ▲ or ▼ button until **HD** (i.e. Horizontal Distance) appears in the viewfinder.
c. Person 1: Hold the reflective surface at the base of the stem so that it is visible to Person 2.
d. Person 2: Look through the laser rangefinder viewfinder, aim the crosshairs at the reflective surface held by Person 1, and press and hold “Power/Fire” until the distance is displayed in the viewfinder; record this distance.

8. Record the **stemAzimuth** to the 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.
   a. After recording the **HD** to the stem above, press ▲ three times until **AZ** (i.e. azimuth from True North) appears in the viewfinder and the angle in degrees is displayed; record this angle.
   b. The angle should be preceded by a “**d**” indicating that declination has been set for the TruPulselaser rangefinder at your current location (as described in Appendix D).
9. Record the **taxonID** and **identificationQualifer** code if needed. This should be a binomial latin name qualified according to technician confidence (

10. Table **8**).

    Note: Only assign an idQ at the resolution of taxonomic ID that was achieved. For 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**.

    a. Record field keys used in the **identificationReferences** field at the top of the datasheet.
    b. When **stemStatus =** 2, dead (see SOP C), assign to species if possible. If it is not clear what species a dead stem is, assign to genus, family, unknown hardwood or unknown softwood, in that order of preference.
    c. If **taxonID =** unknown and the stem is alive, obtain leaf samples and bring back to the lab to identify.
        1) In the lab, identify the specimen to the finest taxon resolution possible, and record in the **taxonID** field on the datasheet.
        2) Place collected unknown specimens in sealable plastic bags.
        3) Label plant with a unique (to the technician) unknown name (according to guidelines in RD[07]), number, description, botanist, date, and plot number.
        4) Process unknowns according to the plant diversity protocol if adding the sample to domain-specific reference collection would be helpful.

Table 8. identificationQualifier codes for species ID. Leave this field blank if technician is confident in the genus and species ID.

identificationQualifier	Description
cf. species	roughly equals but "not sure" about the species
aff. Species	similar to, but is not the species
cf. genus	roughly equals but "not sure" about the genus
aff. Genus	similar to, but is not the genus
cf. subspecies	roughly equals but "not sure" about the subspecies
aff. Subspecies	similar to, but is not the subspecies
cf. family	roughly equals but "not sure" about the family
aff. Family	similar to, but is not the family
cf. variety	roughly equals but "not sure" about the variety

11. Record the three letter **growthForm** code. This is assessed for each individual rather than by species. Refer to **Table 6** for more details about the growth forms listed below.
    - lia = liana
    - sbt = single-bole tree
    - mbt = multi-bole tree
    - sms = small shrub
    - sis = single shrub
    - sgr = shrub group
    - smt = small tree
    - sap = sapling
    - frn = ferns
    - plm = palm
    - yuc = yucca
    - agv = agave

Tip: It is helpful to mark trees you have just 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.

B.6 Tagging

As stems are mapped, attach an aluminum tag with **tagID** to the largest stem on the individual 10 cm above the measurement location (the measurement location is typically DBH or ddh but may differ if stem irregularities are present) (Appendix H). Tags are attached with either an aluminum nail or with aluminum wire wrapped loosely around the measured stem so that the wire will not cut into the stem as it grows. Wire should be used for any stems < 5 cm diameter at measurement height (DBH or ddh).

SOP C Biomass/Productivity Measurements

The measurements collected as part of this procedure will be used as variables in allometric equations to estimate biomass of individuals. Annual re-measurement of individuals will enable calculation of Annual Net Primary Production (ANPP). Generalized allometric equations vary by growth form and require different types of information. Here we describe field techniques for measuring stem diameter, height, canopy 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 6**.

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. Because of this variety, consistently choosing the appropriate measurement point is paramount. For the most part, this protocol adopts guidelines established by Gerwing et al. (2006), Schnitzer et al. (2008), Dahlin et al. (2011), and the U.S. Forest Service (2012). Diameter measurements are typically taken at 130 cm (breast height, DBH) or at 10 cm from the ground (ddh).

Vegetation structure data are collected systematically from qualifying apparent individuals, groups, and portions of groups rooted inside each plot (Figure 2). All individuals with DBH ≥ 10 cm within a plot or subplot are mapped and measured regardless of density; however, for small diameter trees, shrubs, lianas, and 'other' qualifying plants (e.g., ferns), nested subplots may be used to standardize sampling effort across plots with varying densities of individuals (Sections C.1 and C.2). Subplots are numbered according to the pointID of the SW corner of the subplot (Figure 2 and Figure 7).

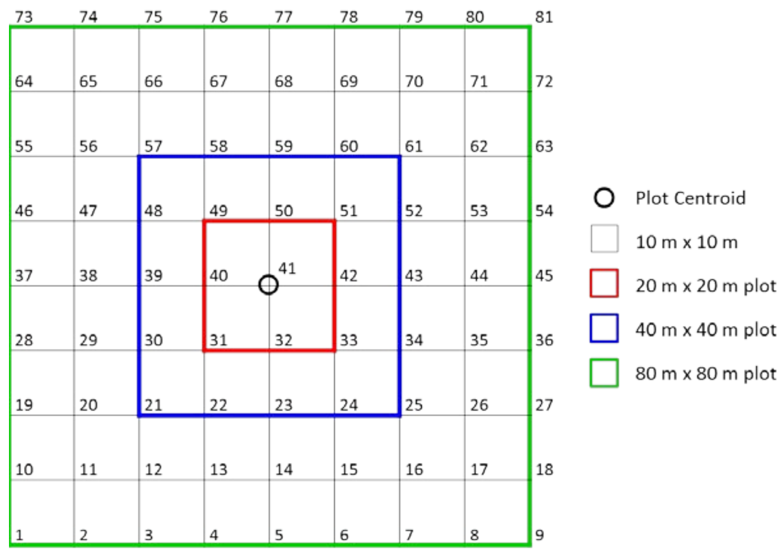


Figure 7**.** Point IDs for NEON plots of varying sizes.

