# TOS PROTOCOL AND PROCEDURE: VST – MEASUREMENT OF VEGETATION STRUCTURE

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# Change Record

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

| REVISION | DATE | ECO # | DESCRIPTION OF CHANGE |
|---|---|---|---|
| | | | Multi-bole tree measurement strategy now consistent with FIA approach, no longer based on liana guidelines.<br>• SOP C: Changed 'stemStatus' to 'status', updated code definitions, added a new code for 'no longer measured'<br>• SOP C: Added paragraph calling out types of 'other' growth forms that require measurement, provided cross-reference to Appendix D for details.<br>• SOP E: Added standardized data entry text<br>• Appendix: Removed *Toxicodendron* handling appendix, due to imminent release of *Toxicodendron* handling SOP. |
| G | 03/09/2017 | ECO-04408 | Summary of protocol changes:<br>• Sampling completion: Specified that bouts must be completed within 4 months of sampling onset.<br>• Expanded instructions for recording Plot Metadata, and changed to annual basis to improve tracking and reporting of sampling effort.<br>• Updated numerous field names to be consistent with Data Products implementation.<br>• Added more guidance for recording `identificationReferences` in the Plot Metadata table, and in the growth-form-specific tables.<br>• Added `tagStatus` to facilitate tracking individuals through time.<br>• Changed `status` to `plantStatus` to comply with pre-existing Data Products term definitions, and added new plantStatus choices.<br>• Expanded broken bole guidance.<br>• Appendix D.2: Updated forking guidelines to be consistent with 2016 Forest Service FIA rules.<br>• Appendix D.5: Clarified that ddh is not measured if access is denied along first 30 cm of stem.<br>• Appendix D.6: Added measurement guidelines for 'sap' and 'sms' individuals.<br>• Appendix F: Clarified that agave and other yucca-like growth forms with large basal rosettes should be measured similar to yucca.<br>• Appendix H: Converted dates from DOY to MM/DD<br>• To address problem with consistent field implementation, shrub 'shape' no longer limited to leafy crown, now consider the entire individual.<br>• Appendix I: Added site-specific modifications, including changes to annual Tower Plot measurement frequency |

| REVISION | DATE | ECO # | DESCRIPTION OF CHANGE |
|---|---|---|---|
| | | | at cold/dry sites (identified 'efficiency' required to be implemented in 2017). |
| H | 7/26/2018 | ECO-05698 | • Sections 1 and 3: Re-organized and simplified text.<br>• Section 3.1: New section with protocol implementation guidelines by plot type, including reference to new Survey Method for Assessment of Vegetation Cover SOP.<br>• Section 4.1: Change to schedule Distributed and Tower Plots in different years at a site.<br>• Section 4.2.1: Clarified that bouts should be completed within 60 d at sites with no distinct growing season.<br>• Section 6: Updated equipment list to support move away from Maximo.<br>• SOP B: Integrated support for digital data collection workflow.<br>• SOP B.1: Clearly called out Shrub Group designation criteria.<br>• SOP B.2, B.3: Added 3 $m^2$ nested subplot size.<br>• SOP B.4: Nails no longer used to tag small trees; loose aluminum wire only to avoid damage.<br>• SOP B.6: Added 'Mapping QA/QC' section to integrate use of 'VST Mapper' application into workflow.<br>• SOP C: Integrated support for digital data collection workflow.<br>• SOP C.1: Simplified tagStatus to 'ok', 'replaced', and 'notTagged'.<br>• SOP C.1: Added plantStatus = 'downed'.<br>• SOP C.1.2: Added explicit guidance to avoid sloughing off bark during DBH measurement.<br>• SOP C.3: Combined agave and yucca growthForm into one 'yucca' growthForm, due to identical measurements.<br>• SOP C.3.2: Added guidance for measuring tree ferns.<br>• SOP E: Added content to support digital data workflow<br>• Appendix I: New site-specific appendices for D04, D14; added WREF to list of sites in Appendix I.1. |
| J | 03/05/2020 | ECO-06386 | • Updated to new template (NEON.DOC.050006vJ)<br>• Reorganized SOPs to better reflect workflow in the field.<br>• Section 4: Re-organized and updated tables to better present scheduling information at different site types and for different event types. |

| REVISION | DATE | ECO # | DESCRIPTION OF CHANGE |
|---|---|---|---|
| | | | • Section 4: Clarified that Tower Plot subset measured annually is 5-10 lowest Morton Order plots with qualifying vegetation.<br>• SOP C.3: Clarified that at sites with both 20m x 20m and 40m x 40m Tower Plots, Vegetation Structure is implemented in the 20m x 20m 'core' of the four larger Tower Plots.<br>• SOP C.2: Clarified that the sum of 'smt', 'sap', 'sis', 'sms', and shrub groups is used to determine one nested subplot size for all of these growth forms.<br>• SOP C.3: Added Sampling Impractical field.<br>• SOP C.3: Added eventType and dataCollected fields to Plot Meta-Data to account for dendrometer band sampling in Tower Plots.<br>• SOP D.2: Measurement height determination for leaning dead now consistent with leaning live individuals.<br>• SOP D.3: Added recordType field to Mapping and Tagging to identify individuals with dendrometer bands, and better categorize existing record types.<br>• SOP D.4: Added text to clarify error correction strategy for Mapping and Tagging records.<br>• SOP E.1: Clarified when to record a new measurement-Height; added new 'changedMeasurementLocation' field to document movement of measurement location along the stem.<br>• SOP E.1: Restored tagStatus = tagRemoved to indicate when an individual drops out of longitudinal dataset.<br>• SOP E.1: Deprecated plantStatus = 14 and restored all codes to previous definitions in earlier protocol versions.<br>• SOP E.1: Added tempID for use with multi-stem smt, sap, sis, and sms growthForms to make records unique.<br>• SOP E.1.2: Added measurementStrategy field for lianas corresponding to illustrated morphologies in SOP E.1.2.<br>• SOP E.1.2: Clarified which 'other' complex growth forms may be measured like lianas.<br>• SOP E.2: Added canopyPosition and crownDiaimeter requirements for all woody growth forms except 'lia' and shrub groups, and added requirement for recording in all plot types.<br>• SOP E.2.1: For broken multi-stem 'sap' and 'sms', crown is now measured even if all stems are broken. |

| REVISION | DATE | ECO # | DESCRIPTION OF CHANGE |
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| | | | For broken 'sis', a broken individual with all stems now < 130 cm length is measured as a 'sms'.<br>• SOP E.4: Added tempID for use with ferns and other non-woody growth forms to make records unique.<br>• SOP E.4.2: Clarified that height for decumbent tree ferns is height above ground and not total stem length.<br>• SOP E.4.3: Clarified that measurementHeight is required for non-woody individuals any time a stem diameter measurement is taken.<br>• SOP F: New SOP to document annual measurement of Tower Plot subset within fast-growth and slow-growth increment sites. Includes dendrometer band installation and measurement procedure.<br>• Appendix C: Updated to include site-specific dendrometer band status and added new 'site type' column to complement updated Section 4 scheduling table.<br>• Appendix D: Site-specific information added for D03, D06, D14, D20, and all sites implementing dendrometer bands. |

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# 1 OVERVIEW

## 1.1 Background

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

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

## 1.2 Scope

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

### 1.2.1 NEON Science Requirements and Data Products

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

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

## 1.3 Acknowledgments

We acknowledge Benjamin Chemel, of the Northern Rockies Conservation Cooperative, who contributed substantially to the initial development and testing of this protocol. Greg Chapman developed liana measurement rules in Appendix G, and additional NEON Field Ecologists have been invaluable with respect to revision and refinement of all aspects of the 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 Program and Management Plan |
| AD[02] | NEON.DOC.004316 | Operations Field Safety and Security Plan |
| AD[03] | NEON.DOC.000724 | Domain Chemical Hygiene Plan and Biosafety Manual |
| AD[04] | NEON.DOC.001155 | NEON Training Plan |
| AD[05] | NEON.DOC.050005 | Field Operations Job Instruction Training Plan |
| AD[06] | NEON.DOC.004104 | NEON Science Data Quality Plan |
| AD[07] | NEON.DOC.000914 | NEON Science Design for Plant Biomass and Productivity |

## 2.2 Reference Documents

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

| | | |
|---|---|---|
| RD[01] | NEON.DOC.000008 | NEON Acronym List |
| RD[02] | NEON.DOC.000243 | NEON Glossary of Terms |
| RD[03] | NEON.DOC.002652 | NEON Level 1, Level 2 and Level 3 Data Products Catalog |
| RD[04] | NEON.DOC.001271 | AOS/TOS Protocol and Procedure: Data Management |
| RD[05] | NEON.DOC.001573 | Datasheets for TOS Protocol and Procedure: Measurement of Vegetation Structure |
| RD[06] | NEON.DOC.014037 | TOS Protocol and Procedure: HBP – Measurement of Herbaceous Structure and Biomass |
| RD[07] | NEON.DOC.014042 | TOS Protocol and Procedure: DIV – Plant Diversity Sampling |
| RD[08] | NEON.DOC.001025 | TOS Protocol and Procedure: Plot Establishment |
| RD[09] | NEON.DOC.001717 | TOS Standard Operating Procedure: TruPulse Rangefinder Use and Calibration |
| RD[10] | NEON.DOC.002150 | NEON Algorithm Theoretical Basis Document: TOS Vegetation Structure – QA/QC of Raw Field Data |
| RD[11] | NEON.DOC.001715 | TOS Standard Operating Procedure: Cactus Biomass and Handling |
| RD[12] | NEON.DOC.001716 | TOS Standard Operating Procedure: Toxicodendron Biomass and Handling |
| RD[13] | NEON.DOC.005023 | TOS Standard Operating Procedure: Survey Method for Assessing Vegetation Cover |
| RD[14] | NA | Manual for Fulcrum Application: TOS Vegetation Structure [PROD] – All SOPs |
| RD[15] | NEON.DOC.003282 | NEON Protocol and Procedure: SIM – Site Management and Disturbance Data Collection |

## 2.3 Acronyms

| Acronym | Definition |
|---|---|
| BH | Breast height; defined here as 130 cm above the ground. For trees growing on a slope, breast height is measured on the uphill side of the bole. |
| DBH | Diameter at breast height |
| ddh | Diameter at decimeter height |
| FIA | Forest Inventory and Analysis program run by the U.S. Forest Service |
| Ha | hectare(s) |
| LAI | Leaf Area Index |
| LiDAR | Light Detection and Ranging |
| NEE | Net Ecosystem Exchange |
| NEP | Net Ecosystem Productivity |
| NPP | Net Primary Productivity |
| VST | Vegetation Structure |

## 2.4 Definitions

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

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

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

| Term | Definition |
|---|---|
| qualifying stem | A stem that meets listed criteria for a given growth form. |
| stemLength | The length of the stem from the root collar or root pedestal to the base of the leaves. |
| understory | Relatively 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

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

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

- SOP A – Preparing for sampling; includes equipment, organizing previously collected data, and dendrometer band fabrication in the laboratory.
- SOP B – Guidelines for classifying woody and non-woody growth forms in the field.
- SOP C – Plot delineation, guidelines for implementing nested subplots, and recording Plot Metadata.
- SOP D – Mapping and tagging requirements by growth form and offset mapping guidance to enable calculation of stem locations.
- SOP E – Vegetation Structure data collected on a 5-year interval; subsections are devoted to stem diameter (E.1), height and crown measurements (E.2), shrub and liana groups (E.3), and 'other' growth forms (E.4).
- SOP F – Vegetation Structure data collected annually in Tower Plots; subsections are devoted to faster-growth sites (F.1), and dendrometer band installation and measurements at slower-growth increment sites (F.2 and F.3).

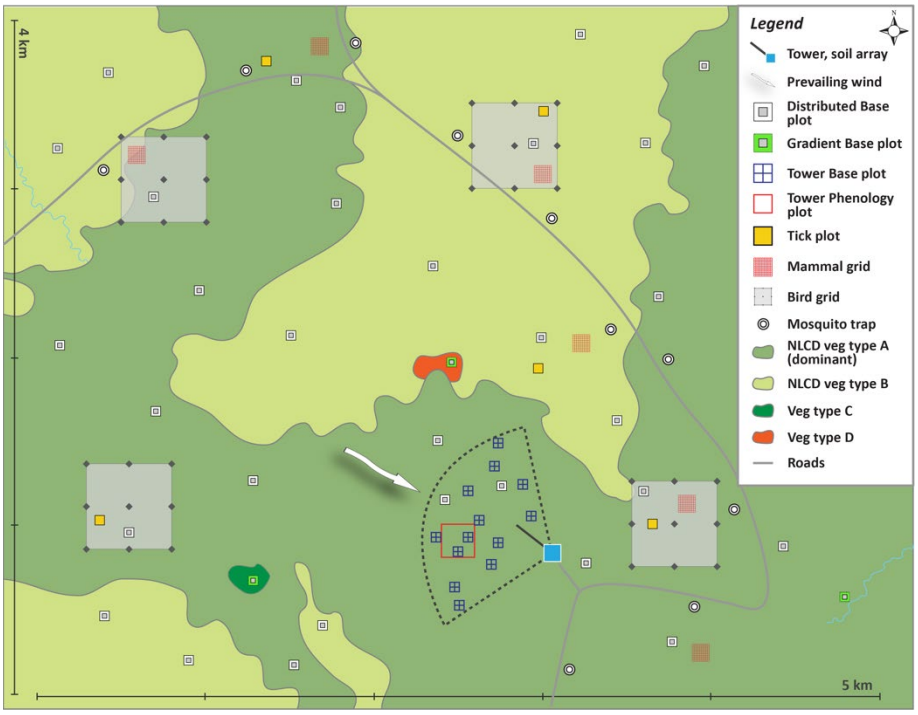



**Figure 1**. Generalized TOS sampling schematic, showing the placement of NEON TOS Plots.

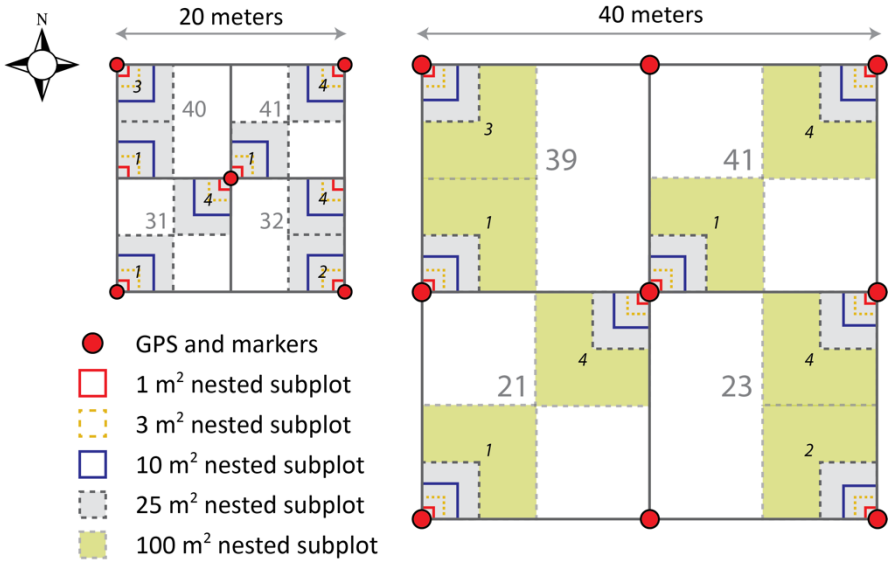



**Figure 2**. A 20m × 20m base plot (left; larger destructive sampling portion of the plot not shown), a 40m × 40m base plot (right), and associated nested subplots used for measuring woody stem vegetation. The 20m x 20m plot size may be used for either Distributed Plots or Tower Plots, and the 40m x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

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

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

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

### 3.1 Protocol Implementation Guidelines by Plot Type

**Table 2**. Vegetation Structure protocol implementation criteria by plot type.

| Plot Type | Guidelines |
|---|---|
| Distributed | • Measurement of Vegetation Structure is determined on a plot-by-plot basis.<br>• Collect data from a plot if any of the following criteria are true:<br>  ○ NLCD vegetation type is Deciduous Forest, Evergreen Forest, or Mixed Forest.<br>  ○ The plot contains at least one single-bole or multi-bole tree individual.<br>  ○ Qualifying woody or non-woody perennial vegetation cover is ≥ 25 % (visual estimate).<br>• If the above criteria are not met, but qualifying woody or non-woody perennial vegetation is present in the plot:<br>  ○ Implement the Survey Method for Assessing Vegetation Cover SOP (RD[13]).<br>  ○ Collect Vegetation Structure data from the plot if qualifying woody or non-woody perennial vegetation is ≥ 10% cover.<br>• Exceptions:<br>  ○ Ferns, Xerophyllum, and Yucca growth forms are not measured when NLCD = Deciduous Forest, Evergreen Forest, or Mixed Forest.<br>  ○ Ferns are not measured when aerial cover is < 50% of the plot by visual estimate AND NLCD is not forest.<br>• Data collection:<br>  ○ Create Plot Meta-Data records for all Distributed Plots assigned to the Vegetation Structure protocol ***if at least one plot contains qualifying vegetation*** (SOP C.3).<br>  ○ 'Mapping and Tagging' and 'Apparent Individual' records are not created for those Distributed Plots with no qualifying vegetation – i.e., Target Taxa Present = 'No' for the entire plot. |
| Tower | • Collect Vegetation Structure data from all plots if any of the following criteria are true:<br>  ○ There is at least one single-bole or multi-bole tree in ≥ 10% of plots.<br>  ○ Qualifying woody or non-woody perennial vegetation cover is ≥ 25 % *averaged across all plots* (visual estimate).<br>• If the above criteria are not met, but qualifying woody or non-woody perennial vegetation is present in ≥ 10% of plots:<br>  ○ Implement the Survey Method for Assessing Vegetation Cover SOP (RD[13]) in all plots.<br>  ○ Collect Vegetation Structure data from plots if qualifying woody or non-woody perennial vegetation is ≥ 10% cover *averaged across all plots.*<br>• Data collection:<br>  ○ Create 'Plot Meta-Data' records for all Tower Plots if Vegetation Structure data are collected from any plots.<br>  ○ Create 'Mapping and Tagging' and 'Apparent Individual' records as above. |

# 4 SAMPLING SCHEDULE

## 4.1 Sampling Frequency and Timing

Vegetation Structure is scheduled in a coordinated fashion with other TOS plant protocols in order to maximize the number of years data are collected from a site, and to minimize spikes in required labor (**Table 3**). The interval between bouts depends on plot type (**Table 4**), and for all plot types, no more than one VST bout is ever scheduled per year. Site specific exceptions are documented in Appendix C.

**Table 3**. Coordination of Measurement of Vegetation Structure with other TOS plant and soil protocols through time. Years 1 through 7 are shown to illustrate the temporal grouping of protocols, and the pattern repeats beyond year 7. Grey cells indicate synchronized 'chemistry' and 'productivity' protocol groups; brown cells indicate protocols implemented annually in Tower Plots; orange cells are protocols implemented every 5 y in Tower Plots.

| Protocol* | Interval (y) | Plot Type | Plot Number | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 | Year 6 | Year 7 |
|---|---|---|---|---|---|---|---|---|---|---|
| BGB | 5 | tower | 20 or 30† | X | | | | | X | |
| CFC | 5 | both | 16-20 | X | | | | | X | |
| LAI | 5 | distributed | 20 | X | | | | | X | |
| LTR-bgc | 5 | tower | 20 or 30† | X | | | | | X | |
| NTR | 5 | both | 10 | X | | | | | X | |
| SLS-bgc | 5 | both | 10 | X | | | | | X | |
| SLS-mb | 5 | both | 10 | X | | | | | X | |
| CDW | 5 | distributed | 20 | | X | | | | | X |
| HBP | 5 | distributed | 20 | | X | | | | | X |
| ***VST*** | 5 | distributed | 20 | | X | | | | | X |
| HBP | 1 | tower | 5 to 30† | X | X | X | X | X | X | X |
| LAI | 1 | tower | 3 | X | X | X | X | X | X | X |
| LTR | 1 | tower | 20 or 30† | X | X | X | X | X | X | X |
| ***VST*** | 1 | tower | 5-10 | X | X | X | X | X | X | X |
| CDW | 5 | tower | 20 or 30† | | | | X | | | |
| ***VST*** | 5 | tower | 20 or 30† | | | | | X | | |

* Protocol codes and definitions: **BGB** = Belowground Biomass of fine root sampling; **CFC** = Canopy Foliar Chemistry sampling; **DIV** = Plant Diversity sampling; **LAI** = Leaf Area Index sampling; **LTR-bgc** = Litterfall biogeochemistry analysis; **NTR** = soil nitrogen mineralization incubation; **SLS-bgc** = Soil biogeochemistry analysis; **SLS-mb** = Soil microbial biomass analysis (PLFA); **CDW** = Coarse Downed Wood tally sampling; **HBP** = Herbaceous Biomass and Productivity sampling; **VST** = Vegetation Structure sampling; **LTR** = Litterfall sampling (no chemistry).

† The total number of Tower Plots sampled varies by site.

***!!!*** Note that for annual VST sampling in Tower Plots a spatially-balanced subset of Tower Plots is selected based on NLCD class and lowest Morton Order. In addition, at sites with dendrometer bands, all banded trees are measured annually regardless of plotID.

- Lists of annually sampled Tower Plots are available via the SSL.

**Table 4**. Scheduling details and SOP implementation on a per site-type and event-type basis. Determine the event type for a given year with reference to the inter-annual schedule and **Table 3**.

| Site Type* | Event Type | Plot Number | Field SOPs | Bout Interval | Remarks |
|---|---|---|---|---|---|
| Faster-growth | All Tower Plots | 20-30 (site dependent) | SOP C<br>SOP D<br>SOP E | 5 y | • All growth forms measured |
| | Distributed and Tower Subset | Dist = 20 (max) | SOP C<br>SOP D<br>SOP E | 5 y | • All growth forms measured |
| | | Tower = 5-10 | SOP C<br>SOP D<br>SOP F.1 | Annual | • Ferns and fern allies not measured |
| | Tower Subset | 5-10 plots | SOP C<br>SOP D<br>SOP F.1 | Annual | • Ferns and fern allies not measured |
| Slow-growth | All Tower Plots | 20-30 (site dependent) | SOP C<br>SOP D<br>SOP E | 5 y | • All growth forms measured |
| | Distributed and Tower Subset | Dist = 20 (max) | SOP C<br>SOP D<br>SOP E | 5 y | • All growth forms measured |
| | | Tower = 5-10 | SOP C<br>SOP D<br>SOP F.2<br>SOP F.3 | Annual | • Ferns and fern allies not measured<br>• Dendrometer band installation and measurement |
| | Tower Subset | 5-10 plots | SOP C<br>SOP D<br>SOP F.2<br>SOP F.3 | Annual | • Ferns and fern allies not measured<br>• Dendrometer band installation and measurement |
| Sensitive | All Tower Plots | 20-30 (site dependent) | SOP C<br>SOP D<br>SOP E | 5 y | • All growth forms measured<br>• No annual measurement of Tower Subset. |
| | Distributed Plots | 20 (max) | SOP C<br>SOP D<br>SOP E | 5 y | • All growth forms measured<br>• No annual measurement of Tower Subset. |
| Survey | All Tower Plots | 20-30 (site dependent) | RD[13] | 5 y | • All plots surveyed<br>• Schedule survey in year prior to potential VST year. |
| | Distributed Plots | 20 (max) | RD[13] | 5 y | • Plot-specific survey criteria<br>• Schedule survey in year prior to potential VST year. |

* See Appendix C for site-specific designations.

***Scheduling Considerations***

1. Bout duration:
    a. All bouts should be complete within 4 months OR before the next growing season begins.
2. Annual Measurements in Tower Plots
    a. A 'productivity subset' of Tower Plots must be measured annually; these plots are typically the 5-10 lowest Morton Order Tower Plots.
        i. The same subset of lowest Morton Order Tower Plots are measured every year.
        ii. In the event that one of the lowest Morton Order Tower Plots does not have qualifying vegetation, the subset of Tower Plots measured annually should be the 5-10 that do have qualifying vegetation.
    b. In addition, at slow-growth increment sites:
        i. Ensure there is enough time in the schedule to measure all banded trees and repair any damaged bands (if necessary).
        ii. Larger individuals may be banded in additional Tower Plots and these individuals are also measured annually.
3. 'Other' vegetation (e.g., cacti, ferns)
    a. Measurement of woody stemmed individuals (i.e. trees, shrubs, lianas) should ideally be coincident with measurement of species classified as 'other' (e.g., ferns, cacti), in order to enable a single sampling effort per year for vegetation structure work.
    b. This idealized sampling schedule means that, at a typical north temperate site, ferns will not be measured at peak greenness.
    c. For those sites with fern species that senesce aboveground every year – e.g., Bracken Fern (*Pteridium aquilinum*) – a separate bout may be required to measure ferns before senescent leaves and stems begin to break apart.

### 4.1.1 Scheduling the Survey Method for Assessment of Vegetation Cover

Section 3.1 describes the vegetation cover criteria that must be met for scheduling Measurement of Vegetation Structure at a site. The Survey Method is used to determine whether a site meets those criteria when a visual assessment is inadequate (**Table 2**, RD[13]).

Scheduling the Survey Method:

- ***All plots***: To enable adequate planning for hiring required staff, schedule the survey the year before a full bout of Vegetation Structure would be needed.
- ***Distributed Plots***: Every 5 y, survey scheduled on a per plot basis.
- ***Tower Plots***: Every 5 y, survey scheduled for all plots.

## 4.2 Criteria for Determining Onset and Cessation of Sampling

***Sampling Onset***

The guiding principle is that vegetation structure measurements should begin after the majority of annual growth in a given growing season has completed. In many systems, the onset of sampling therefore coincides with the end-of-growing-season onset of the senescence phenophase for deciduous and herbaceous plants – i.e., the appearance of colored leaves / needles for trees and shrubs, and reduction in % green for herbaceous plants (**Table 5**).

**Table 5**. Sampling onset guidelines for different site and vegetation types.

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

Estimated sampling windows, including estimated sampling onset and cessation dates, are provided on a per site basis in Appendix C.

- The dates in the appendix are multi-year averages derived from satellite data, and as such, individual future years will vary somewhat with respect to these dates.
- Once a sampling onset date has been selected for vegetation structure measurements at a given site by Field Operations, the onset of sampling in subsequent years should be consistent – i.e. within the same season and vegetation phenophase.
- At each site, the onset of sampling should be the same for all growth forms (except for ferns as discussed above).
    - That is, all growth forms should be measured at a given plot when that plot is sampled.
    - Staff should **NOT** sample trees in all plots first, then re-sample plots for saplings/shrubs and lianas.

***Sampling Cessation***

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

### 4.2.1 Sites with No Distinct Growing Season

For sites with no distinct growing season:

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

## 4.3 Timing for Laboratory Processing and Analysis

Not applicable.

### 4.4 Sampling Timing Contingencies

When unexpected field conditions require deviations from this protocol, the guidance in **Table 6** must be followed to ensure that basic data quality standards are met.

**Table 6**. Schedule delays, contingency guidelines, required actions, and possible outcomes for data product quality.

| Delay | Action | Outcome for Data Products |
|---|---|---|
| Hours to 4 weeks | • If delay prevents completion of a plot or sub-plot, track progress using a plot-specific tagID checklist and mark the measurementHeight with a paintstick for individuals for which data have already been collected.<br>• Resume data collection from the plot or subplot ASAP. | None for woody stem data; ferns may senesce in this time frame, leading to increased uncertainty for this growth form. |
| | • If delay occurs between plots or sub-plots, resume data collection from the next plot or sub-plot ASAP. | None for woody stem data; ferns may senesce in this time frame, leading to increased uncertainty for this growth form. |
| ≥ 4 weeks, outside scheduled window, within protocol window | • If delay prevents completion of a plot or sub-plot, track progress using a plot-specific tagID checklist and mark the measurementHeight with a paintstick for individuals for which data have already been collected.<br>• Reschedule data collection within protocol sampling window ASAP.<br>• Submit incident ticket if growth is active and measurements not completed within originally scheduled window. | • Temporary flagging may be lost, causing duplicate measurements of individuals.<br>• Significant wood growth could occur at sites with year-round growth.<br>• Increased error in aboveground biomass and NPP estimates if growth is active. |
| | • If delay occurs between plots or sub-plots, reschedule data collection within protocol sampling window ASAP.<br>• Submit incident ticket if growth is active and measurements not completed within originally scheduled window. | |
| ≥ 4 weeks, outside scheduled window, AND outside protocol window | • Submit incident ticket if measurements are not completed within the sampling window defined in the protocol. | • Significant wood growth could occur due to onset of next growing season.<br>• Increased error in aboveground biomass and NPP estimates if measurements span > 1 growing season. |

### 4.5 Missed or Incomplete Sampling

Measurement of Vegetation Structure must occur as scheduled and cannot be skipped. See SOP G.1 to document incomplete sampling if a plot or plots cannot be sampled for a bout.

### 4.6 Estimated Time

The time required to implement a protocol will vary depending on a number of factors, such as skill level, system diversity, environmental conditions, and distance between sample plots. The timeframes provided below are estimates 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)(**Table 7**). Use these estimates as a framework for assessing progress. If a task is taking significantly longer than the estimated time, a problem ticket should be submitted. Please note that if sampling at particular locations requires significantly more time than expected, Science may propose to move these sampling locations.

**Table 7**. Estimated staff and labor hours required for implementation of Vegetation Structure SOPs.

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

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

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

# 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.

***Laser Rangefinder Safety***

A laser rangefinder/hypsometer/compass instrument is used to map individual woody stems as points, and to measure various stem structural attributes. Safety considerations for this instrument include:

- Avoid staring directly at the laser beam for prolonged periods. The rangefinder is classified as eye-safe to Class 1 limits, which means that virtually no hazard is associated with directly viewing the laser output under normal conditions. However, as with any laser device, reasonable precautions should be taken during operation. It is recommended that you avoid staring into the transmit aperture while firing the laser.
- Never attempt to view the sun through the scope. Looking at the sun through the scope may permanently damage the eyes.

***Toxicodendron Exposure***

Additional safety issues associated with this field procedure include potential exposure to *Toxicodendron* oils.

- Protocol-specific equipment to mitigate exposure is listed in Appendix E.
- Additional general mitigation strategies are discussed in RD[12].

# 6 PERSONNEL

## 6.1 Training Requirements

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

Protocol-specific training requirements:

- Proper care and use of the laser rangefinder
    - Metal objects must be kept ≥ 50 cm from the unit during operation at all times. This include: eyeglasses, watches, rings, earrings, etc.
    - Although this tool is resistant to dust and water, it is important to seal open ports and use lens caps when not in use.
    - Care must also be taken to avoid scratching lenses.
    - Manufacturer stated accuracy is ± 30 cm for distance measurements. Although measured accuracy may be better than 30 cm, avoid using the laser rangefinder for establishing 1 $m^2$ and 3 $m^2$ nested subplots unless there are no other viable options.
- Tree-height measurement
    - Training is required to ensure accurate height measurements.
    - Training should emphasize why the 3-shot height measurement routine is not suitable for trees. In brief, the 3-shot routine assumes the apex of the crown is directly over the base of the bole; substantial errors in the height calculation are introduced when the apex of the crown is offset from the base of the bole.
- Dendrometer band fabrication, installation, and measurement
    - Repeatability is critical
    - Required to complete online training materials before field work (VST SSL)
    - Individuals should receive OJT and oversight in the field when learning to make dendrometer gap measurements.
    - Individuals should only work independently after demonstrating the ability to make consistent gap measurements.

## 6.2 Specialized Skills

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

# 7 STANDARD OPERATING PROCEDURES

## SOP Overview

**SOP A: Preparing for Sampling.** Tasks completed in the Domain lab, in preparation for the field campaign. Steps to carry out:

- Equipment preparation: Load plot data onto the GPS unit, calibrate the laser rangefinder.
- Prepare previously collected data to aid sampling during the current bout.
- Slow-growth increment sites: Prepare dendrometer band materials.

**SOP B: Woody Growth Form Classification.**

- Guidelines for classifying woody vegetation based on structural attributes and taxonID.

**SOP C: Plot Delineation, Nested Subplots, and Recording Plot Meta-Data**

- Guidelines for using nested subplots to standardize sampling effort across plots.
- Instructions for collecting Plot Metadata to scale individual data to the plot level.

**SOP D: Mapping and Tagging Apparent Individuals**

- Instructions for mapping individuals relative to plot markers, and details for how to tag mapped trees, shrubs and lianas.
- Instructions for assigning appropriate taxonIDs to woody vegetation.

**SOP E: Vegetation Structure Data Collected on a 5-year Interval**

- Steps to collect Stem Diameter, Height and Crown data, Shrub Group data, and structure data from 'other' non-woody growth forms.
- Implemented when all Tower Plots or Distributed Plots are sampled on a 5-year interval.

**SOP F: Vegetation Structure Data Collected Annually in Tower Plots**

- Faster-growth sites: Annual structure measurements in the Tower Plot 'productivity subset'.
- Slow-growth increment sites:
    - Dendrometer band fabrication and fitting in the field, as well as initial dendrometer band measurements.
    - Annual structure measurements in the Tower Plot 'productivity subset'.

**SOP G: Field Campaign Follow-up.** Steps following successful completion of field work.

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

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

## SOP A Preparing for Sampling

### A.1 Preparing for Data Capture

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

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

### A.2 Preparing Equipment

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

## A.3 Preparing Previously Collected Data

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

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

### A.4 Dendrometer Band Fabrication in the Laboratory

Laboratory preparation of dendrometer bands for installation in the field is required for NEON sites with relatively slow-growth increment woody vegetation. The list of slow-growth increment sites is provided in Appendix C.

- Site-specific lists of trees for which bands are required are provided via the SSL.
- VST data are analyzed by Science every 5 y to identify any additional trees that may require banding at each slow-growth increment site.
- Dendrometer band components are custom-made in the laboratory using *VST: Apparent Individuals* data from the previous sampling event.
- SOP F.2 describes final fitting and installation of these bands in the field.

***Procedure steps:***

1. Equipment and materials check: Purchase additional banding, springs, and replacement tools as necessary.
2. Download *VST: Apparent Individual* tree data from the previous sampling event and filter to only those trees that will receive new dendrometer bands.
3. Create list of trees per plot and include the following data fields: plotID, subplotID, tagID, taxonID, growthForm, stemDiameter, templateSize, and springLength.
    a. See Appendix G to assign required templateSize and springLength.
4. Calculate total band length needed for each tree using the appropriate template in Appendix G.
    a. Total length (dcm) = [**stemDiameter** (nearest 0.1 cm) + overlap (from template)]
    b. *Example*: For a tree with stemDiameter = 30.1 cm, the band length needed is,

    Total length (dcm) = [30.1 dcm + 4.5 dcm] = 34.6 dcm (measured with DBH tape)
5. Cut a supply of dendrometer band 'collar' pieces; one collar per banded tree plus sufficient extras (**Figure 3**). Collars will be used in the field during band installation.
    a. Cut 2.5 cm length collar pieces: Length = 2X width of band.

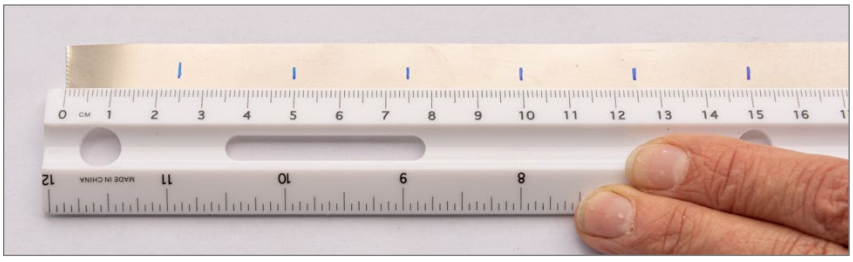


**Figure 3**. Dendrometer band material marked every 2.5 cm for cutting 'collars' in preparation for installation in the field.

6. Pre-fabricate a custom dendrometer band for each tree. For a video tutorial, see Dendrometer Band Installation and Measurement in the Training Center. *Optional: Wear light gloves for protection.*

    a. Stretch DBH tape L to R along work surface with diameter centimeter equivalent (dcm) side facing up and '0' on the left. Secure flat to surface with tape.

    b. Load banding into customized dispenser bucket, and place to left of DBH tape. A bucket with a slit cut in the side at the bottom through which banding may be fed will suffice.

    c. Cut lengths of lab tape (10-15 cm), and label one per band (plotID, subplotID, tagID, springType).

    d. Spool out banding from the bucket and lay on table below DBH tape (closer to yourself).

    e. Use DBH tape and template guidance to cut a custom length of banding for each tree (Appendix G).

    f. Mark the following on the band:

        i. Tip punch location (**point** centered on band).

        ii. Window start (closest to tip punch point).

        iii. Window end.

    g. Create the tip punch.

        i. Wiggle gently to remove the band from the punch if the punch is incomplete.

        ii. Wiggle hanging chad back and forth to break cleanly off from band.

    h. Trim the tip corners.

    i. Cut the window end. Cut perpendicular to the band, width of cut is 1/3 width of band (do not cut more than ½ the band width). Start over if you make the cut > ½ the band width.

        i. Cut must be clean. To minimize burring and deforming the metal, place band deep into snips, do NOT use the tips of the snips (**Figure 4**).

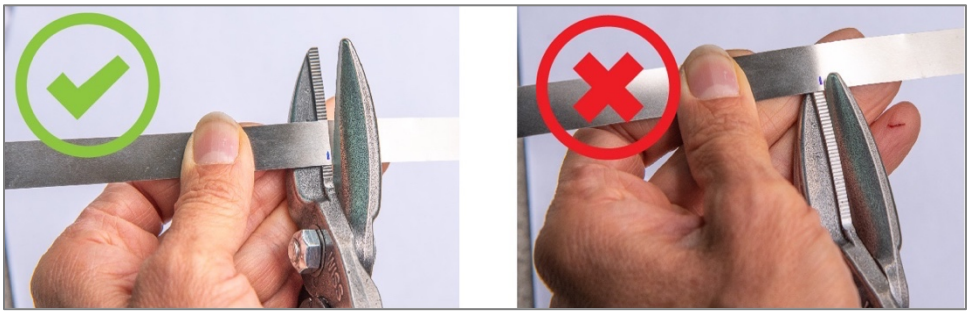


**Figure 4**. (*Left*) Correct metal-snip technique for cutting the measurement window in a dendrometer band. (*Right*) Incorrect technique using the tip of the metal snips will result in burrs and band deformation.

j. Cut the window (**Figure 5**).

i. Begin just before the window start and cut inward toward the window end. The major line of the cut should be 1/3 of the way into the band. Okay to eyeball.

ii. Cut toward the previously made perpendicular window end cut. Intersect at right angles as perfectly as possible to minimize burring and to provide a clean right angle for caliper measurement.

iii. Wiggle the window cut-out to break off and remove.

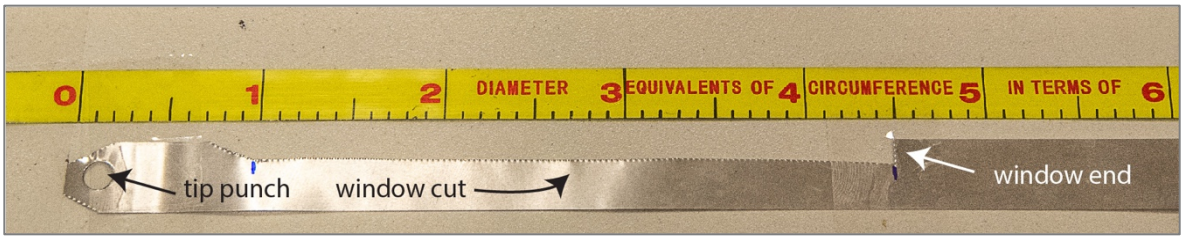



**Figure 5**. Completed preparation of a dendrometer band showing tip punch (left), window cut (center), and window end from which measurements are made in the field (right). Note the DBH tape is taped to the work surface with diameter centimeter equivalents (dcm) facing up, not centimeters.

k. Flatten/remove any burrs or bends. Burrs prevent smooth sliding through the buckle during installation.

l. Roll up and secure with labeled tape.

7. Bag up all bands for a given plotID. Suggest using 1 gallon ziploc per plotID.

8. Load a 'tackle box' with:

a. Collars

b. Springs

c. Spare banding material

d. Nails, stainless steel or aluminum (1-3 per tree for trees with DBH ≥ 60 cm)

## SOP B Woody Growth Form Classification

Consistent classification of woody individuals to growth form is required for:

- SOP C – Implementation of nested subplots; selecting an appropriate nested subplot size depends on the abundance of different growth forms within the plot.
- SOP D – Understanding which woody individuals are mapped within the plot.
- SOP E – Determining a consistent measurement strategy for woody apparent individuals.

Woody vegetation is broadly classified to growth form according to USDA Plants Growth Habits. Growth forms assigned to individuals are therefore informed by stem diameter (DBH or ddh), height, and site-specific knowledge of the species in question (**Table 8**, **Figure 6**, **Figure 7**, and see **Box 1** for examples). Required measurements for each growth form are summarized in **Table 9**. Note that individuals may change growth form from one year to the next, due to normal growth or damage (i.e., loss of boles or stems). Additional 'other' growth forms are used for non-woody vegetation that is also measured via this protocol (see SOP E.4).