Nested subplots are numbered in sequence beginning with the SW corner of the subplot; SW=1, SE=2, NW=3 NE=4 (**Figure 2**). Stems are only measured when ≥ 50% of the individual (or ≥ 50% of the stems, for a multi-stemmed individual) are rooted within the measurement area. **Each plot that is visited must be assessed for the presence of these growth forms, and measured accordingly.** Assessments for the presence of different growth forms should take place every time a plot is measured.

- Record stem measurement data in the SOP C: Biomass/Productivity Measurements, Apparent Individuals datasheet.

During annual re-measurement of a plot, pay careful attention to:

- Map, measure, and tag new stems that now meet the minimum 10 cm DBH cutoff; and
- Update stem status as some individuals may have died, others may have become damaged.

C.1 Using nested subplots to standardize the sampling effort

Small diameter trees (including saplings), shrubs and lianas are measured on a per subplot basis within plots in order to facilitate tracking individuals that have and have not been measured. Because saplings, shrubs, and lianas can attain very high stem densities, even within a single subplot, it may be necessary to employ a nested subplot approach in order to standardize the sampling effort across plots. Subplot and nested subplot sizes are shown in Figure 2. To be consistent within plots, ***the same size measurement unit (e.g. the chosen nested subplot size) must be used for the entire plot, and the same size nested subplots within a given plot should be used from year to year***.

Measurement areas for a 20 m x 20 m base plot (**Figure 2**):

- Plot: 400 m^2, 20 m x 20 m
- Subplot: 100 m^2, 10 m x 10 m
- Nested Subplot:
    - 25 m^2, 5 m x 5 m
    - 10 m^2, 3.16 m x 3.16 m
    - 1 m^2, 1 m x 1 m

Measurement areas for a 40 m x 40 m base plot (**Figure 2**):

- ***Only two of the four subplots are randomly selected for sampling by Science Operations. A JIRA ticket indicates the location of lists of subplots randomly selected for sampling.***
- Plot : 1600 m^2, 40 m x 40 m
- Subplot: 400 m^2, 20 m x 20 m;
- Nested Subplot:
    - 100 m^2, 10 m x 10 m
    - 25 m^2, 5 m x 5 m
    - 10 m^2, 3.16 m x 3.16 m
    - 1 m^2, 1 m x 1 m

C.2 Select the optimal measurement area

In the first year of sampling, the optimal measurement area is selected once per plot independently for each of these groups of growth forms: 1) lianas, 2) small trees, sapling, single shrubs, shrub groups, small shrubs; and 3) 'other' qualifying vegetation (**Table 6**). The following guidelines apply:

- A shrub group that receives a single ID is counted as 1 individual for the purpose of selecting an appropriate nested subplot size.
- Visually assess the density of qualifying, apparent individuals across the whole plot for each of the three groups listed above, and choose a nested subplot size appropriate for each group.

1. Assess the plot or subplots for the presence of qualifying vegetation (i.e. the presence of growth forms in **Table 6**) Record 'yes' or 'no' in the **targetTaxaPresent** field of the 'QAQC datasheet' RD[12]. If there is no qualifying vegetation and targetTaxaPresent = 'no', continue to the next plot.

2. If a plot HAS been measured previously use the **same measurement area each year (nestedSubplotArea)** in order to ensure that repeat measurements are made on tagged stems. Check the QAQC datasheet which summarizes measurement area for all plots before selecting a new measurement area for a given plot.
    - In a given plot, if significant changes in stem density have occurred over time, due to succession, self-thinning, natural disturbance, or management activities, discuss with Science Operations whether a change in nested subplot implementation is warranted.

3. To select an optimal measurement area, assess vegetation density. The appropriate density depends on plot size:

   In a 20 m x 20 m base plot:

   - Goal: Sample a minimum of 20 individuals across the entire 20 m x 20 m plot

     FOR INDIVIDUALS DISTRIBUTED RELATIVELY HOMOGENEOUSLY, THIS IS EQUIVALENT TO:
   - 5 apparent individuals per subplot
     OR
   - 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.*

   In a 40 x 40 m base plot:

   - Goal: Sample a minimum of 20 apparent individuals ***for at least one*** 20 m x 20 m subplot

     FOR INDIVIDUALS DISTRIBUTED RELATIVELY HOMOGENEOUSLY, THIS IS EQUIVALENT TO:
   - 10 apparent individuals per nested subplot (any size)

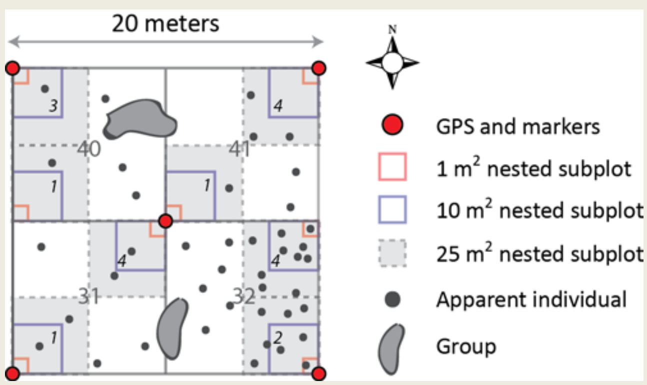
   *Note: In a 40m x 40 m plot one 20m x 20 m subplot must have a **minimum** of 20 individuals. **It is acceptable if only one subplot meets this threshold** and the other randomly selected subplot has fewer than 20 individuals (see scenario in Box 3).*

4. Record the selected **nestedSubplotArea** (1, 10, 25, or 100 m^2) for each of the groups of growth forms listed above in the 'QAQC datasheet' (RD[12]).

Box 2. Guidelines for selecting nested subplot size in a 20m x 20m 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 20m x 20m plot with heterogenously distributed vegetation. Grey numbers indicate subplot IDs, and black italic numbers indicate nested subplot IDs.

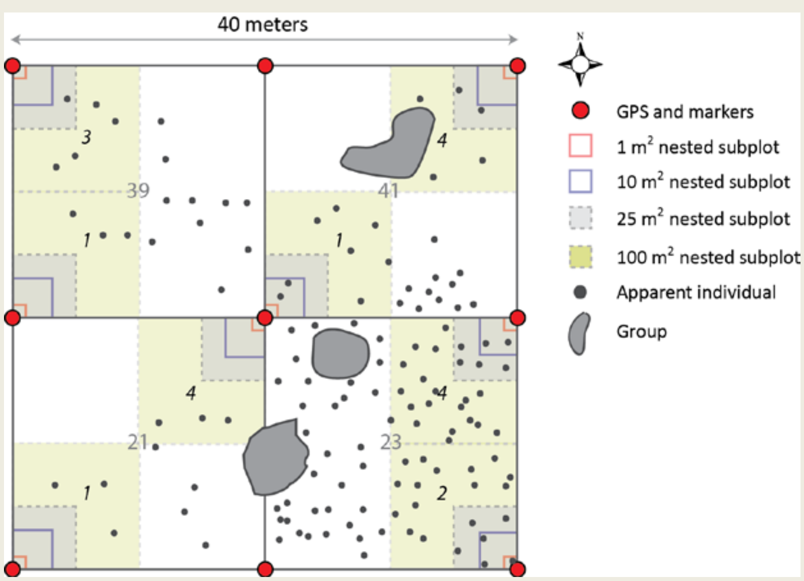
Box 3: Guidelines for selecting nested subplot size in a 40m x 40m base plot with heterogeneously distributed vegetation.

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. An initial visual survey of the plot indicates that qualifying individuals are relatively dense in subplot 23 (n=81, including 2 groups) are 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



A 40m x 40m plot with heterogeneously distributed vegetation. Grey numbers indicate subplot IDs, and black italic numbers indicate nested subplot IDs.

C.3 Setting up a plot

1. **Check the QA/QC datasheet to determine whether a plot has been measured before, and if so, which nested subplot area must be used.** If a plot has been measured before, it is important to use the same subplot size each year, so that tagged, mapped individuals can be tracked through time.
2. Delineate the plot. Use existing plot markers, the 50 m tapes, and chaining pins to carefully delineate the plot and subplots.
   - 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.
   - 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. The one-sided length of the nested subplots are listed above in Section C.1
   - If measuring a plot for the first time, be sure to record the size of nested subplot used in the QA/QC datasheet.

C.4 Stem diameter

Stem diameter will be measured for all qualifying stems within the measurement area. This applies to all growth forms defined in SOP B:

- Lianas
- Single bole trees
- Multi-bole trees
- Single Shrubs
- Small trees
- Small shrubs
- Saplings

Stem diameter is typically measured at two standard measurement heights and we record either: 1) diameter at breast height (DBH), or 2) diameter at decimeter height (ddh). Separate sections below describe measurement at each location. If abnormalities exist at the desired measurement height, measure according to rules in Appendix H. On the datasheet, diameter is recorded in the **stemDiameter** field, and height at which diameter was measured in the **measurementHeight** field.

Diameter at Breast Height (DBH)

1. Guidelines for determining the measurement location for DBH are provided in **Table 6**. In many cases, the measurement location will already be marked with lumber crayon following the Mapping and Tagging activity.

- Use a DBH tape for stems with DBH ≥ 5 cm.
- Use calipers for stems with DBH < 5 cm and all lianas

2. Mark (or re-mark) the measurement location with lumber crayon so that repeat measurements at exactly the same location are possible.
   - Mark stems with DBH ≥ 30 cm at multiple points around the bole to ensure accurate re-measurement.
   - Re-mark the stem if the lumber crayon mark is faded or difficult to discern.

3. Place the DBH tape or calipers directly over the lumber crayon marking(s). For large boles, the tape must not slip above or below the desired measurement point.
4. For each stem with DBH ≥ 10 cm, do the following:

   - Record the **plotID** and the **subplotID** (the "nestedSubplotID" and "nestedSubplotArea" fields on the datasheet are left blank for stems with DBH ≥ 10 cm).
   - Record the **stemID** from the aluminum tag.
   - Record the **supportingStemID** for lianas
     - If the supporting stem does not have a tagID, leave field blank and note 'support stem not tagged' in the remarks field
   - Record the **stemDiameter** to the nearest 0.1 cm.
     - If the calipers being used only have 0.5 cm increments, use ocular estimation to determine finer scale measurement.
     - If lianas are present, especially *Toxicodendron sp.,* and use of a DBH tape is impractical, use large calipers instead. Take two measurements, perpendicular to one another and calculate the average of the two, and record as stemDiameter
   - Record the **measurementHeight.**
     - Standard measurement height for DBH is 130 cm above the ground,
     - Measurement height for ddh is 10 cm above the ground.
     - For trees and shrubs with anomalous and complicated growth forms that are not adequately described here, measurement location and method may be determined according to the guidelines for measuring lianas (Appendix H).

   - If you are measuring diameter on a stem which is > 5 cm DBH and is a supporting stem for lianas, use the following options, listed in order of preference:
     a. Attempt to thread tape under liana stems; if not possible,
     b. Use calipers to measure the stem at its widest point, and also perpendicular to its widest point. Calculate the average, and record; if not possible,
     c. Measure whole diameter (supporting stem + liana), and note how the measurement was taken in the 'Notes' datasheet and indicate that there is a note by check marking the 'remarks' field on the 'apparent individuals' datasheet.

It is helpful to mark trees you have just 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 plot or subplot. [NEED TO FOLLOW LINK AT LEFT]

Diameter at Decimeter Height (ddh)

Diameter at decimeter height (ddh) will be measured for qualifying stems ≥ 1 cm diameter 10 cm above the ground and < 130 cm height, and for shrubs with > 5 stems with DBH ≥ 1 cm. The strategy for measuring ddh is similar to that described for DBH above except that measurements will be taken on primary stems ≥ 1cm diameter at 10 cm above the ground. All stems that do not meet this criterion will not be measured.