The distinction between 'apparent individuals' and 'groups' is also used when woody classifying vegetation. In general small trees, saplings, shrubs, and small shrubs can exist either:

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

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

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

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

**Table 8**. Growth forms into which woody vegetation is classified and their definitions. Parentheses following terms in the list below indicate the 3-letter code used for each growth form.

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

***Box 1.*** *Growth form classification examples.*

***Example 1***: A *Quercus alba* individual in the eastern U.S. may be classified as either a sapling (sap), a small tree (smt), a single-bole tree (sbt), or a multi-bole tree (mbt), depending on life stage and the specific growth habit of the individual. However, a small *Q. alba* individual would not be classified as a small shrub (sms) or single shrub (sis) because this species is broadly recognized as a tree species (e.g., USDA PLANTS), and the biomass of large and small individuals can be estimated using general allometric equations developed for trees (e.g., Jenkins et al. 2004, Chojnacky et al. 2013).

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

***Example 3****: Rhododendron spp.* may grow large enough that one or more stems have DBH ≥ 10 cm. If only DBH and stem count are considered, **Figure 7** on its own would have large *Rhododendron* individuals classified either as a single-bole tree (multiple stems, but DBH of only one bole ≥ 10 cm) or a multi-bole tree (more than one bole with DBH ≥ 10 cm). However, considering *Rhododendron spp.* are usually < 4 – 5 meters height, these large individuals are classified as single shrub (sis).

***Example 4****:* A young Interior Live Oak (*Quercus wislizenii*) may split below 130 cm into multiple boles with 10 cm > DBH ≥ 1 cm. Because this species routinely achieves single- and multi-bole tree status, smaller individuals are classified as 'small tree', rather than 'single shrub' (see dashed arrow in **Figure 7**).

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

***Example 6****:* Species information may not be informative with respect to assigning growth form. For example, *Toxicodendron spp*. commonly exist as lianas, small shrubs, and shrub groups. For species like *Toxicodendron spp*., growth form is assigned on a per individual basis according to observed attributes and not species-level tendencies.

Below, **Figure 6** provides high-level classification information, and **Figure 7** indicates how low-level growth form classifications are informed by structural and taxonomic data. To make a consistent classification, use the flow charts in combination with the definitions in **Table 8**, and use knowledge of species-level growth habits at a site.

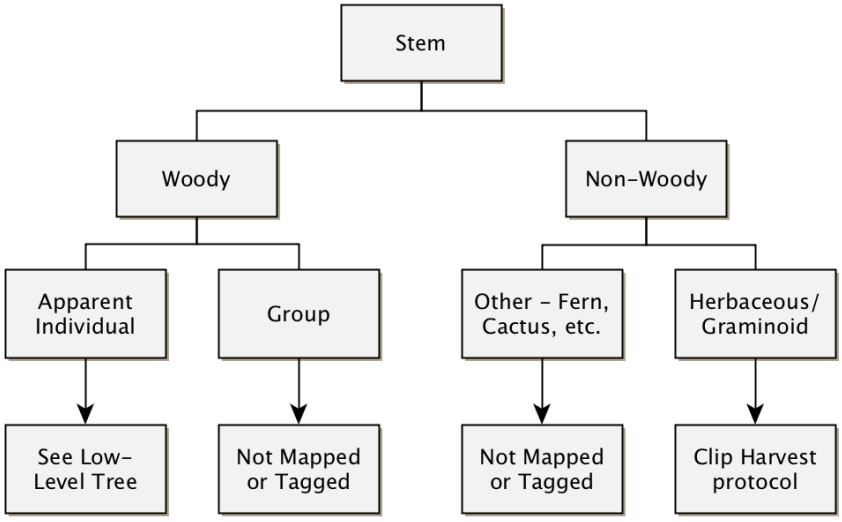



**Figure 6**. High-level classification tree for assigning vegetation to growth form and assigning the correct protocol.

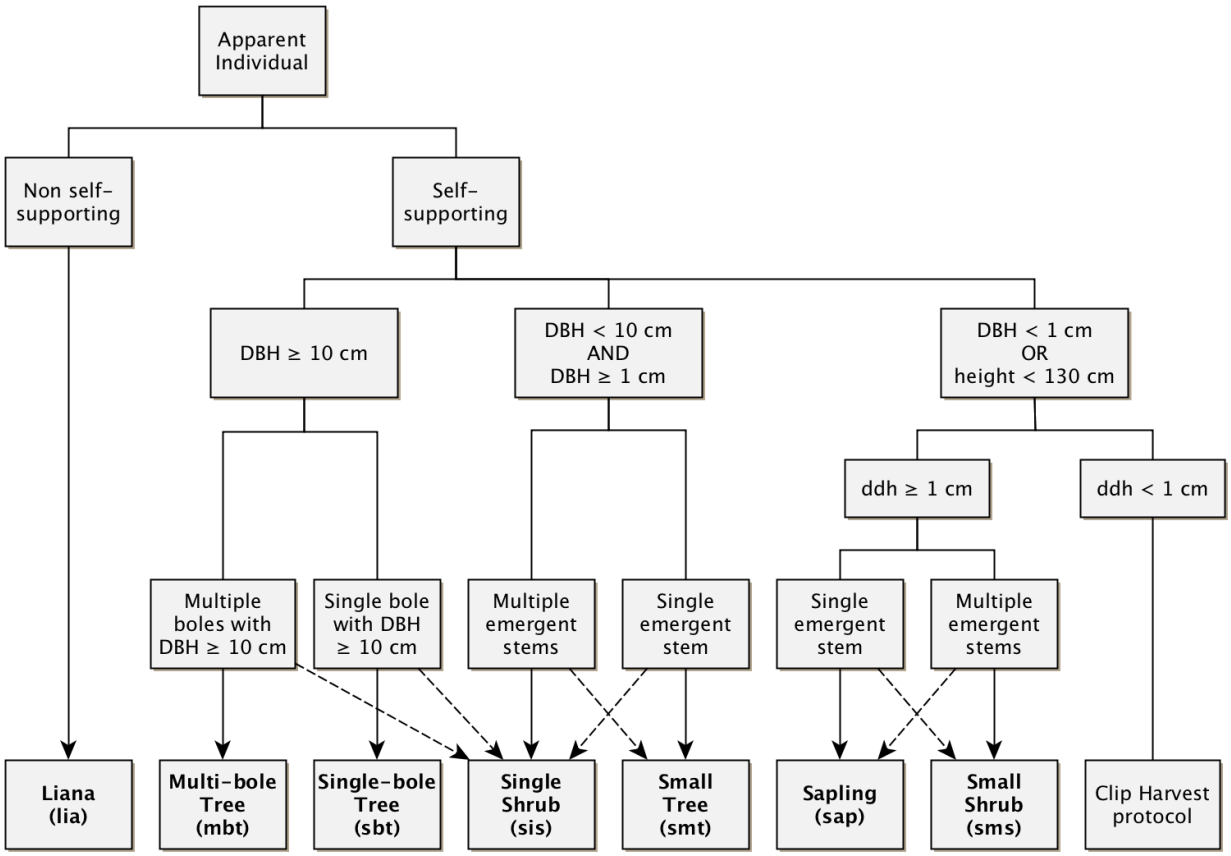



**Figure 7**. Detailed classification tree indicating how structural observations and stem diameter data inform the classification of apparent individuals to growth form. Dashed lines call out points where growth form classification may change after considering height and species-specific information.

**Table 9**. Summary of required measurements for each growth form. Note that individuals may change growthForm from one year to the next, potentially necessitating different measurements from year-to-year (e.g., a change from 'sapling' to 'small tree').

| Growth Form | Stem Diameter | Height | Crown Diameter | Additional Measurements |
|---|---|---|---|---|
| **Liana (lia)** | • stemDiameter (DBH)<br>• measurementHeight<br>• see Appendix E for complex cases | • Not measured | • Not measured | • plantStatus |
| **Single bole tree (sbt)** | • stemDiameter (DBH)<br>• measurementHeight<br>• See **Table 13** and SOP E.1 for complex cases | • vdApexHeight = Maximum height above observer<br>• vdBaseHeight = Height from observer to base of tree (typically a negative number) | • Maximum diameter<br>• Perpendicular to max | • plantStatus<br>• canopyPosition (**Table 17**) |
| **Multi-bole tree (mbt)** | • stemDiameter (DBH, per bole)<br>• See Appendix D.2 to determine correct measurementHeight | Measure per individual, not per bole.<br>• vdApexHeight = Maximum height of tallest bole above observer (not per bole)<br>• vdBaseHeight = Height from observer to base of tree (typically a negative number) | • Per individual, not per bole<br>• Maximum diameter<br>• Perpendicular to max | • plantStatus (per bole)<br>• canopyPosition (per individual, not per bole, **Table 17**) |
| **Small tree (smt)** | • stemDiameter (DBH)<br>• measurementHeight<br>• See **Table 13** and SOP E.1 for complex cases<br>• Measure multiple boles if applicable | Measure per individual (not per bole).<br>• vdApexHeight (top) and vdBaseHeight (ground)<br>• Record vdBaseHeight = 0 if total height is measured from the ground with a collapsible ruler | • Per individual, not per bole<br>• Maximum diameter<br>• Perpendicular to max | • plantStatus (per bole)<br>• canopyPosition (per individual, not per bole, **Table 17**) |
| **Sapling (sap)** | • basalStemDiameter (ddh)<br>• measurementHeight<br>• Measure multiple emergent boles if present (SOP E.1) | Measure per individual, not per bole.<br>• vdApexHeight = Maximum height<br>• Record vdBaseHeight = 0 if total height is measured from the ground with a collapsible ruler | • Not measured | • plantStatus (per bole)<br>• canopyPosition (per individual, not per bole, **Table 17**) |

| Growth Form | Stem Diameter | Height | Crown Diameter | Additional Measurements |
|---|---|---|---|---|
| **Single shrub (sis)** | • basalStemDiameter (ddh, per qualifying emergent bole)<br>• stemDiameter (DBH, only on largest diameter fork per emergent bole)<br>• ddh and DBH measurementHeight<br>• See SOP E.1 for complex cases | Measure per individual, not per bole.<br>• vdApexHeight = Maximum height<br>• Record vdBaseHeight = 0 if total height is measured from the ground with a collapsible ruler | • Per individual, not per bole.<br>• Maximum diameter<br>• Perpendicular to max | • plantStatus (per bole)<br>• canopyPosition (per individual, not per bole, **Table 17**)<br>• shape<br>• If shape=icn: maxBaseCrown-Diameter, and ninetyBaseCrown-Diameter<br>• If shape=elp: height to crown base |
| **Small shrub (sms)** | • basalStemDiameter (ddh, per qualifying emergent stem)<br>• measurementHeight<br>• Measure multiple emergent stems if present (SOP E.1)<br>• Broken emergent stems must be ≥ 30 cm height (or stem length) to qualify for measurement (SOP E.1) | Measure per individual, not per stem.<br>• vdApexHeight = Maximum height<br>• Record vdBaseHeight = 0 if total height is measured from the ground with a collapsible ruler | • Per individual, not per bole<br>• Maximum diameter<br>• Perpendicular to max | • plantStatus (per bole)<br>• canopyPosition (per individual, not per bole, **Table 17**)<br>• If shape=icn: maxBaseCrown-Diameter, and ninetyBaseCrown-Diameter<br>• If shape=elp: height to crown base |
| **Shrub group (sgr)** | • Not measured | • Five points that best represent overall height of the group | • Crown area; graph paper method | • % contribution to total volume (per species)<br>• % live (per species)<br>• % dead (per species) |
| **Fern (frn)** | • Species dependent; see SOP E.4 | • Height measured for tree ferns only<br>• Maximum height<br>• Record vdBaseHeight = 0 if total height is measured from the ground with a collapsible ruler | • Not measured | • plantStatus<br>• Species dependent; see SOP E.4 |

| Growth Form | Stem Diameter | Height | Crown Diameter | Additional Measurements |
|---|---|---|---|---|
| **Palm (plm)** | • stemDiameter (DBH, tree palms only)<br>• If present, record 'DBH contains leaf base' in **remarks** field<br>• See SOP E.4 | • Maximum height<br>• For tree palms, typically measure vdApexHeight (top) and vdBaseHeight (ground)<br>• Record vdBaseHeight = 0 if total height is measured from the ground with a collapsible ruler | • Species dependent; see SOP E.4 | • plantStatus<br>• canopyPosition (**Table 17**)<br>• Species dependent; see SOP E.4 |
| **Yucca (yuc)** | • Not measured | • Maximum height<br>• Record vdBaseHeight = 0 if total height is measured from the ground with a collapsible ruler | • Maximum diameter<br>• Perpendicular to max | • plantStatus |
| **Bear Grass (xer)** | • basalStemDiameter (per flowering stem) | • Not measured | • Not measured | • meanLeafLength |
| **Ocotillo (oco)** | • Not measured | Measure per individual, not per stem.<br>• Maximum height<br>• Record vdBaseHeight = 0 if total height is measured from the ground with a collapsible ruler | • maxBase Crown-Diameter<br>• ninetyBase Crown-Diameter | • Basal count of stemNumber |

## SOP C Plot Delineation, Nested Subplots, and Recording Plot Meta-Data

***Overview***

This SOP describes implementation of nested subplots to standardize sampling effort across plots and growth forms, and recording critical plot meta-data that allows data-users to accurately scale biomass estimates to the plot level (**Figure 8**).

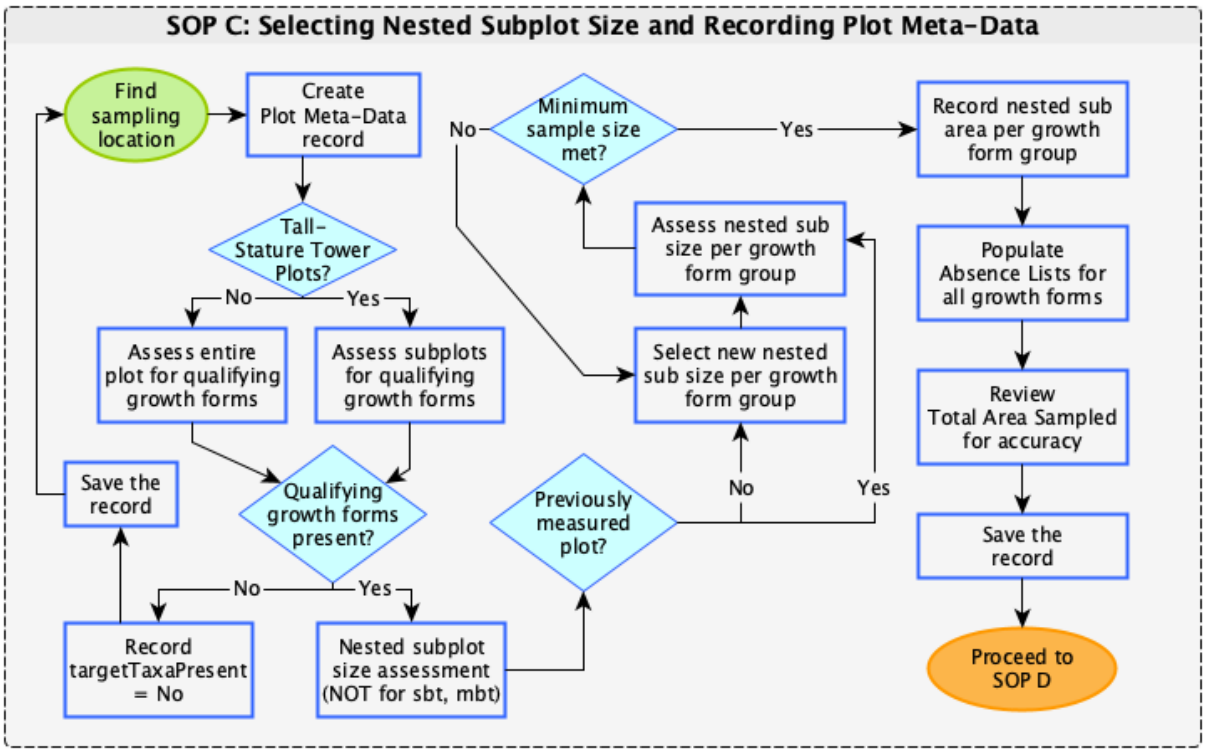



**Figure 8**. SOP C workflow diagram for growth form survey, nested subplot assessment, and recording Plot Meta-data. The term 'Tall-Stature Tower Plot' applies to sites where all Tower Plots are 1600 $m^2$. Diagram supports and does not replace protocol text; most common workflow is outlined.

Fulcrum applications used to collect data for this SOP:

- ***VST: Plot Meta-Data [PROD]*** application. Collect growth form presence/absence data and nested subplot size data.
- The Vegetation Structure Fulcrum Manual on the SSL contains detailed data entry instructions.

## C.1 Spatially Linked Protocols

***Plant Diversity***

- Plant Diversity sampling occurs in all Distributed Plots that support Measurement of Vegetation Structure.
- Plant Diversity sampling occurs in 3 selected Tower Plots that support Measurement of Vegetation Structure.
- Plant Diversity and Vegetation Structure utilize the same 1 $m^2$ and 10 $m^2$ nested subplots.
- Mitigate trampling and impact on the vegetation as much as possible when implementing Vegetation Structure in 1 $m^2$ and 10 $m^2$ nested subplots. This will ensure that data are of the highest possible quality from these sampling locations.

***Litterfall and Fine Woody Debris***

- Litterfall collections take place in all Tower Plots that support Measurement of Vegetation Structure.
- Avoid foot traffic through 3m x 0.5m litter ground traps to prevent damage to qualifying particles within the ground traps.

## C.2 Nested Subplot Dimensions and Guidelines

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

- On a per plot basis, nested subplot size may be chosen independently for:
    - The sum of '***smt + sap + sis + sms + shrub groups***'
    - Lianas
    - Any '***other'*** qualifying vegetation, including palms, yucca, ferns, etc. (see **Table 18** for a full list of 'other' qualifying vegetation).
- ***For all growth forms, the chosen nested subplot size must be used for the entire plot***.
    - *In a 20m x 20m Distributed or Tower Plot*: Sample a minimum of 20 individuals across the entire plot (see ***Box 2***).
    - *In a 40m x 40m Tower Plot*: Sample a minimum of 20 individuals for at least one 20m x 20m subplot (see ***Box 3***).

Subplot and nested subplot details are illustrated in **Figure 2**, and compiled below in **Table 10**. Nested subplots are numbered in sequence beginning with the SW corner of the subplot; SW=1, SE=2, NW=3 NE=4 (**Figure 2**).

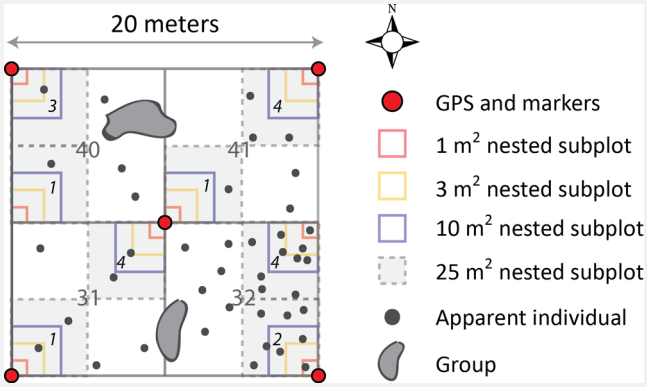
**Table 10**. Supported subplot and nested subplot dimensions that vary with plot size. The decision to use nested subplots is made on a per plot basis, and allows standardization of sampling effort across plots.

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

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

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

- 1 $m^2$: 2 apparent individuals sampled → insufficient sample size
- 3 $m^2$: 5 apparent individuals sampled → insufficient sample size
- 10 $m^2$: 12 apparent individuals sampled → insufficient sample size
- 25 $m^2$: 28 apparent individuals sampled → sufficient sampling effort, use 25 $m^2$ nested subplots throughout the entire plot.




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

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

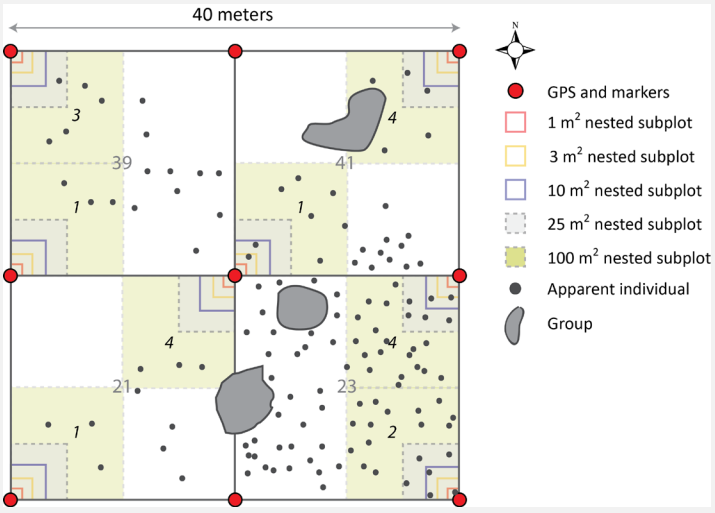
In this scenario, we again consider whether nested subplots might be employed for measuring individuals with DBH < 10 cm that are heterogeneously distributed throughout the plot (Figure below). Here, assume subplots 23 and 41 are prescribed for sampling, so we do not consider subplots 21 and 39 further.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

- 1 $m^2$: 1 apparent individual sampled → insufficient sample size
- 3 $m^2$: 2 apparent individuals sampled → insufficient sample size
- 10 $m^2$: 5 apparent individuals sampled → insufficient sample size
- 25 $m^2$: 12 apparent individuals sampled → insufficient sample size
- 100 $m^2$: 45 apparent individuals sampled → sufficient sampling effort, use 100 $m^2$ nested subplots throughout the entire plot.