- Remember: Use calipers for all diameter measurements < 5 cm.
- Stems are never perfectly round; therefore, when using calipers for diameter measurements, measure the longest and shortest diameter axes of stems and record the average stem diameter.

C.5 Stem height

Record the stem height at the highest canopy point to the nearest 0.1 meter with the laser rangefinder. Stem height is always height above the ground, not length of the stem – i.e. for leaning stems, measure the highest point above the ground.

- **VD1**: The vertical distance from the highest canopy point to the observer, typically a positive number.
- **VD2**: The vertical distance from the base of the stem where it meets the ground to the observer, typically a negative number.

Individuals with height > approximately 2 m:

- Use the laser rangefinder (see Appendix D).
- Record both **heightVD1** and **heightVD2**
- On uneven or sloped terrain, measure VD2 from the uphill side of the stem base, if possible.

For individuals with height < approximately 2 m:

- Use a meter tape or rigid collapsible ruler.
- Manually stretch the tape or ruler from the ground to the top of the canopy.
- If the individual is growing on uneven or sloped terrain, measure from the uphill side of the stem(s), if possible.
- Record the value from the meter tape as **heightVD1**, and enter a "0" (zero) for **heightVD2**.

For shrub groups:

- Use either the laser rangefinder (> 2 m), a meter tape (< 2 m) or rigid collapsible ruler (< 2 m)
- Record the **height** of each of the tallest 5 stems within the group, to the nearest 0.1 m
- For groups that include lianas, measure height for the majority of the group, do not account for climbing stems extending to the canopy. Use the '**Shrub Groups'** datasheet.

C.6 Canopy diameter

Record the **canopy diameter** for each individual to the nearest 0.1 m. Two measurements will be recorded:

- **maxCanopyDiameter** = the maximum extent of the canopy
- **ninetyCanopyDiameter** = the diameter at 90˚ to maxCanopyDiameter

Canopy diameters can be measured via either of the two techniques outlined in the Rangefinder SOP (RD[09]), and are required for the following growth forms:

- All single shrubs and small shrubs in the selected measurement area (so that volume may be calculated)
- Trees ≥ 10 cm DBH ***in Distributed plots only*** (to create links with parameters measured by the NEON AOP)
- Small trees within the selected measurement area *in Distributed plots that do **NOT** have an overstory* (to create links with AOP). That is, if an overstory exists anywhere in the plot, do not measure canopy diameter for small trees.

Broken boles

When either live or dead broken boles are encountered, the **maxCanopyDiameter** field is used to record the diameter of the bole at the break-point, and the **ninetyCanopyDiameter** field is left null.

1. Measure and record the diameter of the bole at the breakpoint:
    a. Search for the broken top of the bole, which should be nearby. Measure the diameter of the bole as near the break-point as possible where the bole is regular, and record to the nearest 0.1 cm in the **maxCanopyDiameter** field.
        i. If a diameter tape cannot be used, measure two diameters with calipers and record the average.
    b. If the broken top cannot be found, or if it cannot be determined which broken top corresponds to the standing broken bole of interest, two people may estimate the diameter of the break-point on the standing broken bole using calipers:

i. Person 1: Stand away from the broken bole at a sufficient distance such that you can see the break-point and the base of the bole (i.e. the same distance required for measuring the height of the bole).
ii. Person 2: Stand at the base of the broken bole with the calipers held open and in front of you.
iii. Person 2 directs Person 1 to open the calipers until the jaw gap appears to Person 2 to be the diameter at the break-point (squinting may help).
iv. Record the diameter shown on the calipers in the **maxCanopyDiameter** field.

Multi-bole Individuals with Broken Boles

1. Measure **maxCanopyDiameter** and **ninetyCanopyDiameter** once for the group of intact boles. Record these values as the canopy diameter entries associated with the largest un-broken primary bole.
    - Smaller qualifying boles tagged with 'a', 'b', 'c', etc. are left null for **maxCanopyDiameter** and **ninetyCanopyDiameter**
2. Measure the diameter of the broken bole(s) as described above, and record the diameter at the break-point in the **maxCanopyDiameter** field for each broken bole.

C.7 Canopy Position

Record the **canopyPosition** (see Table 9 for required codes).

Table 9. Canopy position definitions. Modified from USFS Forest Inventory Analysis program Crown Class definitions (USDA Forest Service 2012).

Code	Description
1	Open Grown – **Full sun, not touching other plants** - crowns that received full light from above and from all sides throughout most of its life, particularly during its early developmental period.
2	Dominant – **Full sun** -crowns extending above the general level of the canopy and receiving full light from above and partly from the sides. These individuals are taller than the average in the stand and their crowns are well developed, but they could be somewhat crowded on the sides. Also, individuals whose crowns have received full light from above and from all sides during early development and most of their life. Their crown form or shape appears to be free of influence from neighboring plants.
3	Co-dominant – **Partially shaded -**individuals with crowns at the general level of the crown canopy. Crowns receive full light from above but little direct sunlight penetrates their sides. Usually they have medium-sized crowns and are somewhat crowded from the sides. In stagnated stands, co-dominant trees have small-sized crowns and are crowded on the sides.

Code	Description
4	Intermediate –**Mostly shaded -** individuals that are shorter than dominants and co-dominants, but their crowns extend into the canopy of co-dominant and dominant trees. They receive little direct light from above and none from the sides. As a result, intermediate trees usually have small crowns and are very crowded from the sides.
5	Overtopped – **Full shade** - individuals with crowns entirely below the general level of the crown canopy that receive no direct sunlight either from above or the sides.

C.8 Stem status

Record the **stemStatus** according to the definitions provided in Table 10.

- See **Box 1** for how to deal with multi-bole individuals when not all boles have the same stemStatus value.

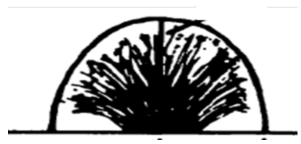
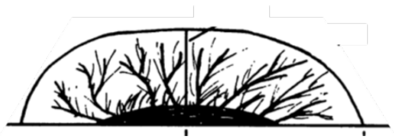
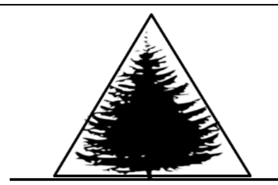
Table 10. Stem Status value definitions

Code	Description
1	Live tree – any live tree (new, re-measured or ingrowth)
2	Dead tree, or bole within a multi-bole tree, either new or re-measured, regardless of cause of death. The entire tree or bole must be dead.
3	Removed – a tree that has been cut and removed by direct human activity related to harvesting, silviculture or land clearing (re-measurement plots only).
4	Damaged - insect
5	Damaged - disease
6	Damaged – abiotic (i.e. lightning strike, windthrow, fire etc)
7	Damaged - other
8	Failed to re-locate previously tagged individual

C.9 Shrub shape

Shrub canopy dimensions and height will be used to calculate volume. In order to produce the most accurate estimates, shrub volume must be calculated according to a three dimensional shape. Record the **shape** of each measured shrub according to the guidelines in Table 11.

Table 11. Shrub shapes for volume estimates.

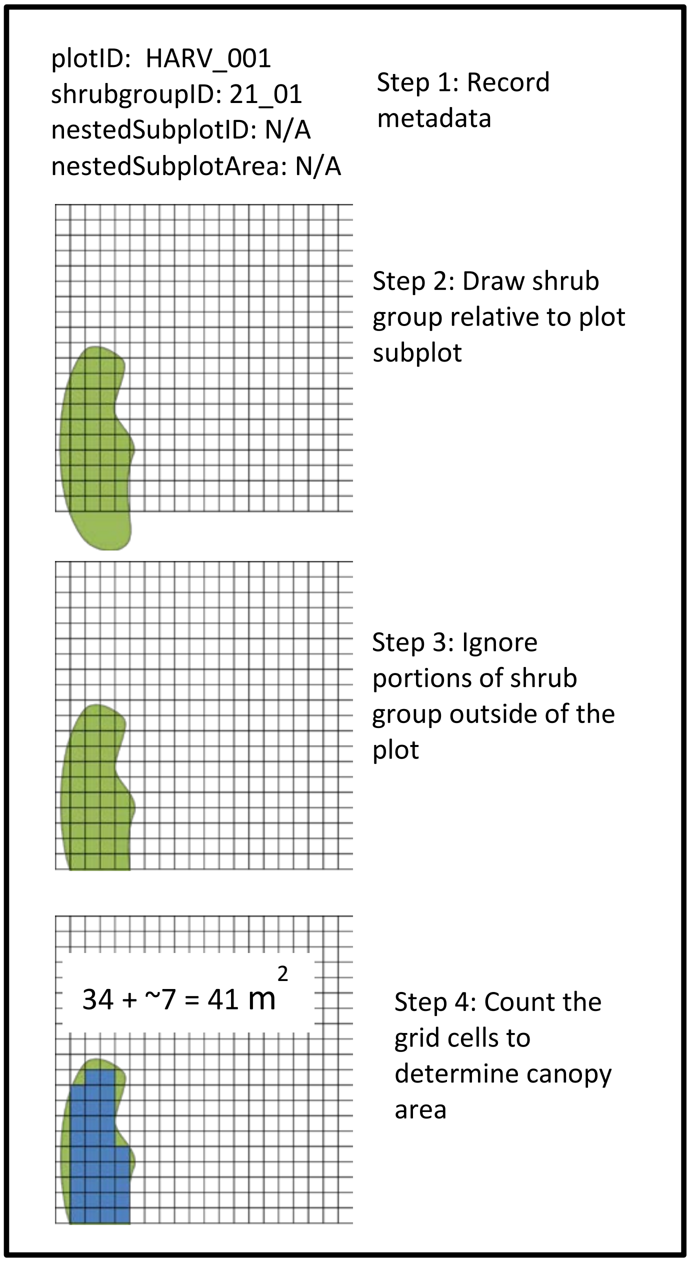
Shape	Example	Additional measurements
Half- sphere (hsp)		None
Oblate half sphere (ohs)		None
Cone (cne)		None
Inverted cone* (icn)		baseCrown diameterMax, baseCrown diameter90
Cylinder (cyl)		None

* images from Ludwig et al. (1975)

1. When shrubShape = ‘inverted cone’
   - Record **baseCrownDiameterMax** = the maximum diameter of the base of the crown at ground level. Using the image in the penultimate row of **Table 11** as an example, this diameter is the distance corresponding to the red line. This distance may be larger than the diameter of the stem(s).
   - Record **baseCrownDiameter90** = the diameter at the base of the crown that is perpendicular to baseCrownDiameterMax.
   - 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
     - A rigid collapsible meter stick
     - A meter tape, or
     - A laser rangefinder

C.10 Shrub Group Measurements

Shrub groups are not mapped relative to a plot marker, and are not tagged. Shrub groups are measured so that the volume of the group may be estimated as a function of ‘canopy area’ x ‘average height’. Data are recorded on the **SOP C: Biomass/Productivity Shrub Groups** datasheet. 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 (**Error! Reference source not found.Error! Reference source not found.**).



Each shrub group receives a unique **shrubgroupID** using the form ##_## where the first two numbers are the subplot ID followed by an underscore then an incremental number (01, 02, 03…) for the plot. This number is not a permanent assignment; it is temporary uniqueID used, in part, to group data related to multi-species shrubgroups.

Figure 8. Example of graph paper method for determining shrub group area within a 20 m x 20 m subplot. In this example, **canopyArea** = 41.

1. Assess the % cover of the group relative to the measurement area:
   - There is no need to map the shrub group with graph paper 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.
   - If the shrub group covers <100% of the measurement area, map the area of the group using the graph paper methods described in step (2).