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

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

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




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

## C.3 Plot Delineation and Recording Plot Meta-Data

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

The *VST: Plot Meta-Data [PROD]* application communicates an accurate, detailed per plot per year report of growthForm presence / absence at the scale of the nested subplot, such that the total area sampled and completeness of the scheduled sampling effort are clearly documented in the data for end-users. These data are critical for scaling purposes – i.e., calculation of biomass or productivity per unit area.

***Procedure steps:***

1. Create a record in the *VST: Plot Meta-Data [PROD]* application. Enter required information:
    a. **siteID**
    b. **yearBoutBegan**; for bouts that span > 1 calendar year, ALL records should be assigned the year in which the bout began.
    c. **eventType**; choices correspond to the types of plots scheduled for sampling for the year, as shown in **Table 4**. Select from:
        i. **allTowerPlots**; all Tower Plots are measured for the bout and NO Distributed Plots are measured.
        ii. **towerSubset**; select when a subset of Tower Plots are measured on an annual basis and NO Distributed Plots are measured.
        iii. **distributedAndTowerSubset**; all specified Distributed Plots are measured AND the subset of Tower Plots measured annually are sampled.
    d. **plotID**
        i. If working in a site with both 20m x 20m and 40m x 40m Tower Plots, implement the Vegetation Structure protocol in the 20m x 20m 'core' of the four larger Tower Plots.
        ii. If working in a site with all Tower Plots = 40m x 40m, the app will display **randomSubplotA** and **randomsubplotB** subplotIDs that have been selected for sampling.
    e. **Previous year's plotID**; if the plot has been measured in a prior year, the nested subplot sizes selected in the previous bout will be displayed for reference.

f. **Sampling Impractical**; populate if it is not possible to collect VST data from the plot for the current bout (**Table 11**).

**Table 11**. Protocol-specific Sampling Impractical reasons entered in the Fulcrum application. In the event that more than one is applicable, choose the dominant reason sampling was missed.

| Sampling Impractical reason | Description |
|---|---|
| Extreme weather | Events (e.g., thunderstorms, hurricanes) that compromise safety and access |
| Location flooded | Standing or flowing water too deep to complete sampling |
| Logistical | Site or plot access compromised, staffing issues, errors (e.g., equipment not available in the field) |
| Management | Management activities such as controlled burn, pesticide applications, etc. |
| Other | Sampling location inaccessible due to other ecological reason described in the **remarks** |

g. **dataCollected**; indicates which data are collected in the plot for the current bout. The selected choice controls whether **Nested Subplot Sampling Area** is entered and thus whether data can be scaled to the plot (e.g., kg $ha^{-1}$).

i. **allGrowthForms**; select when all growth forms that exist in the plot are measured for the current bout.

ii. **dendrometerOnly**; select if only trees fitted with dendrometer bands are measured within the plot for the current bout. Combined with **eventType**, this selection allows end-users to find data needed for annual productivity calculation at slow-growth increment sites.

h. **samplingProtocolVersion**; the version of the Vegetation Structure protocol used.

2. Delineate the plot or subplot. Use existing plot markers, meter tapes, and chaining pins to carefully delineate the plot / subplot boundaries.

a. 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.

b. Individuals are only measured when ≥ 50% of the individual (or ≥ 50% of the stems, for a multi-stemmed individual) are rooted within the measurement area.

c. 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. Assess the entire plot or the entirety of the assigned random subplots for presence/absence of ***qualifying*** woody and non-woody growth forms (**Table 8** and **Table 18**). Per plot presence/absence data demonstrate the completeness of the sampling effort to data users.
    a. Not required when **dataCollected** = 'dendrometerOnly'.
    b. If ***qualifying*** vegetation for all growth forms is absent from the entire plot or both randomly selected subplots:
        i. Select **targetTaxaPresent** = 'No' in the *VST: Plot Meta-Data* 'presenceAbsence' section.
        ii. Save the record and proceed to the next plot.
    c. If ***qualifying*** vegetation is present in the plot, further indicate which growth forms are present somewhere in the plot or in the assigned random subplots.
        i. Select **targetTaxaPresent** = 'Yes' in the *VST: Plot Meta-Data* 'presenceAbsence' section.
        ii. Record growth form-specific **targetTaxaPresent** = 'Yes/No' for all growth forms listed below. If vegetation is present but does not qualify for measurement select **targetTaxaPresent** = 'No'.
            a) Trees (sbt, mbt)
            b) Shrubs, Saplings, and Small Trees (includes sum of sis + sms + smt + sap + shrub groups)
            c) Lianas
            d) Other – Cacti
            e) Other – Ferns; note that in Distributed Plots it is possible for ferns to be recorded as present here, but no Apparent Individual data are recorded if fern cover within the plot is < 50%.
                (1) Record in **remarks**, "Insufficient fern cover for measurement".
            f) Other – Yucca
            g) Other – Palms
            h) Other – Ocotillo
            i) Other – Xerophyllum (Bear Grass)

4. For the 'Shrubs, Saplings, and Small Trees' group, 'Lianas', and all 'Other' growth forms present in the plot, determine separately whether nested subplots may be employed to constrain sampling effort (SOP C.2). ***Never use nested subplots for 'sbt' or 'mbt' growth forms.***
    a. Not required when **dataCollected** = 'dendrometerOnly'.
    b. For a plot that HAS been sampled previously: Typically use the **same nested subplot size each year** in order to ensure that repeat measurements are made on tagged stems.
        i. In the *VST: Plot Meta-Data* app, select **previous year's plotID** to view previously selected nested subplot sizes.
        ii. Survey for recruitment of newly qualifying individuals. If significant and persistent changes in stem density have occurred over time, due to succession, self-thinning, natural disturbance, or management activities, discuss with Science whether a change in nested subplot size is warranted.
    c. For a plot that has NOT been measured previously: Assess vegetation density and select an optimal nested subplot size (SOP C.2).
5. Delineate nested subplots and record the **Nested Subplot Sampling Area** in the *VST: Plot Meta-Data* app for each growth form present in the plot that qualifies for nested subplots.
    a. Not required when **dataCollected** = 'dendrometerOnly'.
    b. Enter 'noneSelected' if not using nested subplots for a growth form due to low stem density.
    c. 'noneSelected' is also auto-populated for growth forms not present in the plot.
6. Populate **Absence Lists** to demonstrate to end-users that all subplots/nested subplots have been surveyed for all growth forms present and to manage expectations of which records are expected in the Apparent Individuals table.
    a. Not required when **dataCollected** = 'dendrometerOnly'.
    b. For each growth form present in the plot, select any subplots or nested subplots that were surveyed and did NOT contain individuals of that growth form.
    c. Select 'presentInAll' if the growth form was present in all nested subplots surveyed.
7. Review auto-calculated **Total Area Sampled** values to ensure a match between what is recorded and what was sampled in the field.
    a. If necessary: Update **Nested Subplot Sampling Area** to match actual sampling effort
8. Save the record.

## SOP D Mapping and Tagging Apparent Individuals

***Overview***

This section describes the tagging procedure for woody and non-woody perennial individuals that qualify for measurement, and provides the offset mapping procedure for individuals that additionally qualify for mapping.

- See **Table 12** for mapping and tagging requirements by growth form.
- Data collected as part of this SOP are recorded in the ***VST: Mapping and Tagging [PROD]*** application.
- Consult the 'Manual for Fulcrum Application: TOS Vegetation Structure [PROD] – All SOPs' for data entry details (RD[14]).
- If structure measurements are made at the same time as 'Mapping and Tagging' data are collected, record structure data in the ***VST: Apparent Individuals [PROD]*** application (SOP E).

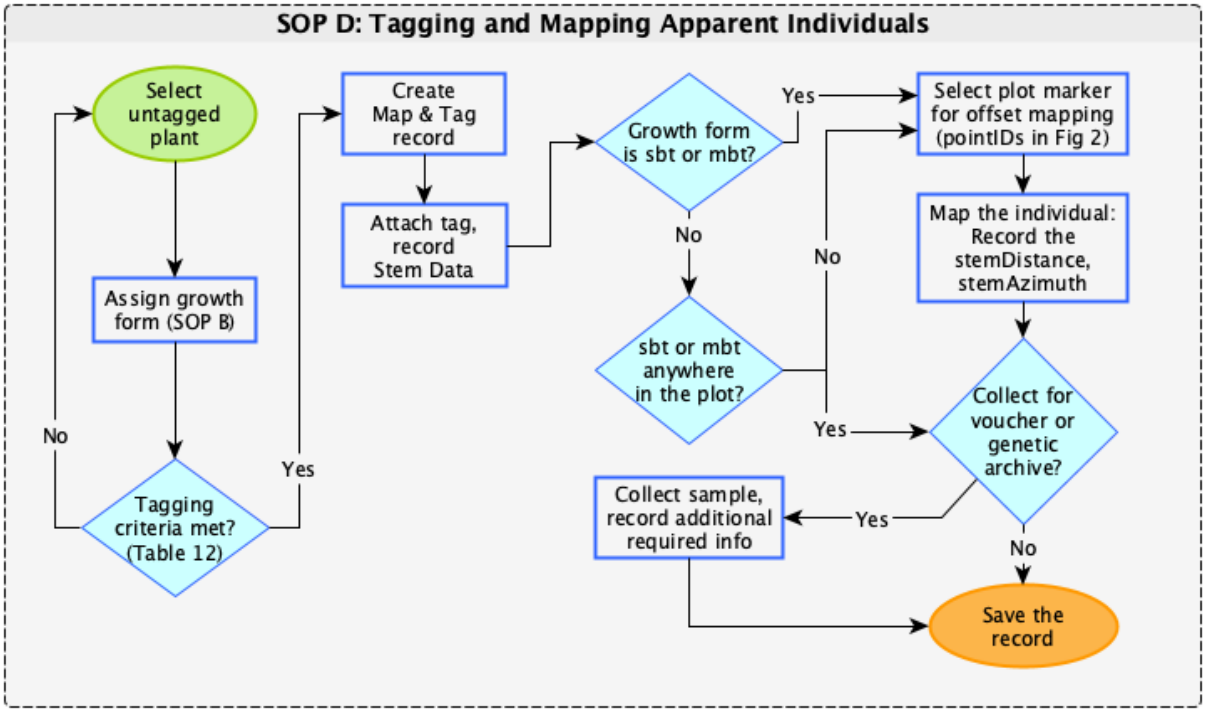



**Figure 9**. SOP D workflow diagram for tagging and mapping apparent individuals. Diagram supports and does not replace protocol text; most common workflow is outlined.

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

- The procedure described here applies to apparent individuals only (i.e., not Shrub Groups).
- Stems must be ≥ 50% rooted in the plot in order to be considered 'in' and included in long term monitoring.
- Dead individuals are tagged and mapped if they are leaning < 45° from vertical, but note this criterion does not apply to decumbent growth forms.
- The mapping procedure is completed for:
    - Single bole trees **stemDiameter** ≥ 10 cm
    - Multi-bole trees with **stemDiameter** ≥ 10 cm for at least one bole
    - Single shrubs, if no trees with DBH ≥ 10 cm are present in the entire plot
    - Small trees, if no trees with DBH ≥ 10 cm are present in the entire plot
    - Small shrubs, if no trees with DBH ≥ 10 cm are present in the entire plot
- Assigned **tagIDs** must be unique across both the Vegetation Structure and Plant Phenology protocols. The NEON database does not differentiate the protocol with which a **tagID** is associated.

## MAPPING TOOLS

- The steps below assume the use of a laser rangefinder (see RD[09] for detailed rangefinder instructions); 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.
- A declination-corrected compass is helpful to check agreement with the rangefinder and ensure the rangefinder unit is calibrated.
- Training is required to properly set declination and accurately use a compass.

### D.1 Requirements for Mapping and Tagging by Growth Form

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

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

Mapping and tagging requirements also vary by growth form:

- *Apparent Individuals*:
  - May be mapped as points; growth form specific mapping and tagging requirements are provided in **Table 12** (below).
  - Are tagged with a unique aluminum ID tag for repeat measurements.
  - Mapping and tagging data are recorded in the ***VST: Mapping and Tagging [PROD]*** application.
  - 'Other' non-woody individuals are measured like Apparent Individuals, but are typically not mapped and tagged (except for tree palms, large-stature cacti, etc.).
- *Shrub Groups:* The locations of shrub groups are mapped relative to the plot with polygons and graph paper (SOP E.3), and location data are NOT entered into the NEON database. Individual stems within the group are not tagged.

**Table 12**. Summary of tagging and mapping requirements by growth form.

| Growth Form | Map | Stem Diameter Measurement Location | Tag Type, Location, and Method | Additional Required Data |
|---|---|---|---|---|
| **Single bole tree (sbt)** | Record **stemDistance** and **stemAzimuth** relative to pointID (plot marker) | • 130 cm along bole<br>• See SOP E.1 for complex cases | • Unique #<br>• 10 cm above stemDiameter measurement location<br>• Aluminum nail | • taxonID<br>• idQ |
| **Multi-bole tree (mbt)** | Record **stemDistance** and **stemAzimuth** of largest bole relative to pointID (plot marker) | • 130 cm along qualifying boles if pith intersection occurs below 30 cm<br>• See SOP E.1 if pith intersection is >30 cm along stem | • Unique # on largest live stem (e.g., 1234); tag most stable dead bole if all boles dead<br>• A,B,C… on additional qualifying stems (e.g., 1234a)<br>• 10 cm above stemDiameter measurement location<br>• Aluminum nail | • taxonID<br>• idQ |
| **Small tree (smt)** | Record **stemDistance** and **stemAzimuth** relative to pointID if no overstory is present in the plot* | • 130 cm along qualifying boles<br>• See SOP E.1 if multi-bole and pith intersection >30 cm along stem | • Unique #<br>• 10 cm above stemDiameter measurement location OR a consistent, visible location<br>• Loose aluminum wire<br>• If multi-bole, Temp ID assigned to qualifying boles (SOP E) | • taxonID<br>• idQ<br>• nestedSubplotArea |
| **Sapling (sap)** | Not mapped | • 10 cm along stem | • Unique #<br>• Consistent, visible location<br>• Loose aluminum wire<br>• If multi-bole, Temp ID assigned to qualifying boles (SOP E) | • taxonID<br>• idQ<br>• nestedSubplotArea |
| **Single shrub (sis)** | Record **stemDistance** and **stemAzimuth** of shrub center relative to pointID if no overstory is present in the plot* | For each qualifying emergent bole:<br>• 10 cm along stem (if possible), AND<br>• 130 cm along stem on largest diameter fork<br>• See SOP E.1 for complex cases. | • Unique # on largest live emergent stem (primary)<br>• No tag on additional qualifying stems.<br>• Mark secondary qualifying stems with lumber crayon<br>• 10 cm above stemDiameter measurement location (nail) OR ground level (wire)<br>• Aluminum nail or loose wire as appropriate<br>• If multi-bole, Temp ID assigned to qualifying boles (SOP E) | • taxonID<br>• idQ<br>• nestedSubplotArea |

| Growth Form | Map | Stem Diameter Measurement Location | Tag Type, Location, and Method | Additional Required Data |
|---|---|---|---|---|
| **Small shrub (sms)** | Record **stemDistance** and **stemAzimuth** of shrub center relative to pointID if no overstory is present in the plot* | • 10 cm along each qualifying stem | • Unique #<br>• Consistent, visible location<br>• Loose aluminum wire<br>• If multi-bole, Temp ID assigned to qualifying boles (SOP E) | • taxonID<br>• idQ<br>• nestedSubplotArea |
| **Shrub group (sgr)** | Graph paper method used to calculate area only; location not recorded in NEON database | • Not applicable | • Tagging not required, but may be tagged for internal tracking purposes<br>• Unique ID assigned per bout if not tagged | • nestedSubplotArea |
| **Liana (lia)** | Not mapped, but supporting stem tagID is recorded when applicable | • 130 cm along stem<br>• See SOP E.1 for complex cases | • Unique #<br>• 10 cm above stemDiameter measurement location, or above the rooting point most proximal to the ascending stem<br>• Loose aluminum wire<br>• One tag per apparent individual, regardless of branching<br>• If multi-stem, Temp ID assigned to qualifying stems (SOP E) | • Supporting stem tagID<br>• taxonID<br>• idQ<br>• nestedSubplotArea |
| **Ferns (frn)** | Not mapped | • Species dependent, see SOP E.4 | • Not tagged<br>• Temp ID assigned to measured stems during data collection (SOP E) | • taxonID<br>• idQ<br>• nestedSubplotArea |
| **Palm (plm)** | *Tree palms:* Record **stemDistance** and **stemAzimuth** relative to pointID (plot marker)<br>*Other palms:* Relative position if no overstory is present in the plot | • Species dependent, see SOP E.4 | • Unique #<br>• 10 cm above stemDiameter measurement location (nail) OR ground level (wire)<br>• Aluminum nail or loose wire as appropriate | • taxonID<br>• idQ<br>• nestedSubplotArea |
| **Yucca (yuc)** | Not mapped | • Not applicable | • Tagging not required, but may be tagged for internal tracking purposes | • taxonID<br>• idQ<br>• nestedSubplotArea |

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

## D.2 Exceptions to Standard Mapping and Tagging Guidelines

There are numerous instances in which the generalized guidelines provided above in **Table 12** are insufficient when it comes to deciding on an appropriate measurementHeight and tagging location. Complex and non-standard individuals that require special consideration, are summarized in **Table 13**, and illustrated in detail in SOP E.1. Site-specific modifications are described in Appendix D.

**Table 13**. Measurement location and tagging guidelines for complex woody stems not covered in **Table 12**.

| **Measurement location and tagging guidelines for complex woody stems** | |
|---|---|
| **Stem/Site Characteristics** | **measurementHeight and tag location** |
| Growing on sloped or uneven terrain | Measure stem diameter 130 cm from uphill side, tag 10 cm above measurementHeight. |
| Thickened base | Measure stem diameter 50 cm above the point where stem becomes 'regular' again. |
| Leaning or twisted stems | Measure stemDiameter 130 cm along the underside of the stem; diameter measurement is perpendicular to the direction of stem growth, not parallel to ground. Tag 10 cm above measurementHeight. |
| Stems with anomalies at 130 cm (e.g., bulge, node/branch, or minor, localized damage). | Measure above the anomaly where stem becomes 'regular' again. Tag 10 cm above measurementHeight. When damage is a major feature of the stem, do not move the measurementHeight and tag location. |
| Deep litter/duff layer heaped around bole base | The measurementHeight and tagging location are determined from ground level, not the top of the duff layer. |
| Bole / stem is broken | • For break points ≥ 130 cm height, follow standard measurementHeight and tagging guidelines.<br>• For 'sbt', 'mbt' and 'smt', ignore live or dead broken boles < 130 cm height, but follow guidelines for resprouts if present (see below).<br>• For 'sap' and 'sms', broken stems < 30 cm length are ignored (live and dead, see SOP E.1). Tag largest, live qualifying stem. |
| Multi-bole tree with mix of live and dead stems (includes stump ≥ 130 cm height and DBH ≥ 10 cm w/ re-sprouts) | • Location of measurementHeight and tag depends on where pith of resprout intersects with pith of main bole. See SOP E.1.<br>• Broken boles, either dead or alive, must be > 130 cm height to qualify for tagging.<br>• Resprouts NOT required to be ⅓ diameter of main bole when main bole is dead. |
| Downed live, with vertically growing resprouts | Measurement and tagging strategy depends on whether the pith of the downed bole is above or below the forest floor. See SOP E.1. |

| Measurement location and tagging guidelines for complex woody stems | |
|---|---|
| **Stem/Site Characteristics** | **measurementHeight and tag location** |
| Standing dead | • For standing dead ≥ 130 cm length, follow standard measurementHeight and tagging guidelines.<br>• For 'sbt', 'mbt', 'smt' and 'sis', dead boles < 130 cm length are ignored.<br>• For 'sap' and 'sms', dead stems < 30 cm length are ignored and not tagged (see SOP E.1). |
| Leaning dead | • If lean is < 45° off vertical, measure and tag same as standing dead.<br>• If lean is ≥ 45°, ignore stem, will be assessed as Coarse Downed Wood (except in the case of decumbent growth forms such as manzanita species). |
| Plot burned since previous bout | Do not change measurement strategy. Do not need to search for fallen, tagged individuals for re-measurement. |

### D.3 Procedure for Mapping and Tagging

***Procedure steps:***

1. Choose a plot marker with high-resolution GPS coordinates that can be used for offset mapping.
    a. ***Only pointIDs shown in red in* Figure 2 *may be used for offset mapping.***
    b. Avoid using pointID = 41 unless absolutely necessary. Mapping from this pointID leads to trampling of nested subplots used for smaller growth forms.
2. Mount the laser rangefinder on the non-magnetic tripod and position the body of the rangefinder directly over the selected plot marker.
    a. Use of a tripod ensures the rangefinder is centered over the plot marker. Hand-holding the rangefinder may result in swinging the unit from side-to-side, introducing errors in azimuth (primarily) and distance (secondarily).
    b. Care should be taken to avoid placing tripod legs within nested subplots.
3. For each individual that requires a tag, create a record in the *VST: Mapping and Tagging* app. See **Table 12** for tagging criteria. Enter the following:
    a. **Foliar Canopy Sampling Tag** status; select 'Yes' if the individual is specifically tagged for Canopy Foliar Sampling and is not otherwise measured for Vegetation Structure.
    b. **domainID** and **siteID**; these fields narrow the list of plotIDs.
    c. **plotID**; the list of available plotIDs is populated by records created in the *VST: Plot Meta-Data* app. Create Plot Meta-Data records prior to Mapping and Tagging records.
    d. **yearBoutBegan** and **date**; typically the former is part of the latter, but may be different if the bout began in a previous year and continued over the Dec 31$^{st}$ to Jan 1$^{st}$ transition.
    e. **samplingProtocolVersion**; the version of the Vegetation Structure protocol used to guide sampling.
    f. **recordType**; select from the following:
        i. **Map and Tag**; individual is both mapped and tagged.
        ii. **Tag Only**; individual is tagged and not mapped.
        iii. **Band**; individual is mapped, tagged, and dendrometer band is installed.
        iv. **Temporary**; individual that is measured but not tagged. Applies to approved domains only (Appendix D); consult with Science if potentially applicable to your site – i.e., chronic loss of tagged individuals before next measurement bout.