2. Measure Shrub Group area 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, to scale, the shape of the shrub group 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.
    e. Record this number on the grid paper and in the **canopyArea** field on the datasheet

3. Measure Shrub Group average height:
    - Use either the laser rangefinder (> 2 m), a meter tape (< 2 m) or rigid collapsible ruler (< 2 m).
    - Record the height at 5 locations, to the nearest 0.1 m, that you feel best represents 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.
    - For groups that include lianas, measure height for the majority of the group, do not account for climbing stems extending to the canopy.

4. Record the % contribution by volume (ocular estimation) of each species within the shrub group (includes live + dead biomass).
    - If more than 1 species is present, record the % volume associated with each taxonID on a separate row of the datasheet, repeating the shrubgroupID on each row. Do not repeat canopyArea or groupHeight measurements.
        - The sum of the % volume of all species present should = 100
    - Record the % live and % dead for each species present
        - Sum of % live and % dead should = 100 for each taxonID.

C.11 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. There are, however, a limited number of fern allometries available for estimating biomass for this group.

For Distributed plots only: Ferns may be ignored when sampling Distributed plots if aerial cover of ferns is < 50% of the entire plot area as seen by AOP.

To measure Ferns and fern allies:

1. Determine 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 12)

Table 12. Fern and fern ally morphology groups, and associated required measurements.

Morphology	**Required measurement(s)**
Tree fern or similar	Height
Bracken Fern (*Pteridium sp.)* or similar	Basal stem diameter
Other fern types	Refer to Appendix D for species specific measurements
Not listed here or in Appendix D	• Average frond length (select representative frond to measure) • Number of total fronds

SOP D Field Campaign Follow-up

D.1 Sample preservation

- Place plastic bags with unknown voucher specimens 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 high-resolution 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 Data Dictionary and plot location files that are no longer needed from the high-resolution GPS unit.

SOP E Data Entry and Verification

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

Stem Data Collected Manually with Paper Datasheets

If data were collected manually, transcribe into the appropriate Access database or WebUI according to the procedure outlined in the data entry protocol (RD[04]).

- If data entry occurs within an Access database, there should be one csv file exported for each table, corresponding to each of the four field datasheets for all of the plots measured in a given year.
    - Choose the appropriate table for the field datasheets at hand.
    - Enter data into the data entry tables, identified by '_in' following the table name.
    - Once data have been entered from all plots, append data to running list of entered data, save each tab appended tables as a .csv file for CI ingest.
- Following the first mapping bout at a site, the QAQC datasheet may be filled out as plot data are entered in the ingest workbook to minimize the number of active datasheets in the field.

SOP F Sample Shipment

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

8 REFERENCES

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APPENDIX A DATASHEETS

The following datasheets are associated with this protocol:

Table 13. Datasheets associated with this protocol

NEON Doc. #	Title
NEON.DOC.001573	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 (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 module or subplot 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 "OTHER" NON-WOODY, NON-HERBACEOUS VEGETATION

Growth Form	taxonID	leafNumber[1]	maxCanopyDiameter	ninetyCanopy Diameter	height	basalStemDiameter	aveLeafLength	oldPadNum	newPadNum	Reference
Palms (plm)	*Serenoa repens*	x	x	x	x					Schafer and Mack (2014)
	Sabal etonia	x	x	x	x					Schafer and Mack (2014)
Ferns[2] (frn)	*Athyrium filix-femina*	x					x			Gholz et al. (1979)
	Blechnum spicant	x					x			Gholz et al. (1979)
	Dryopteris austriaca	x					x			Gholz et al. (1979)
	Polystichum munitum	x					x			Gholz et al. (1979)
	Pteridium aquilinum					x				Gholz et al. (1979)
	Cyathea sp.				x					Alves et al. (2010)
Opuntia sp. (cac)								x	x	
Yucca sp. (yuc)			x	x	x					
Xerophyllum tenax (xer)						x	x			Gholz et al. (1979)
Agave sp. (agv)			x	x	x					

[1] Use for Frond-bearing species as well
[2] 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.

APPENDIX E SAFE HANDLING AND MEASUREMENT OF *TOXICODENDRON* SPECIES

The following are best-practice techniques for minimizing exposure to toxic oil during measurement of *Toxicodendron* species.

1. Prior to field work, if *Toxicodendron* is likely to be present in measurement plots:
   - Include safe handling equipment (Table 5) in field supplies
   - Make sure all field technicians are able to identify *Toxicodendron* species by sight.

2. To handle and measure *Toxicodendron* biomass in the field:

- Wear cotton gloves and dispose after single use. Toxic oils can pass through nitrile or latex gloves.
- Wear a thin outer layer of disposable PPE over clothes and shoes.
- Use a pair of clippers dedicated solely to clipping *Toxicodendron spp* to remove leaves from the measurement area to expose the stem and minimize contact
- Measure stem diameter with dedicated, labeled calipers.
- If measuring diameter on a supporting stem > 5 cm DBH:
  - Attempt to thread tape under liana stems if possible; if not possible,
  - Measure the maximum and minimum diameters with calipers and record the average diameter; if not possible,
  - Measure whole diameter (supporting stem + liana) and note in the remarks field (Notes datasheet) how measurement was taken. Use dedicated, labeled DBH tape.
- Clean all equipment that comes in contact with *Toxicodendron* with Tecnu (or equivalent) after each use. Store separately from other equipment to prevent accidental contact.
- Bring a clean, new plastic bag to the field for storing and transporting contaminated gloves and clippers after use.
- After field work is complete, wash clothing according to these guidelines or similar:
- http://laundry.about.com/od/removeoutdoorstains/a/poisonivylaundry.htm

APPENDIX F 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 has been for defined for every 10 m spacing; 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, those identified as bold in this diagram. Plot subplotIDs are determined by the pointID of the SW corner of the subplot area. Plot center will always be pointID 41.

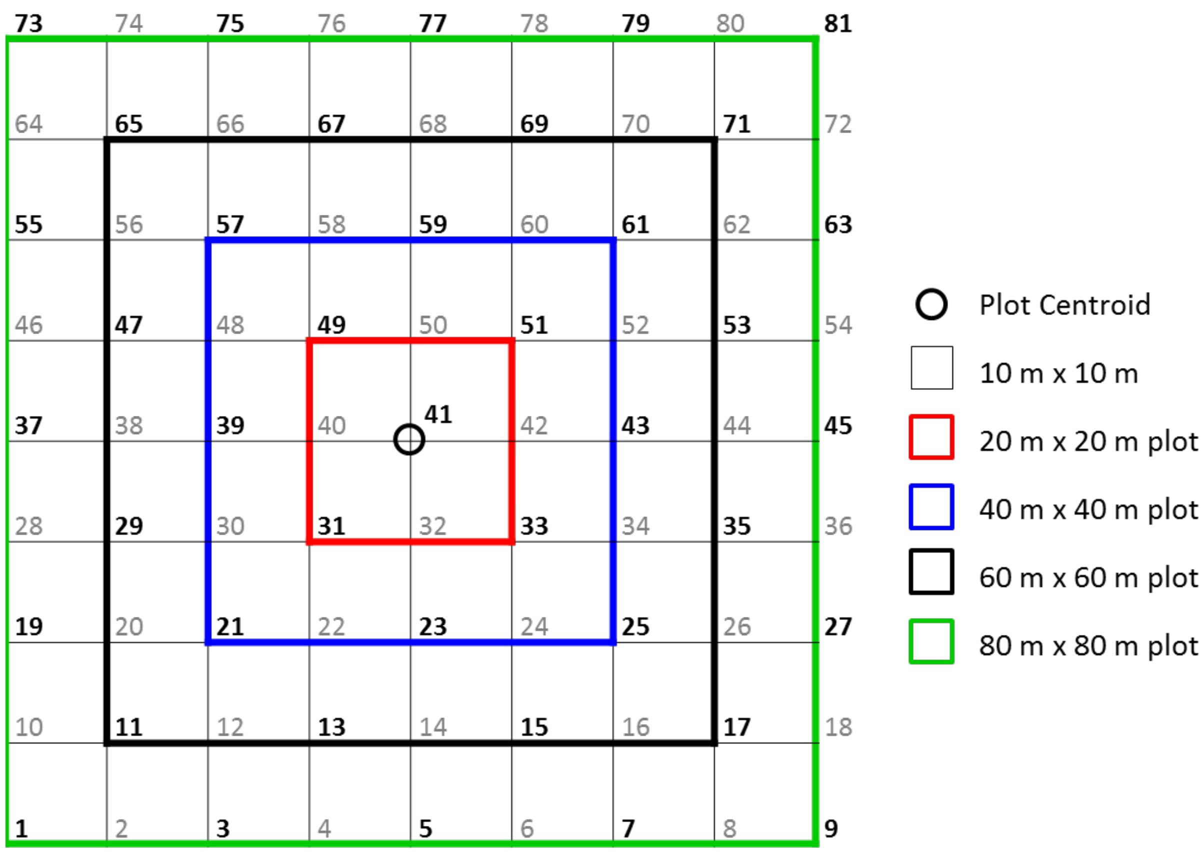

Figure 9. Plot map

APPENDIX G ESTIMATED DATES FOR ONSET AND CESSATION OF SAMPLING

The dates in Table 14 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 14 are estimated from MODIS-EVI phenology data averaged from 2001-2009. Unless indicated otherwise, "End Date" values are in the next calendar year. All dates are provided in day-of-year format.

See Table 15 for "day-of-year → Gregorian date" conversions.

Table 14. Site-specific sampling start and end dates for vegetation structure measurements

Domain Number	Site ID	Start Date	End Date	Protocol Implementation by Plot Type	Additional Sampling Information
01	BART	220	120	Dist = Yes Tower = Yes	Access problems may exist during proposed measurement window.
	SAWB	220	110	Dist = Yes	
	HARV	220	110	Tower = Yes	Access problems may exist during proposed measurement window.
02	BLAN	210	75	Dist = Yes Tower = Yes	
	SCBI	220	85	Dist = Yes Tower = Yes	
	SERC	220	80	Dist = Yes Tower = Yes	

Domain Number	Site ID	Start Date	End Date	Protocol Implementation by Plot Type	Additional Sampling Information
03	DSNY	190	60	Dist = Yes Tower = No	
	JERC	220	90	Dist = Yes Tower = Yes	
	OSBS	190	70	Dist = Yes Tower = Yes	Not all Distributed plots may have qualifying stems.
04	GUAN	Any	60d after start	Dist = Yes Tower = Yes	Start Date should be consistent from year to year (± 2 weeks).
	LAJA	Any	60d after start	Dist = Yes Tower = Yes	Start Date should be consistent from year to year (± 2 weeks).
	MAME	Any	60d after start	Dist = Yes Tower = Yes	Start Date should be consistent from year to year (± 2 weeks).
05	STEI	215	120	Dist = Yes Tower = Yes	Not all Tower plots may have qualifying stems.
	TREE	215	120	Dist = Yes Tower = Yes	
	UNDE	215	125	Dist = Yes Tower = Yes	
06	KONA	NA	NA	Dist = No Tower = No	
	KONZ	210	90	Dist = Yes Tower = No	Isolated stems may be encountered in Distributed plots.
	KUFS	210	75	Dist = Yes Tower = Yes	
07	GRSM	215	90	Dist = Yes Tower = Yes	
	MLBS	220	110	Dist = Yes Tower = Yes	
	ORNL	210	90	Dist = Yes Tower = Yes	
08	CHOC	200	70	Dist = Yes Tower = Yes	
	DELA	205	60	Dist = Yes Tower = Yes	
	TALL	195	75	Dist = Yes Tower = Yes	
09	DCFS	205	120	Dist = Yes Tower = Yes	Isolated stems may be encountered in Distributed plots.