4. Determine the **measurementHeight** using **Table 12**, **Table 13**, and figures in SOP E.1. Attach a pre-numbered aluminum tag according to guidelines in **Table 12**; this number is the **tagID**.
    a. When multi-bole apparent individuals are in close proximity and emergent boles from one apparent individual intermingle with another, it is best to treat each qualifying emergent bole/stem as an individual.
    b. Mark the **measurementHeight** on the qualifying stem(s) using lumber crayon or equivalent.
    c. ***TIP:*** It is helpful to mark trees you have just tagged, mapped, and/or measured with a small length of flagging in order to track work progress. All temporary flagging must be removed once data have been collected from all trees within a given subplot.
5. Record required **Stem Data** for the individual:
    a. **subplotID**; select the subplot in which the individual is rooted. Helps to relocate individuals in subsequent bouts.
    b. **nestedSubplotID**; select if rooted within a nested subplot. Helps to relocate individuals in subsequent bouts; may be left NULL for many trees (sbt, mbt).
    c. **tagID**; the numeric identifier for the individual. Should be unique within a domain.
    d. **supportingStemTagID**; required for the liana (lia) growth form only.
    e. **previouslyTaggedAs**; enter the previous, incorrect identifier if an individual was previously tagged in the field and associated with an incorrect tagID value in the database.
        i. The correct tagID value is recorded in the **tagID** field.
    f. **taxonID**; select from the NEON master list of USDA plant species codes for species present within the domain. Identify to the greatest taxonomic resolution possible.
        i. Record the USDA plants code rather than the scientific name.
        ii. If **taxonID** is unknown and the stem is alive, assign a morphospecies ID as indicated in steps below, obtain leaf, bark, and/or reproductive part samples (e.g., cones, nuts), and bring back to the lab to identify.
        iii. When stem **plantStatus = '**2 – standing dead' or '10 – dead, broken', assign to species if possible. If the species cannot be determined, assign to genus, family, unknown hardwood or unknown softwood, in that order of preference.

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

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

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

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

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

**Table 14**. Taxon identificationQualifer (idQ) codes. Leave this field blank if the person making the identification is confident in the species ID.

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

6. Map the individual if it qualifies for mapping (see **Table 12**). Skip this step if the individual is only tagged. See RD[09] for rangefinder operation instructions.

a. Make sure **recordType** = 'Map and Tag' or 'Band' in the *VST: Mapping and Tagging [PROD]* app.

b. Record the **pointID**; this is the plot marker number over which the laser rangefinder is positioned. Refer to Appendix F if plot markers are not numbered.

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

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

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

    i. Keep metal objects > 50 cm from the rangefinder at all times during operation; metal objects interfere significantly with compass accuracy. This includes watches, earrings, rings, glasses, etc.

7. Record additional **Stem Data** for the individual:

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

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

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

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

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

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

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

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

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

9. Save the record and proceed to the next individual.

## D.4 QA/QC for Mapping and Tagging Data

Ensuring that mapping and tagging data are accurate is important because:

- Mapping data are used by the external community to link ground-based measurements with airborne remote-sensing data.
- Mapping data reveal whether larger trees are accurately classified 'in' or 'out' of the plot; accurate 'in/out' classification can have significant downstream consequences for biomass per unit area estimates.
    - Mapping QA/QC is particularly important in steep terrain or dense brushy vegetation when it is difficult to determine plot boundaries.
- Correct taxonIDs are necessary for accurate biomass estimation via allometric equations. For example, different parameters are used for estimating biomass of hard maples vs. soft maples.

Use the VST QA/QC application to view stem mapping results on a plot-by-plot basis as soon as the data records are entered into Fulcrum. Pay particular attention to:

- Mapped stems that appear to reside outside of plot boundaries. It is important to verify mapping data for these individuals in the field.
- Mapped stems that appear to be located in a different part of the plot than where you remember the rooting point. Verify mapping data for these individuals in the field.
- The VST QA/QC application is only available within the NEON network (and via VPN) in order to prevent external access to raw L0 data that have not been QA/QC'd.

***To Correct Errors in Mapping and Tagging Data:***

1. If the record is locked *and was originally created in a different year than the current one*:
    a. Create a new *VST: Mapping and Tagging* record and enter all required fields. Enter updated information into those fields that require correction. Data in other fields should remain unchanged. Do not use 'duplicate record' functionality.
2. If the record is locked *and was created in the current year:*
    a. Request deletion of the Fulcrum record and the loaded data.
    b. Create a new Fulcrum record and enter updated information into only those fields that require correction. Data in other fields should remain unchanged.
3. If the record is not locked:
    a. Edit the existing record and enter updated information into only those fields that require correction. Data in other fields should remain unchanged.

## SOP E Vegetation Structure Data Collected on a 5-Year Interval

### *Overview*

In this SOP, we describe measurements collected on a 5-year interval for all qualifying woody and non-woody growth forms (**Figure 10**). All qualifying woody and non-woody individuals are measured every 5 years in Distributed Plots (**eventType** = distributedAndTowerSubset) and Tower Plots (**eventType** = allTowerPlots). Importantly, the full complement of VST Distributed Plots are measured in a different year than the full complement of VST Tower Plots (**Table 3**). Additional measurements performed annually in a subset of Tower Plots are described in SOP F.

Woody stemmed vegetation may exhibit numerous growth forms – from single, straight boles to multiple curved, branched stems, and more. The measurement strategy for woody individuals depends on growth form because allometric equations that relate structure to biomass require growth-form dependent input data. This protocol modifies guidelines established by the U.S. Forest Service (2012) for measuring tree species. Shrubs are measured according to Lutz et al. (2014), and liana measurements are derived from Gerwing et al. (2006) and Schnitzer et al. (2008).

### *Goals*

1. Accurately classify individuals to growth form and thoroughly assess each plot for the presence of qualifying growth forms.
    a. Review current bout ***VST: Plot Meta-Data [PROD]*** records for each plot and update if any qualifying growth forms were missed during the initial survey (see SOP C).
    b. Communicate with Science if changes to nested subplot size are required.
2. Map and tag new stems that now meet mapping and tagging requirements (see SOP D).
    a. Collect new mapping and tagging data in the ***VST: Mapping and Tagging [PROD]*** app.
3. Determine which structure measurements are required for each qualifying individual in the plot, and collect repeatable data from consistent locations on stems.
    a. The measurements required for an individual are dependent on the assigned **growthForm** (**Table 9**). Check for changes in required measurements based on changes in growth form through time – e.g., ‘sap’ grows to ‘smt’.
    b. Collect data from all individuals with DBH ≥ 10 cm, regardless of stem density – i.e., do NOT use nested subplots for trees (‘sbt’ or ‘mbt’).
    c. Record data in the ***VST: Apparent Individuals [PROD]*** and ***VST: Shrub Groups [PROD]*** applications.
    d. Consult the ‘Manual for Fulcrum Application: TOS Vegetation Structure [PROD] – All SOPs’ for data entry details (RD[14]).

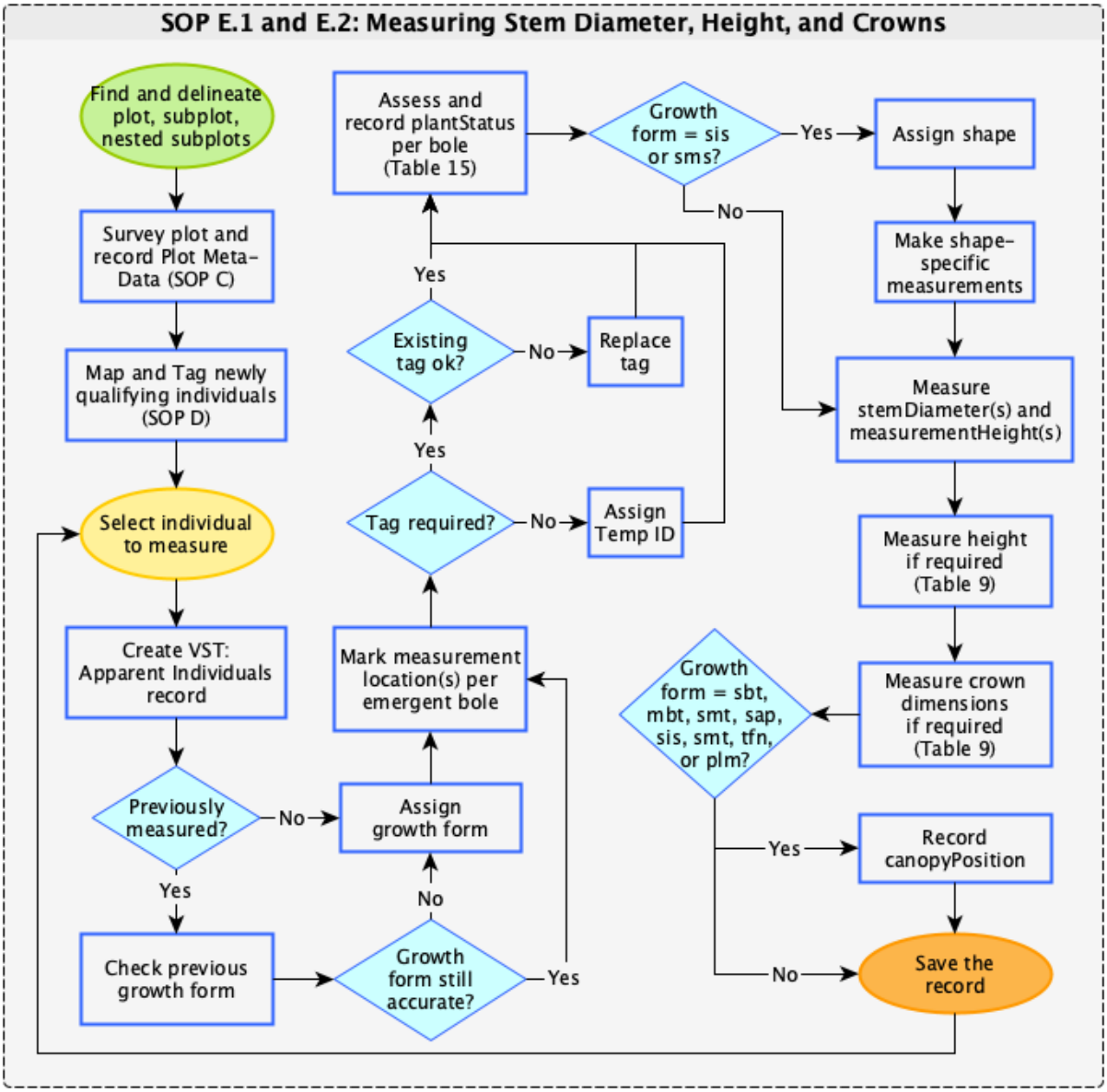



**Figure 10**. SOP E.1 and E.2 workflow diagram for stem diameter, height, and crown dimension measurements collected from apparent individuals. Diagram supports and does not replace protocol text; most common workflow is outlined.

## E.1 Stem Diameter Measurements

This section describes collecting diameter at breast height (DBH) measurements and basal stem diameter measurements that are used as input data for allometric equations used to estimate woody biomass. This section also describes assessment of plant status (live, dead, etc.) and other variables that are required for accurate biomass estimation.

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

***Procedure steps for each qualifying apparent individual:***

1. Determine the **growthForm** for the individual (see **Table 8**).
    a. A quick, initial assessment of **stemDiameter** (DBH or ddh) may help guide classification.
    b. Remember that **growthForm** values may change from year to year (e.g., 'sap' to 'smt').
2. Determine the **measurementHeight**(s) for each of the qualifying stems of the individual – i.e., the distance along the bole(s) at which the **stemDiameter** is measured, beginning from where the bole emerges from the ground (see **Table 12**, **Table 13**, and SOP E.1).
    a. The **measurementHeight** is determined independently for multiple emergent boles that are part of the same individual.
    b. In many cases, the measurement location will already be marked with lumber crayon.
    c. Re-use previously measured **measurementHeight** values if within ± 5 cm of the observed height in the current year.
        i. If re-measuring indicates the previous measurementHeight is more than ± 5 cm different from the actual measurementHeight, update with the new value.
        ii. ***!!!*** Do NOT move the actual location on the bole at which the DBH is measured unless absolutely necessary: A meaningful time-series depends on this location staying constant.
    d. DO move the actual measurement location on the bole and record a new **measurementHeight** if the previous measurement location becomes unusable.
3. Select a bole to measure. For a multi-bole individual, the steps below are repeated per bole.

4. Use the **changedMeasurementLocation** field to document when the actual measurement location on the bole must be moved.
    a. **noChange**; measurement location is consistent with previous measurement location.
    b. **deformityGrowth**; growth of a deformity compromises past measurement location.
    c. **branchGrowth**; growth of a branch compromises past measurement location.
    d. **damage**; localized damage compromises past measurement location.
    e. **newRootingPoint**; the measurement location is shifted relative to a new rooting point (typically applied to lianas).
    f. **boleChange**; a different emergent bole is selected for measurement and the measurementHeight may or may not be different than previously recorded (typically applied to shrubs; e.g., the thickest fork of a 'sis' changes, or the previously measured fork is broken or absent).
    g. **protocolChange**; measurement requirements changed between protocol versions.
5. Mark (or re-mark) the bole at the desired **measurementHeight** with lumber crayon or equivalent to enable repeat measurements at the exact same location.
    a. Mark boles with DBH ≥ 30 cm at multiple points around the bole to ensure accurate re-measurement.
6. Assess whether a diameter tape or calipers should be used to measure stem diameter.
    a. ***Use a diameter tape for***: Self-supporting stems or large lianas with DBH ≥ 5 cm, AND that do NOT have lianas that will interfere with accurate diameter measurement.
    b. ***Use calipers for***:
        i. Self-supporting stems or lianas with DBH < 5 cm; use calipers to measure the stem at its widest point, and perpendicular to its widest point. Calculate the average, and record. Diameter tapes are less accurate for small stems.
        ii. Self-supporting stems with DBH ≥ 5 cm that DO have lianas that will interfere with accurate diameter measurement; use calipers to measure the stem at its widest point (excluding lianas), and perpendicular to its widest point. Calculate the average, and record.
7. (If necessary) Create a parent record in the *VST: Apparent Individuals* app for the plot and enter required information. Then create a child record for the individual and enter the following:
    a. **Go To Mapping & Tagging App**; click 'New' if the individual has not yet been tagged and there is no prior *VST: Mapping and Tagging* record. A *VST: Mapping and Tagging* record must exist prior to creating a *VST: Apparent Individuals* record.

i. **If *VST: Mapping and Tagging* data exist but are incorrect**: Navigate manually to the *VST: Mapping and Tagging* app (do not click the 'Select' or 'New' button within the *VST: Apparent Individuals* app), and:

1. If 'LOAD_STATUS' = LOADED: Create a new Mapping and Tagging record.
2. Else: Edit existing Mapping and Tagging record, update with correct information, and save.
3. Return to the *VST: Apparent Individuals* workflow.

ii. If measuring a woody individual for which a tag is not required (e.g., fire re-sprouts in D03; see Appendix D to determine applicability to your site):

1. Create a Mapping and Tagging record with **recordType** = 'temporary' (SOP D).
2. Records of this type have 'TEMP' in the individualID to aid with discoverability.

**b.** **tagID**; select the individualID from the list of previously created *VST: Mapping and Tagging* records. Verify that the taxonID associated with the tagID is correct.

c. **tagStatus**; select from the following options:

i. **ok**; select if:

1. Previously attached tag exists, is legible, and value is consistent with previously entered value, OR
2. A new tag has been attached because the individual did not previously qualify for measurement, OR
3. A new tag has been attached because the previous tagID value could not be determined with ≥ 90% certainty and the previous tagID was swapped for a new tagID.

ii. **replaced**; tag no longer attached, readable, etc., and the previously recorded tagID value can be surmised with ≥ 90% certainty (via VST Mapper, process of elimination, or other means). Tag has been re-made with previous number.

iii. **notRequired**; applicable to many non-woody ferns, yucca, and cactus (see **Table 12**). Also applicable if 'plantStatus' is assigned any of the 'lost' codes (see **Table 15** below).

iv. **tagRemoved**; tag has been removed and individual will not be measured in future years.

d. **taxonID**; for reference only. Update in *VST: Mapping and Tagging* if corrections are required.

8. Assess and record the **plantStatus** for the selected bole (**Table 15**).

    a. See SOP E.1.1 for guidance for multi-bole individuals with mixed plantStatus.

**Table 15**. List of **plantStatus** codes and definitions.

| Code | Definition |
|---|---|
| 1 | **Live** – any live Apparent Individual (new, re-measured or ingrowth) that is of typical healthy status for the ecosystem in question. E.g., if trace amounts of insect damage or foliar disease are typical on the majority of individuals, use this code rather than code 4 or 5 below. |
| 2 | **Standing dead –** any dead individual, or standing dead bole within a multi-bole individual, regardless of cause of death. The entire tree or bole must be dead, and the main bole is NOT broken. For dead, broken boles see additional code below. Indicate factors associated with death in order of importance in the **remarks** field. Only record a specific cause of death when observable evidence indicates the cause:<br>• Unknown: It is common to have no observable evidence as to the actual cause of death.<br>• Biotic: Suppression, animal damage, mistletoe<br>• Disease: Blister rust, rot, canker, other (specify), unknown<br>• Insect: Bark, defoliating, other; specify insect species if possible<br>• Physical: Crown damage, crushed, lightning, other (specify if possible)<br>• Fire: Crown scorch, crown combustion, bole/stem scorch, bole/stem combustion, burned through at base (for small trees, due to litter & duff burning around base), other (describe). |
| 3 | **Removed** – an individual that has been cut and removed by direct human activity related to harvesting, silviculture or land clearing (re-measurement plots only). If the individual is a species that may resprout and eventually qualify again for measurement record 'no longer qualifies' rather than 'removed'. |
| 4 | **Live, insect damaged** – Visible damage caused by insects that exceeds trace amounts that may be present on typically healthy trees; note 'crown' or 'bole' damage in **remarks**, and indicate type of insect causing damage if there is evidence (e.g., Mountain Pine Beetle, Gypsy Moth, etc.) |
| 5 | **Live, disease damaged** – Visible damage caused by disease that exceeds trace amounts that may be present on typically healthy trees; note 'crown' or 'bole' damage in **remarks**, and indicate type of disease causing damage if there is evidence (e.g., Blister Rust, rot, canker, other (specify), unknown. |
| 6 | **Live, physically damaged** – Visible damage not caused by insects or disease, but of known origin; note 'crown' or 'bole' damage in **remarks**, and indicate type of physical damage (e.g., bole scar, girdling, snow/ice damage, crushed, lightning, crown scorch, bole scorch, ungulate herbivory, human damage) |
| 7 | **Live, other damage** – Visible damage of other origin, e.g. biotic suppression; note 'crown' or 'bole' damage in **remarks**, and note cause of damage if there is evidence. |
| 8 | **No longer qualifies** – note reason in **remarks**; record in multiple years if individual is still alive and may qualify in the future**.** Reasons for not measuring include: Individual no longer qualifies (e.g., broken and remaining live shoots do not qualify), complete consumption by fire, etc. |
| 9 | **Live, broken bole/stem** – individual with broken top, with broken main bole and ascending leaders (that may or may not be taller than the break point), or that is broken and dead at top but live below, etc. If known, indicate factors that may have caused the break and other damage in order of importance in the **remarks** field. When damage does not result in a clean break in the bole/stem, record 'Live, physically damaged'. |
| 10 | **Dead, broken bole/stem** –all parts of the broken bole or stem are dead; may have broken spike top, or dead leaders ascending beyond the break point.If known, indicate factors associated with death and the source of damage in order of importance in the **remarks** field. |
| 11 | **Lost, burned –** A previously measured individual that is not measured in the current bout because the plot has been burned, and the individual could not be re-located for measurement. Cause of loss is presumed to be fire. |

| Code | Definition |
|---|---|
| 12 | **Lost, herbivory –** A previously measured individual that is not measured in the current bout because the individual could not be re-located for measurement. Cause of loss is presumed to be herbivory. |
| 13 | **Lost, presumed dead** – A previously measured individual that is not measured in the current bout because it could not be re-located for measurement. The individual is presumed dead based on evidence within the plot. If known, note presumed cause of death in the **remarks** field (e.g., blowdown event). |
| 14 | *Deprecated – no longer in use* |
| 15 | **Lost, fate unknown** – A previously measured individual that is not measured in the current bout because the individual could not be found. For small individuals, a status of 'lost' may be temporary. |
| 16 | **Downed –** A previously measured individual that is not measured in the current bout because it is > 45˚ from vertical and is dead. |

9. Record the **growthForm** determined in step (1).
10. Measure the **stemDiameter** at the required **measurementHeight**(s). See **Table 9** for growth-form-dependent requirements (DBH, ddh or both). All diameter cutoffs that determine measurements are hard cutoffs – do not round.
    a. Place the diameter tape or calipers directly over the marking(s) from step (2).
        i. Take care to avoid sloughing bark when collecting data. Negative growth can be perceived due to bark loss.
        ii. For large boles, the tape must not slip above or below the desired measurementHeight.
11. Record in the *VST: Apparent Individuals* app:
    a. **stemDiameter** (growthForm dependent): The diameter of the bole perpendicular to the pith, typically 130 cm along the bole for DBH; nearest 0.1 cm. Not recorded when growthForm = 'sap' or 'sms'.
    b. **basalStemDiameter** (growthForm dependent): The basal diameter of the bole, typically 10 cm above the ground; nearest 0.1 cm. Recorded only when growthForm = 'sap', 'sis', or 'sms'.
    c. **measurementHeight**(s): Distance along the bole at which the **stemDiameter** or **basalStemDiameter** is actually measured; nearest 1 cm. Both DBH and ddh are required for 'sis' individuals.
        i. If the desired 'measurementHeight' is out of reach for all but the tallest foresters, adjust downward to ensure that repeat measurements can be made by the average person (see SOP E.1.1 Case B for how to deal with compound splits that often lead to this situation).
    d. **changedMeasurementLocation**; select from the drop-down if the actual location along the bole where the measurement is made moves relative to its position in previous years. See step (4) for definitions.

e. **measurementStrategy (lia only)**; select the liana morphology from SOP E.1.2 that best informs the measurement strategy for the individual.

   i. If multiple measurement strategies are combined, select the most relevant from the drop-down.

   ii. You may record **remarks** to help ensure a consistent measurement strategy if multiple strategies are combined.

12. To record **stemDiameter** for individuals with multiple qualifying boles:

   a. Complete height and crown diameter measurements for the largest bole (SOP E.2).

   b. For trees (growthForm = 'mbt'):

      i. Create a new child record for each qualifying bole, each of which has a *unique* **tagID** – e.g., 1234 (largest bole), 1234a (next largest), 1234b (etc.)

   c. For all others (growthForm = 'smt', 'sap', 'sis', 'sms', or 'lia'):

      i. Create a new child record for each qualifying bole, each of which has the *same* **tagID**.

      ii. Assign a **tempID**; this ID is an incremented integer assigned to each qualifying stem. Combined with the tagID, the tempID uniquely identifies the stem in the database within a year. Incrementing starts over for each individual. Within an individual, it is not important which tempID is assigned to a given bole from year to year.

13. Measure and record required **height** and **crown** measurements according to SOP E.2.

***Procedure steps for apparent individuals that no longer qualify for measurement:*** – e.g., due to a change in nested subplot size, wind-throw, damage, or other change:

1. Create a record in the *VST: Apparent Individuals [PROD]* app. Enter the following:
    b. **tagID**; select the individualID value from the list of previously created *VST: Mapping and Tagging* records. Verify that the taxonID associated with the tagID is correct.
    c. **plantStatus**; select plantStatus = '8 – no longer qualifies') or '16 – downed'.
    d. **remarks**; record 'change in nested subplot size', 'wind-throw', or a pithy equivalent that describes the situation for end-users.
    e. Save the record.
2. Determine whether the tag should be left in place or removed:
    a. The tag may be left in place if there is a chance the individual will be measured again in the future. Examples of when a tag should be left:
        i. Individual may be measured again if nested subplot size changes.
        ii. Non-qualifying living shoots of a downed individual may grow to qualify in the future.
        iii. The individual may be measured by the CDW protocol.
    b. Remove the tag when longitudinal data are no longer possible. Examples of when a tag should be removed:
        i. Downed and too small for CDW.
        ii. The individual was tagged in error – e.g., it is clearly outside the plot or subplot.
        iii. The tag was found loose on the ground and cannot be confidently associated with an individual.

### E.1.1 Stem Diameter Measurement Guidelines

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

**Irregular Boles**

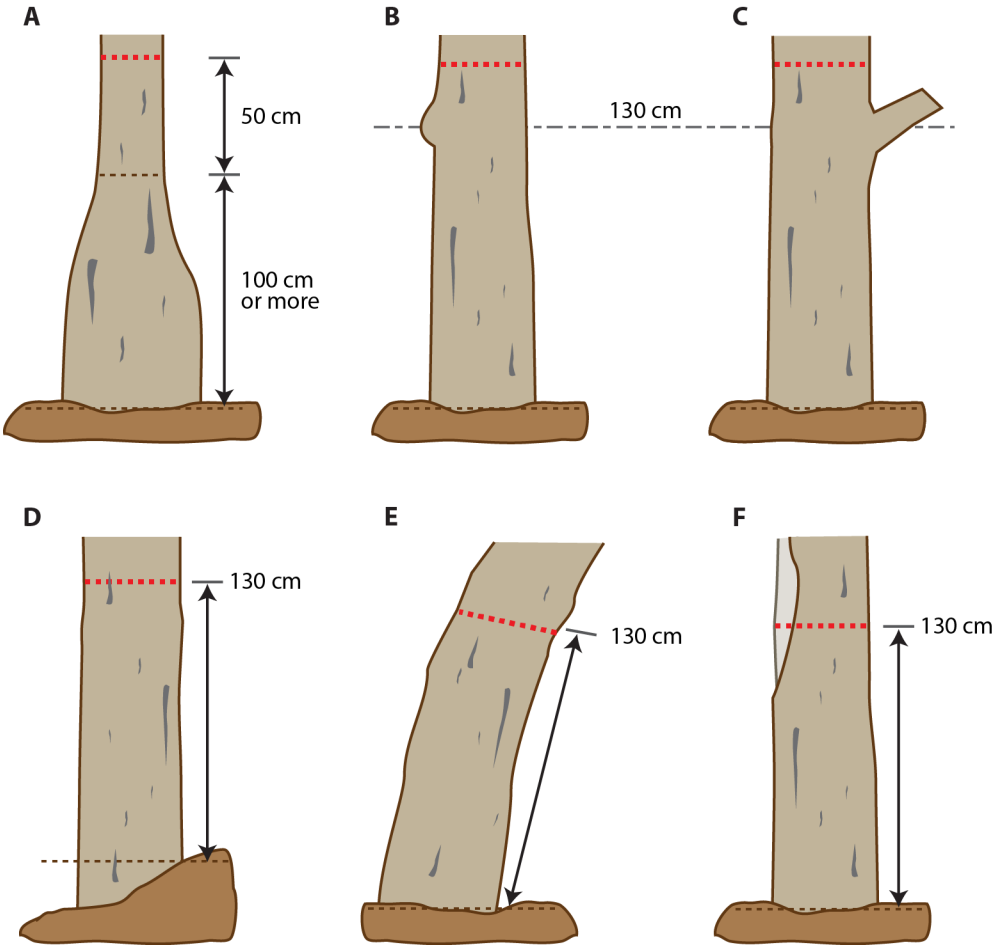



**Figure 11**. Stem diameter measurement guidelines for irregular single-bole trees. The lowest dashed line represents ground level from which the desired measurement height is referenced. The thick dashed red line shows the desired measurement height above ground level. Tags are typically placed 10 cm above the measurement height.

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

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

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

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

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

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

**Multi-Bole Individuals**

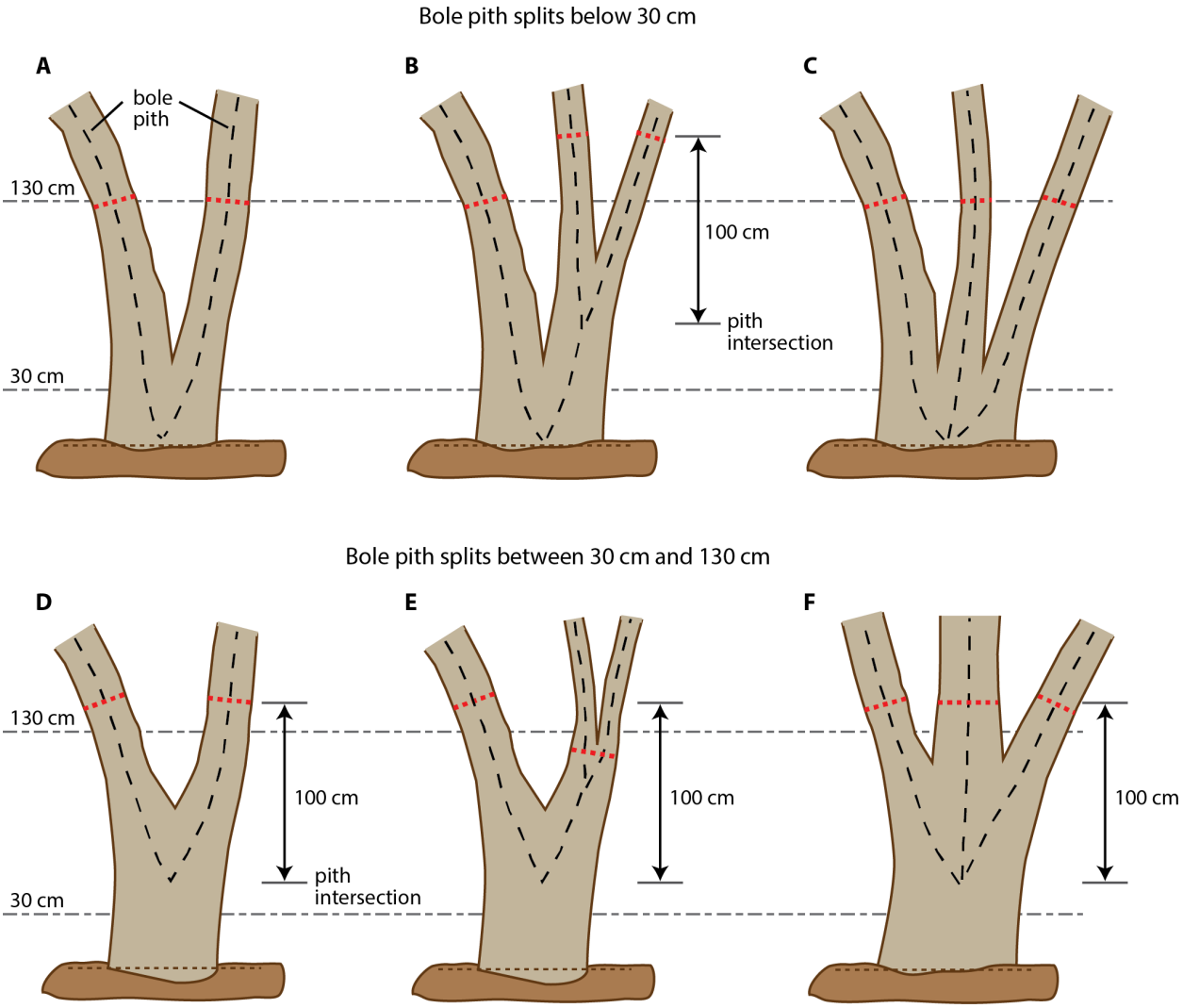



**Figure 12**. Stem diameter measurement guidelines for multi-bole trees with pith splits.

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

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

**(C)** In the event the pith intersection for the secondary fork on the right occurs close to 130 cm, the resulting desired measurement location may be out of reach for all but the tallest foresters. Adjust the measurementHeight downward, if necessary, to ensure that repeat measurements

can be made by the average person. Repeatability through time is more important that reaching exactly 100 cm above the fork in the pith.

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

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

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

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

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

- The lowest, finely dashed line represents ground level from which the 30 cm and 130 cm reference heights are drawn (multi-dashed background lines).
- The thick dashed red line shows the desired measurement height above ground level.
- If the bole is not growing vertically, measure 130 cm along the bole, rather than 130 cm above ground. Diameter is measured perpendicular to the pith.
- Large dashed black lines indicate the pith of each bole.
- Tag 10 cm above the measurementHeight.
- To qualify as a split, or fork, the stem in question must be at least ⅓ the diameter of the main bole, and must branch out from the main bole at an angle of < 45˚.
    - The presence of a qualifying fork may require shifting the measurement height (cases B, D, E, and F). Moving the measurement height upward to the required height may cause one or both forks to no longer qualify for measurement.
    - ***Exception:*** Forks that are < 2.5 cm diameter are ignored and NOT measured, even if they meet the ⅓ diameter requirement. This exception holds for 'mbt' and multi-bole 'smt' individuals.
- Forks originate at the point on the bole at which the piths intersect.

**Live Downed Trees**

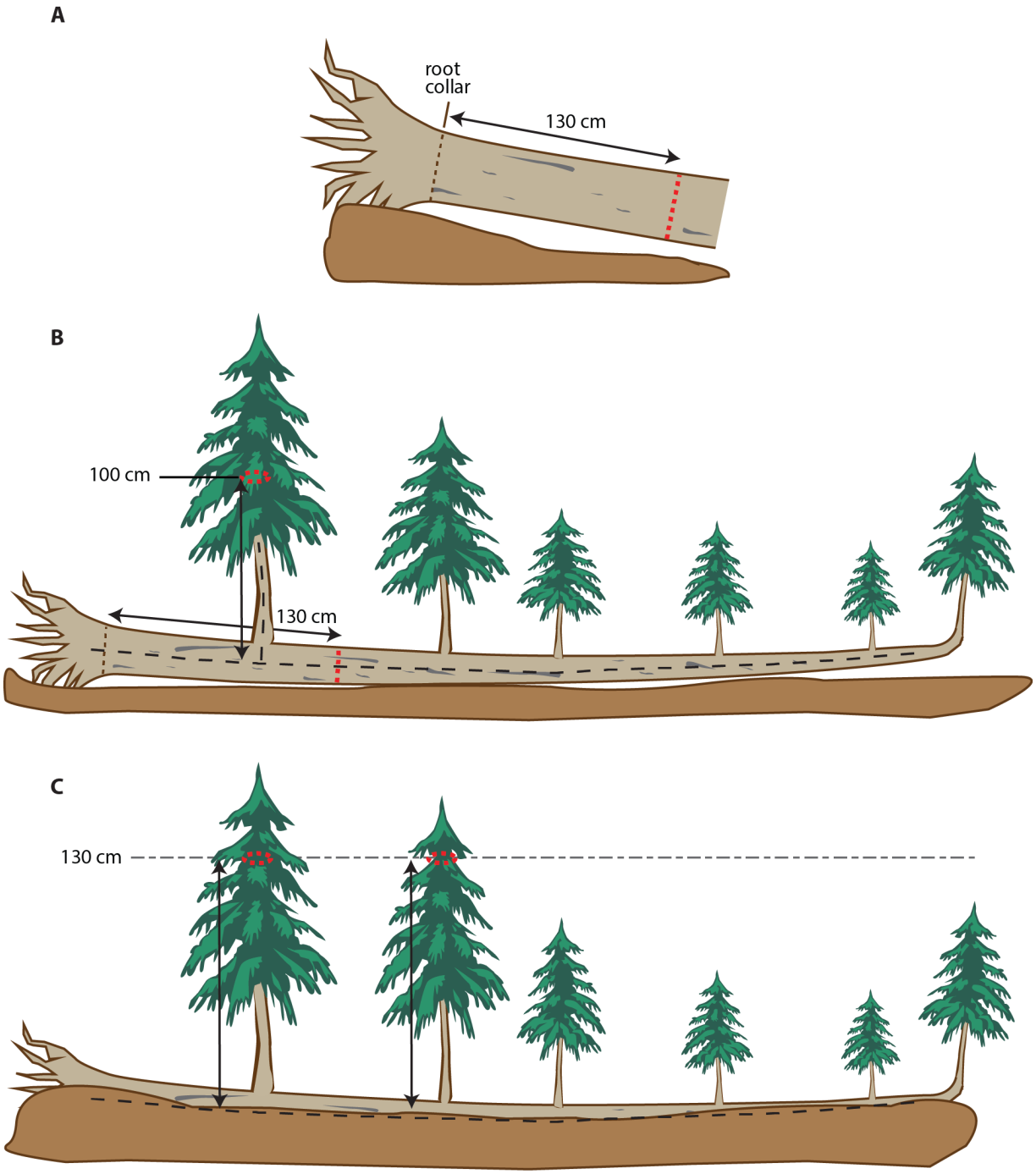



**Figure 13**. Stem diameter measurement guidelines for live, downed trees.

For **(B)** and **(C)**, consider a downed live tree, touching the ground, with tree-like branches that originate from the main bole, AND are less than 45˚ off the vertical. If the pith of the main bole (black dashed line) is above the duff layer, assess according to **(B)**, and if the pith is below the duff layer, assess according to **(C)**.