Domain Number	Site ID	Start Date	End Date	Protocol Implementation by Plot Type	Additional Sampling Information
	NOGP	200	115	Dist = Yes Tower = No	Isolated stems may be encountered in Distributed plots.
	WOOD	210	120	Dist = Yes Tower = No	Isolated stems may be encountered in Distributed plots.
10	CPER	210	90	Dist = Yes Tower = Yes (cactus)	Isolated stems may be encountered in Distributed plots.
	RMNP	210	120	Dist = Yes Tower = Yes	
	STER	NA	NA	Dist = No Tower = No	
11	CLBJ	180	60	Dist = Yes Tower = Yes	
	KLEM	NA	NA	Dist = No Tower = No	
	TBD				
12	BOZE	NA	NA	Dist = TBD Tower = TBD	Urban site on college campus.
	PARA	200	105	Dist = Yes Tower = Yes	Isolated stems may be encountered in Distributed and Tower plots.
	YELL	190	120	Dist = Yes Tower = Yes	Access problems may exist during proposed measurement window.
13	MOAB	225	85	Dist = Yes Tower = Yes	Short shrubs, widely spaced; many may not be qualifying stems.
	NIWO	220	140	Dist = Yes Tower = No	Access problems may exist during proposed measurement window.
	TBD				
14	JORN	245	80	Dist = Yes Tower = Yes	
	SRER	240	150	Dist = Yes Tower = Yes	
	TBD				
15	ONAQ	170	75	Dist = Yes Tower = Yes	
	RBUT	190	105	Dist = Yes Tower = Yes	
	TBD				
16	ABBY	205	110	Dist = Yes Tower = Yes	Not all plots may have qualifying stems.
	THAY	205	110	Dist = Yes Tower = Yes	

Domain Number	Site ID	Start Date	End Date	Protocol Implementation by Plot Type	Additional Sampling Information
	WREF	210	115	Dist = Yes Tower = Yes	
17	SJER	95	270	Dist = Yes Tower = Yes	
	SOAP	185	90	Dist = Yes Tower = Yes	
	TEAK	205	120	Dist = Yes Tower = Yes	Access problems may exist during proposed measurement window.
18	BARO	210	TBD	Dist = No Tower = No	Isolated qualifying stems may exist.
	TOOL	205	160	Dist = Yes Tower = Yes	Abundant shrub-scrub vegetation. Access problems may exist during proposed measurement window.
	TBD				
19	DEJU	210	130	Dist = Yes Tower = Yes	Access problems may exist during proposed measurement window.
	HEAL	210	135	Dist = Yes Tower = Yes	Abundant shrub-scrub vegetation. Access problems may exist during proposed measurement window.
	POKE	205	135	Dist = Yes Tower = Yes	Access problems may exist during proposed measurement window.
20	OLAA	Any	60d after start	Dist = Yes Tower = Yes	Start Date should be consistent from year to year (± 2 weeks).
	PUFO	Any	60d after start	Dist = Yes Tower = Yes	Start Date should be consistent from year to year (± 2 weeks).
	PUGR	Any	60d after start	Dist = Yes Tower = Yes	Start Date should be consistent from year to year (± 2 weeks).

Table 15. Day-of-year calendar for non-leap years

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Day
1	001	032	060	091	121	152	182	213	244	274	305	335	**1**
2	002	033	061	092	122	153	183	214	245	275	306	336	**2**
3	003	034	062	093	123	154	184	215	246	276	307	337	**3**
4	004	035	063	094	124	155	185	216	247	277	308	338	**4**
5	005	036	064	095	125	156	186	217	248	278	309	339	**5**
6	006	037	065	096	126	157	187	218	249	279	310	340	**6**
7	007	038	066	097	127	158	188	219	250	280	311	341	**7**
8	008	039	067	098	128	159	189	220	251	281	312	342	**8**
9	009	040	068	099	129	160	190	221	252	282	313	343	**9**
10	010	041	069	100	130	161	191	222	253	283	314	344	**10**
11	011	042	070	101	131	162	192	223	254	284	315	345	**11**
12	012	043	071	102	132	163	193	224	255	285	316	346	**12**
13	013	044	072	103	133	164	194	225	256	286	317	347	**13**
14	014	045	073	104	134	165	195	226	257	287	318	348	**14**
15	015	046	074	105	135	166	196	227	258	288	319	349	**15**
16	016	047	075	106	136	167	197	228	259	289	320	350	**16**
17	017	048	076	107	137	168	198	229	260	290	321	351	**17**
18	018	049	077	108	138	169	199	230	261	291	322	352	**18**
19	019	050	078	109	139	170	200	231	262	292	323	353	**19**
20	020	051	079	110	140	171	201	232	263	293	324	354	**20**
21	021	052	080	111	141	172	202	233	264	294	325	355	**21**
22	022	053	081	112	142	173	203	234	265	295	326	356	**22**
23	023	054	082	113	143	174	204	235	266	296	327	357	**23**
24	024	055	083	114	144	175	205	236	267	297	328	358	**24**
25	025	056	084	115	145	176	206	237	268	298	329	359	**25**
26	026	057	085	116	146	177	207	238	269	299	330	360	**26**
27	027	058	086	117	147	178	208	239	270	300	331	361	**27**
28	028	059	087	118	148	179	209	240	271	301	332	362	**28**
29	029		088	119	149	180	210	241	272	302	333	363	**29**
30	030		089	120	150	181	211	242	273	303	334	364	**30**
31	031		090		151		212	243		304		365	**31**

APPENDIX H GUIDELINES FOR DETERMINING LIANA MEASUREMENT LOCATION

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 **10**. Guidelines for determining where to measure stem diameter (red line) across a variety of complex woody growth forms. Different growth forms correspond to capital letters, and are described more fully in Table **16** below. Cases A-G (top panel) are commonly encountered, and cases H-R (bottom panel) are less common.

Table **16**. Detailed descriptions of measurement guidelines for complex woody growth forms.

Case	**Description**
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.

Case	Description
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.