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

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

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

**Mixed Status Individuals**

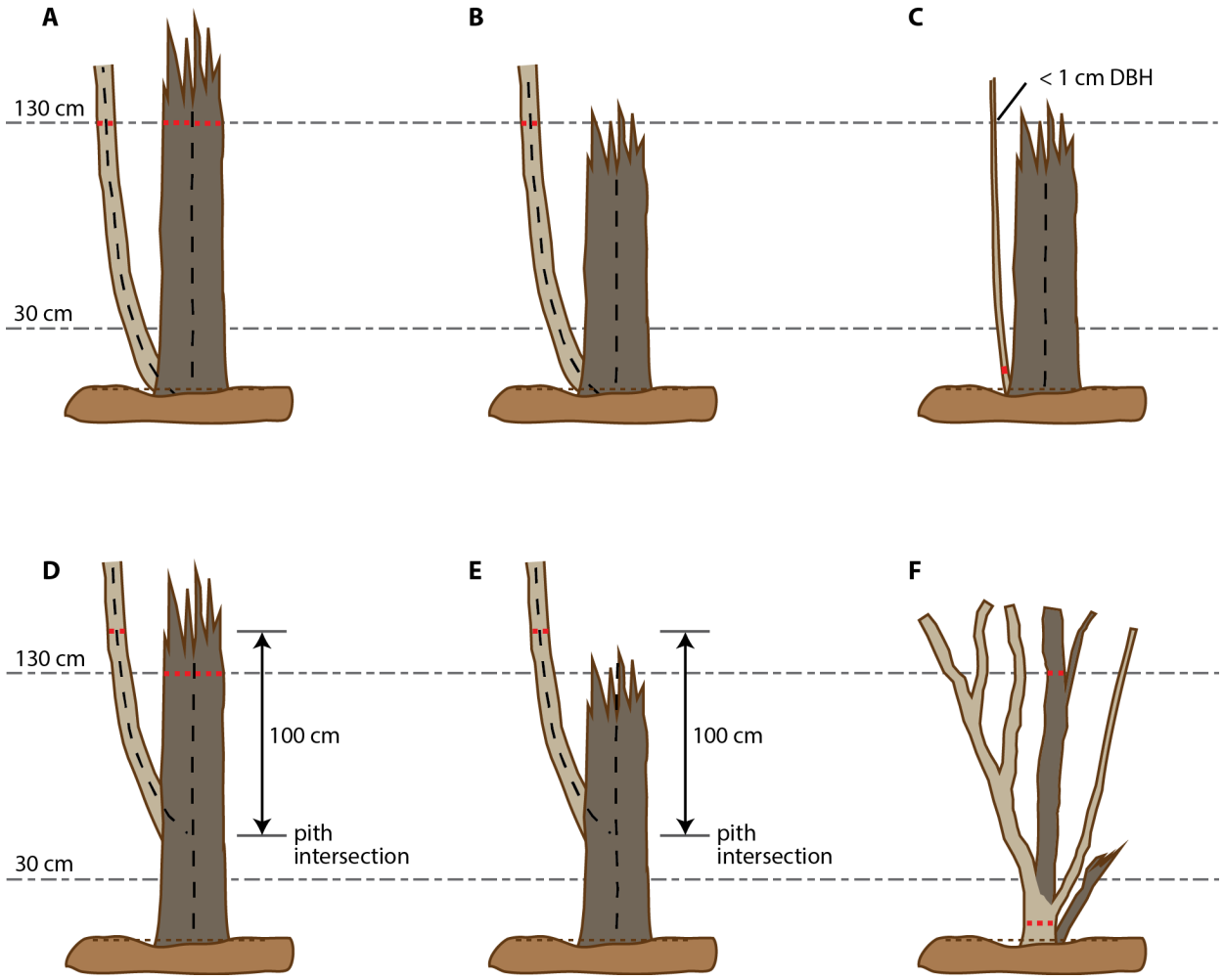



**Figure 14**. Stem diameter measurement guidelines for multi-bole individuals with mixed plantStatus (live/dead).

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

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

**(A)** Resprout with dead main bole that is > 130 cm height. The pith of the resprout intersects with the main dead bole somewhere below the ground. Growth form is a multi-bole tree (mbt). Similar to when both boles are alive, measure the diameter of each bole 130 cm above the ground. For the dead bole on the right, measure the diameter of the break point as well as DBH, and also record the height of the break point.

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

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

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

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

**(F)** Shrub with plantStatus = '2 – standing dead' for largest split, and broken dead stems with plantStatus = '10 – dead, broken'. The assigned plantStatus = '1 – live' for the entire individual, even though the largest split is dead. If the individual has multiple qualifying emergent boles > 130 cm height (or total length) with different status, DO record status separately for each emergent bole. Measure DBH at 130 cm on largest split, and measure ddh. Ignore broken dead emergent stems that are < 130 cm height (or total length if growing off the vertical).

## Shrubs

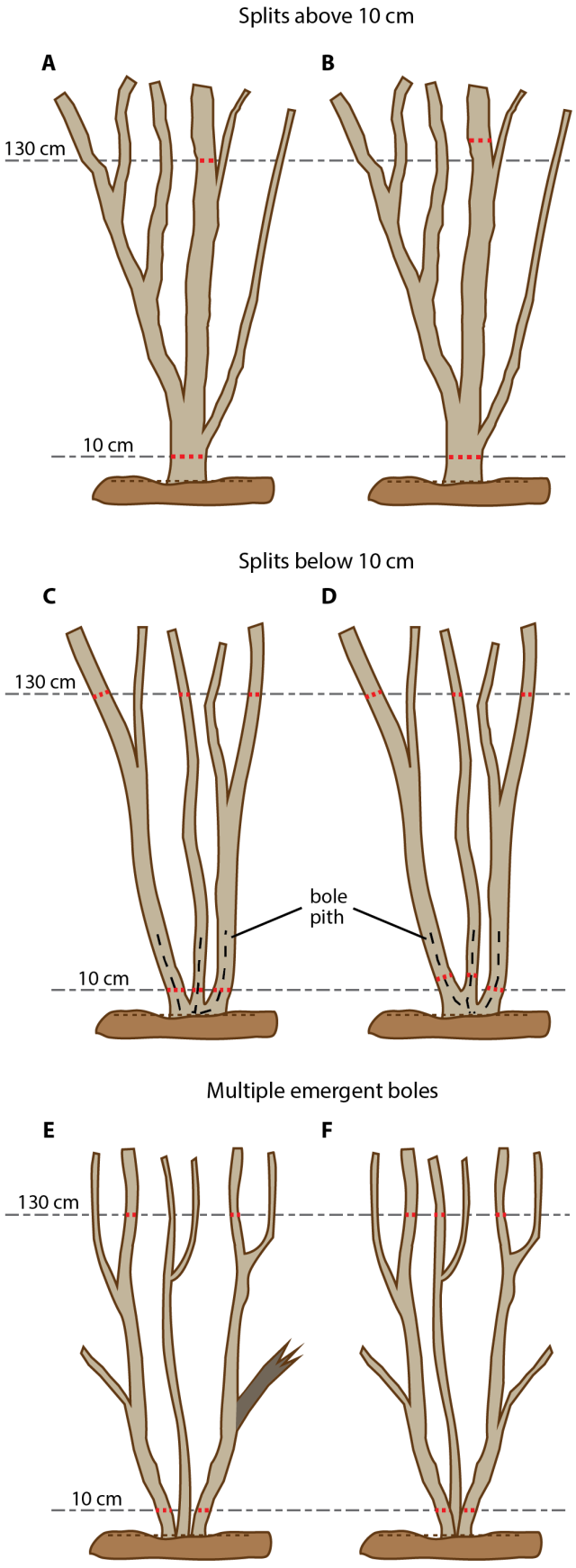



**Figure 15**. Shrub stem diameter measurement guidelines. Simple dashed black lines represent stem piths. Light brown shows live tissue, and dark brown indicates dead.

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

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

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

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

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

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

## Saplings and Small Shrubs

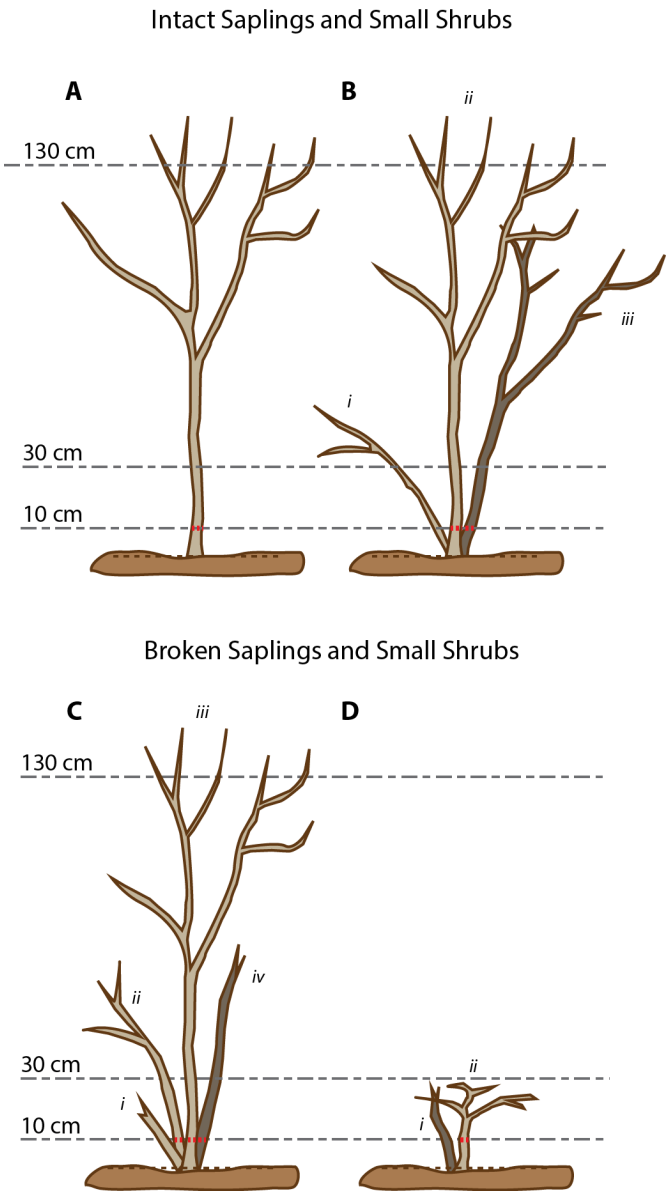



**Figure 16**. Stem diameter measurement guidelines for saplings and small shrubs that have no qualifying DBH. Light brown shows live, and dark brown indicates dead tissue. For all cases, consider emergent stems separately for basal stem diameter measurements, and consider all intact stems together when measuring crown diameter(s).

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

**(B)** ***Multiple intact stems connected below ground.*** *(i)* Ignored: ddh < 1 cm; *(ii)* Measure ddh, plantStatus = '1 – live'; *(iii)* Measure ddh, plantStatus = '2 – dead'.

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

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

### E.1.2 Liana Measurement Guidelines

The guidelines below support consistent measurement of complex liana growth forms (adapted from Schnitzer et al. 2008). Other complex 'liana-like' morphologies that are often adopted by *Vitis spp.*, *Smilax spp.*, *Parthenocissus quinquefolia*, etc. may also be measured according to these strategies.


**Figure 17**. Guidelines for determining where to measure liana stem diameter (red line) across a variety of complex growth forms. Different growth forms correspond to capital letters.

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

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

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

**(1).** If the branch point is less than 40 cm from the ground, measure half-way between the branch point and the ground, where the stem is regular.

**(2).** If the stem is not regular anywhere between the branch point and the ground, measure according to **(G)** below.

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

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

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

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

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

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

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

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

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

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

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

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

**(P)** Deprecated: Refer to Case **(F)**

**(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.

***Implementing Liana Measurement Guidelines***

From the cases presented in the figure above, generalized implementation strategies may be derived.

1. For any liana to qualify for measurement, at least one stem that is ascending toward the canopy must be greater than 1 cm diameter at a distance of 130 cm from the most proximal rooting point to ascension (rules **A**, **D**).
    a. Lianas lacking any ascending branches do not qualify, regardless of their size (rule **L**).
    b. Measurements are taken 130 cm along the stem, including all twists and curves (rule **B**).
    c. Oblong stems qualify if the average of the wide and narrow axes is greater than 1 cm (rule **R**).
2. Exceptions to the above rules:
    a. Individuals that loop from one rooting point to another ("ground to ground") with an ascending branch < 1 cm diameter at a distance of 130 cm are measured along the principle stem 130 cm from the roots, ignoring the branch (rule **M**).
    b. If a "ground-to-ground" individual has an ascending branch ≥ 1 cm diameter at a distance of 130 cm, measure the ascending branch and do not measure below the split.
    c. If a "ground to ground" individual does not have any ascending branches, the individual is not measured (rule **L**).
    d. Lianas completely prostrate on the ground are ignored (rule **N**).
3. Stems that branch below 130 cm may be measured with an altered measurement height depending on the following conditions:
    a. Confirm more than one branch is > 1 cm diameter at 130cm before considering an altered measurement height. If only one branch qualifies at 130 cm, do not alter the measurement height (rules **H, I, O**).
    b. If multiple branches qualify at 130 cm:
        i. Measure 20 cm below the branching point (rule **C**).
        ii. If the branching point is < 40 cm from the roots, measure halfway between rooting point and branch (rule **C**).

4. Multi-bole individuals may be recorded in the following conditions:
    a. If no regular point of measurement exists below a branching point (due to general stem irregularity, or branching very close to the ground), measure each branch separately at 130 cm (rule **G**).
    b. If an individual has one or more branches that loop to the ground and re-root before ascending, measure each qualifying branch 130cm from its most proximal rooting point to ascension (rules **E, K**).
5. Measurement heights may be altered on an individual stem or branch:
    a. If a stem is irregular below 130 cm, measure 20 cm above the point where the stem becomes uniform. If no uniform area is within reach, measure at 130 cm regardless of the irregularity (rule **Q**).
    b. Individuals with rooted adventitious (aerial) roots > 80 cm from the main rooting point are measured 50 cm past the last root (rule **F**).

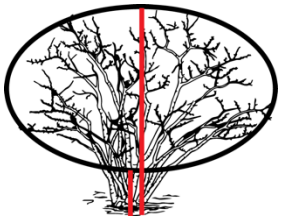
## E.2 Height and Crown Diameter Measurements

This section describes measurement of height, crown diameters, and assessment of 'shape' that informs these measurements for some growth forms.

1. (For growthForm = 'sis' and 'sms' only) Determine the **shape** of the individual (**Table 16**). Shrub crown dimensions and height can be used to estimate volume according to idealized shapes.
    a. Not all shrubs match an idealized shape: Choose the best fit, and consider the stems and branches as they emerge from the ground level, not just the leafy crown.
    b. There will not necessarily be a 'correct' shape to assign for a given shrub; that is, more than one shape can conceivably apply.
        i. Shape may be relatively consistent from year-to-year, so use the previous year's **shape** as a starting point (if available).
        ii. Calibrate your judgement as a team prior to beginning work to enable consistent data collection through time and across teams.

**Table 16**. Idealized shapes for shrub volume estimation.

| Shape | Example | Additional measurements |
|---|---|---|
| Half-sphere (hsp)* |  | None |
| Oblate half sphere (ohs)* |  | None |
| Cone (cne) |  | None |
| Inverted cone* (icn) |  | • **baseCrownMaximum** diameter (red line)<br>• **baseCrownNinety** diameter |

| Shape | Example | Additional measurements |
|---|---|---|
| Cylinder (cyl) |  | None |
| Ellipsoid or sphere (elp) |  | • **baseCrownHeight** (short red line)<br>• **height** (long red line) is already recorded |

* Images from Ludwig et al. (1975)

2. Measure the **height** (if required). See **Table 9** for growthForm dependent requirements. Record in the *VST: Apparent Individuals* app:

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

        i. *Rangefinder:* The vertical distance between the top of the canopy and the rangefinder (typically a positive number); nearest 0.1 m. When using the rangefinder, make measurements until two measurements match within 1%, then record the mean.

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

    b. **vdBaseHeight**; ***Do NOT leave blank!*** The definition depends on the measurement method:

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

        ii. *Collapsible ruler or equivalent*: Enter '0', since **vdApexHeight** already represents total **height** above ground when measured with a collapsible ruler.

    c. See SOP E.2.1 for strategies to deal with broken individuals.

3. Measure **crown** dimensions (if required). See **Table 9** for growthForm-dependent requirements. The **crown** dimensions may include live and dead material from intact boles / stems. However, do not include broken boles in measured **crown** dimensions. Measure crown diameters with the technique that works best given the constraints of the vegetation:
    a. Large calipers ('sms')
    b. Rigid collapsible meter stick ('sms', some 'sis', 'smt')
    c. Meter tape (some 'sis', 'smt', 'sbt', 'mbt')
    d. Laser rangefinder (some 'sis', 'smt', 'sbt', 'mbt')
4. Record in the *VST: Apparent Individuals* app:
    a. **maxCrownDiameter**; The maximum extent of the crown; nearest 0.1 m.
    b. **ninetyCrownDiameter**; The diameter at 90˚ to maxCrownDiameter; nearest 0.1 m.
5. Measure and record additional growthForm dependent crown data (if required). See **Table 9** for growthForm-dependent requirements. Use methods as described above.
    a. For **shape** = inverted cone (icn):
        i. **maxBaseCrownDiameter**; nearest 0.01 m. The maximum diameter of the base of the crown (red line in **Table 16**), always measured at ground level. For a perfect inverted cone, this diameter is the diameter of the stem.
        ii. **ninetyBaseCrownDiameter**; nearest 0.01 m. The diameter at the crown base that is perpendicular to maxBaseCrownDiameter.
        iii. If using paper datasheets: maxBaseCrownDiameter = 'aDatum'; ninetyBaseCrownDiameter = 'bDatum'.
    b. For **shape** = ellipsoid (elp):
        i. **baseCrownHeight**; nearest 0.01 m. Should be a positive number. Use a rigid, collapsible meter stick to measure the average height above the ground surface for the lowest portion of the crown (short red line in **Table 16** above).
        ii. If using paper datasheets: baseCrownHeight = 'aDatum'; 'bDatum' = null.

6. Assess and record the **canopyPosition** (see **Table 17**).
    a. Required for all 'sbt', 'mbt', 'smt', 'sap', 'sis', and 'sms' growth forms in all plots. Not required for 'lia' and shrub groups.
    b. The canopyPosition data are ***critical*** for selecting representative individuals visible to remote sensing for sampling via the NEON TOS Canopy Foliar Chemistry protocol.
    c. *Example*: A closed canopy, northern hardwood forest. A young Red Oak (*Quercus rubra*) with DBH = 12.2 is growing at the center of a narrow gap in the canopy caused by a blow-down that occurred some years before. Assign canopyPosition = 3, based on the fact that the top of the tree's crown is dominating a small canopy gap, and receiving direct sun. The sides receive little direct light, since the gap is narrow.

**Table 17**. Canopy position definitions. Modified from USFS Forest Inventory Analysis program Crown Class definitions to emphasize an individual's visibility to AOP remote-sensing instruments (U.S. Forest Service 2012).

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

7. Review all *VST: Apparent Individuals [PROD]* record fields for completeness and accuracy.
    a. It is valuable to spend a minute to identify missing data or errors while still in the field where the individual can be checked against measurement requirements (see **Table 9**, **Table 16**).
    b. Collecting missing data at a later date and / or correcting errors without access to the measured individual is time-consuming and costly.
8. Save the record and repeat steps for additional qualifying individuals.

### E.2.1 Measuring Broken Individuals

I. **Broken boles: sbt**

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

a. Record **plantStatus** = '9 – live, broken' or '10 – dead, broken' (see **Table 15**).

b. Record: **breakDiameter, vdApexBreakHeight** and **vdBaseBreakHeight.**

i. If leader branches ascend higher than the break height, **vdApexHeight** will be larger than **vdApexBreakHeight**.

ii. If the break height is the highest point, the value recorded for **vdApexBreakHeight** will be the same as that recorded for **vdApexHeight**.

iii. **vdBaseBreakHeight**; often the same as **vdBaseHeight.** May be different than vdBaseHeight for a broken 'mbt' bole growing on a slope, or when a different viewpoint is needed to make the separate height/breakHeight measurements.

iv. If using paper data sheets, record on the next row of the data sheet as **remarks**.

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

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

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

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

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

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

II. **Broken boles: mbt**

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

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

i. Record **plantStatus** individually for each bole (see **Table 15**).

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

iii. Separately measure and record **breakDiameter**, **vdApexBreakHeight**, and **vdBaseBreakHeight** for the broken bole(s) as described above for broken 'sbt.'

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

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

ii. Do NOT record **crown diameter** data.

iii. Separately measure and record **breakDiameter**, **vdApexBreakHeight**, and **vdBaseBreakHeight** for each broken bole as described above for broken 'sbt.'

III. **Broken boles: smt**

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

i. Assign **plantStatus** = '8 – no longer qualifies', and do not measure.

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

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

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

i. For broken boles that do not qualify, assign plantStatus = '8 – no longer qualifies' as for single-bole 'smt'.

ii. Continue to measure qualifying emergent boles as normal.

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

c. When one or more boles of a multi-bole 'smt' have broken, and height is > 130 cm:

i. Record **plantStatus** = '9 – live, broken' or '10 – dead, broken' per broken bole.

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

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

IV. **Broken boles: Multi-stem sap and sms**

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

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

ii. Do not measure ddh.

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

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

i. Assign **plantStatus** = '9 – live, broken' or '10 – dead, broken'

ii. Measure ddh.

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

iv. If all qualifying emergent stems are broken and ≥ 30 cm height, measure extent of 'broken' crown.

V. **Broken boles: sis**

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

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

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

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

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

i. Record **plantStatus** = '9 – live, broken' or '10 – dead, broken' per broken bole.

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

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

i. Leave the tag in place, treat the individual as a 'sms', and measure accordingly.

ii. Assign **plantStatus** = '9 – live, broken' or '10 – dead, broken' per broken bole.

## E.3 Shrub Groups and Liana Groups

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

Classifying vegetation as a 'group' is a measure of last resort, as group measurements are the least useful with respect to allometric biomass estimation (**Figure 18**, see SOP B for explanation and classification guidelines). Shrub and Liana groups are not mapped relative to a plot marker, and it is not required that they be tagged; however, you may tag shrub groups to better enable repeat measurements if you wish. Groups are measured so that the volume of the group may be estimated as 'canopy area' x 'average height'.

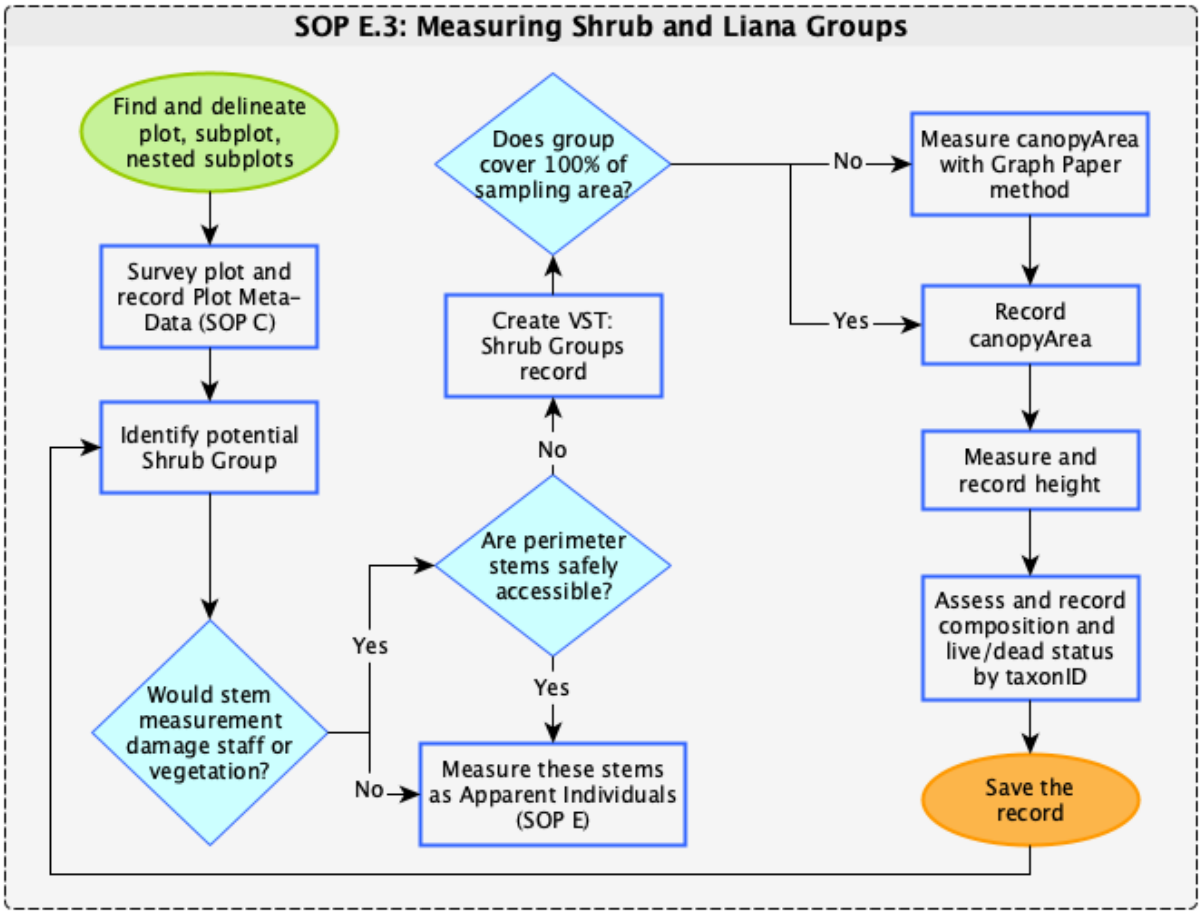



**Figure 18**. SOP E.3 workflow diagram outlining measurement of shrub and liana groups; boxes indicating 'Shrub Group' in the diagram also apply to Liana Groups. Diagram supports and does not replace protocol text; most common workflow is outlined.

Canopy area is estimated using the graph paper mapping technique, with the area covered by the group determined by counting the number of graph squares within the group (**Figure 19**).

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

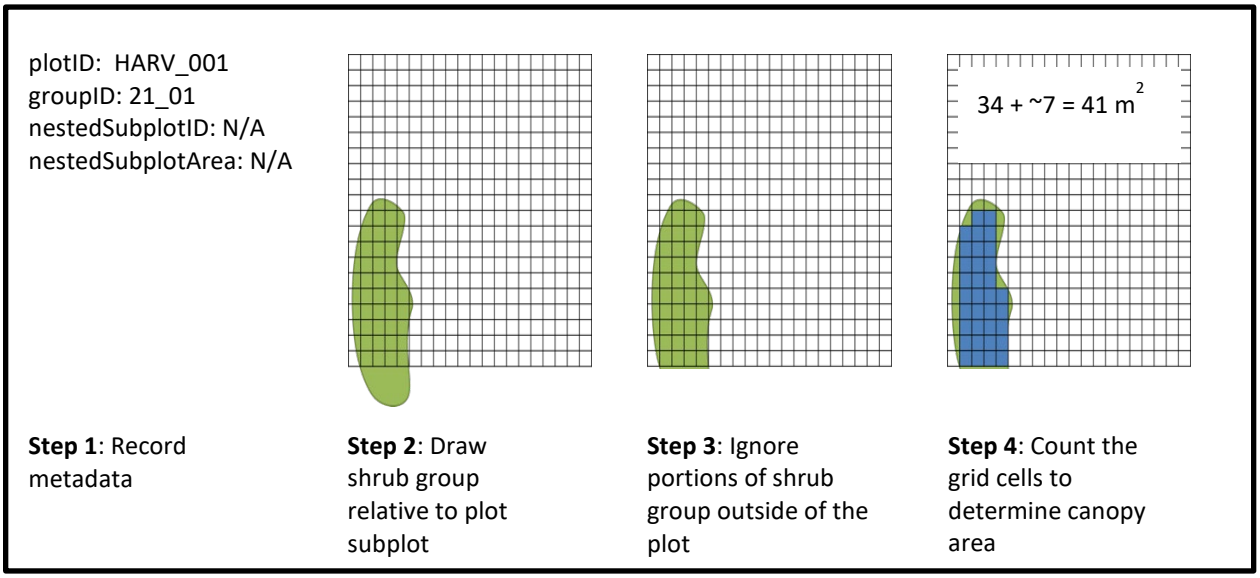



**Figure 19**. Example of graph paper method for estimating shrub group area within a 20 m x 20 m subplot. In this example, **canopyArea** = 41 $m^2$.

***For each Shrub or Liana Group:***

1. Assess the % cover of the group relative to the measurement area:
    a. Do not map the group if cover is 100% for a given subplot or nested subplot - i.e., stems are very dense, and a more-or-less continuous group covers the entire measurement area. When this occurs, record the nestedSubplotArea in the canopyArea field. E.g., if the nestedSubplotArea = 25 m2 and cover is 100%, record canopyArea = 25.
    b. If the group covers <100% of the measurement area, map the area of the group using the graph paper method.
2. Measure Shrub or Liana Group **canopyArea** with the graph paper method (**Figure 19**):
    a. Label plotID, subplotID, nestedSubplotID, nestedSubplotArea on the graph paper.
    b. Draw the measurement area boundaries, (1 $cm^2$ = 1 $m^{2,}$ ).
    c. Draw the shape of the shrub group to scale within the measurement area.

d. Count the number of grid cells contained within the sketched group, begin with whole cells then add up partial cells: the sum is the **canopyArea** for the group.

3. Measure Shrub Group average height:
    a. Use either the laser rangefinder (> 2 m), a meter tape (< 2 m) or collapsible ruler (< 2 m).
    b. Measure the height at 5 locations (**aGroupHeight**, **bGroupHeight**, etc.); nearest 0.1 m.
        i. Choose heights that you feel best represent the average maximum height of the shrub group. Bear in mind that the goal is to estimate the volume of the entire group as accurately as possible.
        ii. For groups that include lianas, measure height for the majority of the group, do not account for climbing stems extending to the canopy.
4. Create a record in the *VST: Shrub Groups [PROD]* application. Enter the following:
    a. **siteID** and **plotID**; select a plotID from the list generated by the *VST: Plot Meta-Data* app. Return to *VST: Plot Meta-Data* and create record for the current bout if one does not yet exist.
    b. **Date**; enter the correct date, *YYYY-MM-DD* format.
    c. **subplotID** and **nestedSubplotID**; the subplot in which the shrub group is located, and if applicable, the nestedSubplotID within the subplot. These data can aid in re-finding shrub groups in future bouts.
        i. If a single group spans > 1 nestedSubplot, record additional nestedSubplotIDs in the **remarks** field.
    d. **eventID**; a unique identifier for the sampling event, '*vst_SITE_YYYY*' format, where *YYYY* is the year the bout began. If an auto-populated value is incorrect, return to *VST: Plot Meta-Data* and update the record.
    e. **samplingProtocolVersion**; the version of the Vegetation Structure protocol used to guide sampling.
    f. **groupID**; unique identifier *within a plot* for the shrub group, using the form '*XX_YY*' where *XX* is the subplotID, and *YY* is an incremental number (01, 02, 03…) assigned in the field, starting over for each plot.
    g. **canopyArea**; the area of the shrub group, nearest 1 square meter.
    h. **aGroupHeight, bGroupHeight, etc**.; enter 5 representative height measurements, nearest 0.1 meter.

5. Assess the Shrub Group to determine taxonomic composition and per taxon live/dead status.
    a. Determine the % contribution by volume (ocular estimation) of each species within the shrub group (sum of live + dead biomass).
        i. Ignore herbaceous species that are quantified via the Herbaceous Biomass protocol.
        ii. It is okay to include woody individuals with ddh < 1 cm in the estimate that, were they not within the group, would be quantified via the Herbaceous Biomass protocol.
    b. For each species present, assess the % live and % dead within the total shrub group volume. The sum of % live and % dead should = 100 for each taxonID, though see below if the %volume is < 5% for a given taxonID.
        i. Do not include dead, downed individuals that would be measured via the Litterfall or Coarse Downed Wood protocols.
    c. Create a child record in the *VST: Shrub Groups* app for each taxonID within the shrub group and record:
        i. **taxonID**; select from the NEON master list of USDA plant species codes for species present within the domain. Identify to the greatest taxonomic resolution possible.
            1. If **taxonID** is unknown and the stem is alive, assign a morphospecies ID as indicated in steps below, obtain leaf, bark, and/or reproductive part samples (e.g., cones, nuts), and bring back to the lab to identify.
        ii. **identificationReferences**; for unknown species that must be keyed out, record the references used (e.g., dichotomous keys, regional flora guides) on a per individual basis the first time the species is encountered. It is not necessary to record the identificationReferences the next time the species is encountered.
        iii. **identificationQualifier**; select the appropriate qualifier when identification below a given taxonomic rank cannot be made – e.g., taxonID = family- or genus-level (**Table 14**).
        iv. **morphospeciesID** (if applicable); enter a concise, descriptive ID that will be possible to link to this species at a later time. Follow all guidance in SOP D.3.
        v. **volumePercent**; visually estimated % volume of the shrub group for a taxonID, nearest 10%. If a taxonID is < 5% of total shrub group volume, record volumePercent = 1%
        vi. **livePercent**; the estimated percent of the biomass that is alive for a taxonID in the shrub group, nearest 10%.

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

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

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

## E.4 Measuring 'Other' Growth Forms

### E.4.1 Ferns and Fern Allies

Ferns and fern allies are one of the most common 'other' growth forms encountered across the Observatory. As a group, ferns and fern allies have a range of shapes and sizes. However, there are a limited number of fern allometries available for estimating biomass for this group. Measurements required for common fern species are provided in **Table 18**.

***For Distributed Plots:*** Ferns may be ignored when sampling Distributed plots if visually estimated aerial cover of ferns is < 50% of the entire plot area (**Figure 20**). That is, visually estimate the fern cover as seen by AOP.

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

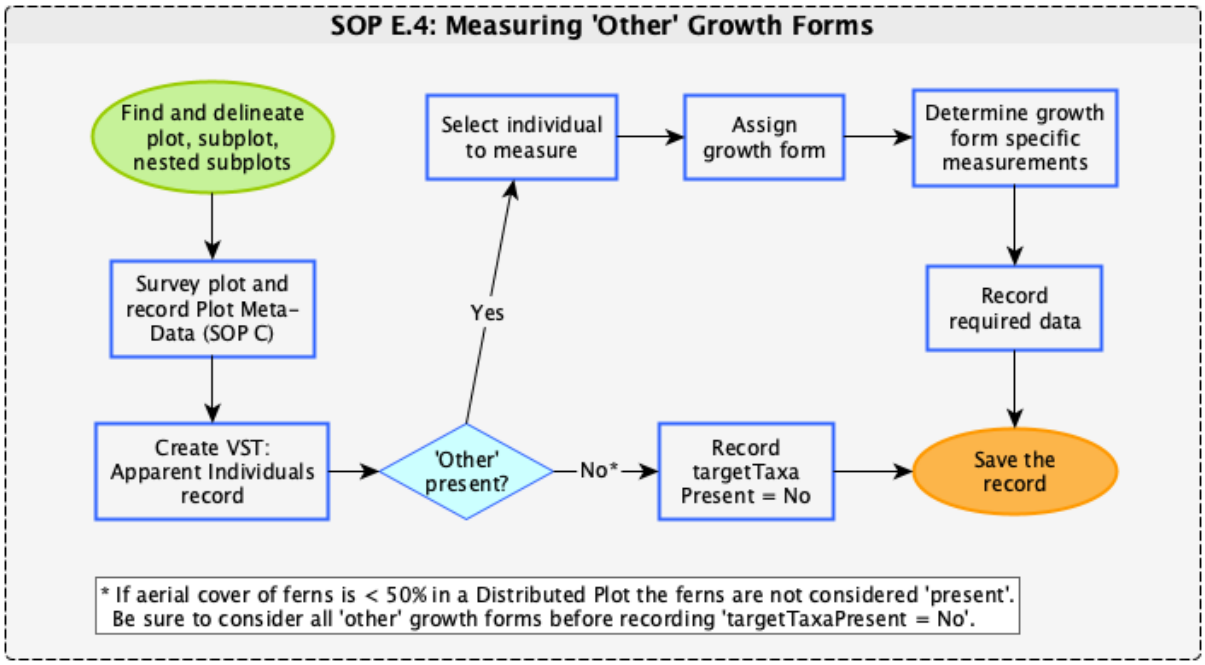



**Figure 20**. SOP E.4 workflow diagram outlining measurement of 'other' woody and non-woody stems. Diagram supports and does not replace protocol text; most common workflow is outlined.

***To Measure Ferns and Fern Allies:***

1. Determine the appropriate measurement area.
    a. 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.
    a. ***!!!*** *Note: This will likely disqualify many fern allies from consideration for this protocol.*
3. Create a record in the *VST: Apparent Individuals* app and create a non-woody child record for each fern.
4. Assign a **tempID** to each individual fern that is measured. The tempID auto-increments within each plot.
    a. If multiple teams are working within the same plot, one team should begin the auto-incrementing tempID sequence with '1' and the other team should begin the tempID sequence with '500' in order to avoid overlap and duplicates within the data.
5. For densely clustered ferns that form an impenetrable mass (e.g., some D20 PUUM species):
    a. Consider dense patches as 'groups' similar to Shrub Groups (SOP E.3), and create a *VST: Shrub Groups [PROD]* record.
    b. Groups count as '1' when determining the correct nested subplot size to use.
6. Determine species or morphology group and measure accordingly (**Table 18**). If a species is not listed, record:
    a. Average frond length (select representative frond to measure).
    b. Number of total fronds.

### E.4.2 Tree Ferns

Tree ferns are measured similarly to woody individuals. See **Table 18** for a summary of required measurements.

1. Select a nested subplot area as per standard woody tree growth forms:
    a. Tree ferns with DBH ≥ 10 cm: Do NOT use nested subplots. Measure these individuals throughout the plot.
    b. For tree ferns with DBH < 10 cm and with ddh ≥ 1 cm, use nested subplots as per woody growth forms.
2. Mapping tree ferns:
    a. Map all individuals with DBH ≥ 10 cm.
    b. Map the root point, not the crown.
3. Measure and record the **measurementHeight**:
    a. Measure diameter 130 cm along the stem from the 'root collar' or 'root point'.
        i. For downed individuals that are still growing, find the rooting point, and measure 130 cm along the downed stem to find the measurement location.
        ii. For individuals with pedestals, define the zero point as the top of the pedestal, then measure 130 cm along the stem from the top of the pedestal.
    b. For individuals with the frond attachment point at 130 cm (or close to it):
        i. Move the measurement location down the stem until the stem is regular.
        ii. Record the modified measurementHeight.
    c. Guidance in SOP E.1 may help with other complex situations.
4. Measure and record the **stemDiameter**:
    a. Use calipers when boles are extremely furrowed, moss-covered, or there are other irregularities like roots / shrubs / lianas that prevent accurate use of tapes.
    b. Avoid sloughing off bark to ensure repeat measurements do not yield negative changes in stemDiameter.
5. Measure the **stemLength**. The stemLength is the length of the stem from the root collar or root pedestal to the base of the leaves.
    a. The stemLength is equivalent to **height** for vertically growing individuals. For decumbent individuals the stemLength is used to allometrically estimate biomass, whereas height is meaningless.

b. At the apex of the plant, the stem terminates at the point where woody parts stop and fronds emerge.

    i. The point at which woody material stops and fronds emerge is often obscured. When possible, probe by hand to determine where woody parts stop.

    ii. For very tall individuals for which manual probing is not possible, use experience with shorter individuals to consistently visually estimate the correct vdApexHeight.

c. Use a measuring stick or a rangefinder to measure the required distance.

### E.4.3 Additional 'Other' Growth Forms

1. 'Other' growth forms that are also measured according to this protocol are listed below. Required measurements are unique to each growth form, and are listed in **Table 18**.
    a. Palm trees. Distinct measurements are required for:
        i. 'shrub'-type palms (e.g., Serenoa repens); ignore individuals with < 30 cm mean total leaf length.
        ii. 'tree'-type palms (e.g., Butia capitata)
    b. *Fouquieria splendens* (i.e., Ocotillo)
        i. Stem count is basal stem count, not terminal stem count.
    c. Xerophyllum species (i.e., Bear Grass)
    d. Yucca species
        i. Include agave species with yucca-like growth form in this group.
    e. Cactaceae species:
        i. The Cactus SOP is implemented concurrently with this protocol. Measurement of Cactaceae species is described in the companion Cactus SOP (RD[11]).
2. As above, create a *VST: Apparent Individuals* record for each plot that contains non-woody growth forms, then create a child Non-Woody record for each individual.
3. Assign an incrementing **tempID** to each non-woody 'other' individual within the plot as described above for ferns in SOP E.4.1.
4. Measure and record the **measurementHeight** any time a stem diameter measurement is made.

### E.4.4 Summary of Required Measurements for 'Other' Growth Forms

**Table 18**. Summary of required measurements for ferns, tree ferns, palms, and additional non-woody 'other' growth forms.

| Growth Form | taxonID | leafNumber/ stemCount | maxCrown Diameter | ninetyCrown Diameter | height | stem Diameter | measurement Height | stemLength[10] | meanPetiole Length | meanBlade Length | meanLeaf Length | canopy Position |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Ferns[1] (frn)** | *Athyrium filix-femina*[4] | leaf | | | | | | | | | x | |
| | *Blechnum spicant*[4] | leaf | | | | | | | | | x | |
| | *Dryopteris austriaca*[4] | leaf | | | | | | | | | x | |
| | *Polystichum munitum*[4] | leaf | | | | | | | | | x | |
| | *Pteridium aquilinum*[4] | | | | | basal[2] | x | | | | | |
| **Tree Ferns (tfn)** | *Cibotium spp.*[5] | | | | x | DBH or basal | x | x | | | | x |
| | *Cyathea spp.*[6] | | | | x | DBH or basal | x | x | | | | x |
| **Palms (plm)** | *Leucothrinax morrisii*[7] | leaf | crown | crown | x | | | | x | x | | x |
| | *Serenoa repens*[7] | leaf | crown | crown | x | | | | x | x | | x |
| | *Sabal etonia*[7] | leaf | crown | crown | x | | | | x | x | | x |
| | *Arecaceae spp.*[8] *(i.e., tree palms)* | | | | x | DBH or basal | x | x | | | | x |
| *Fouquieria splendens*[9] – Ocotillo (oco) | | basal stem | basal[3] | basal[3] | x | | | | | | | x |
| *Xerophyllum tenax*[4] – Bear Grass (xer) | | | | | | basal[2] | x | | | | x | |
| *Yucca sp.* (yuc) *Includes agave, and species with yucca-like, large basal rosette growth forms* | | | crown | crown | x | | | | | | | |

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

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

[3] See the 'icn' shape in **Table 16** for illustration of the maxBaseCrownDiameter and ninetyBaseCrownDiameter measurement location.

[4] Allometry from Gholz et al. (1979).

[5] Allometry from Ostertag et al. (2014), Selmants et al. (2014)

[6] Allometry from Alves et al. (2010).

[7] Allometry from Gholz et al. (1999).

[8] Allometry from Morel et al. (2011).

[9] Allometry from Bobich and Huxman (2009).

[10] **stemLength** definition: See SOP E.4.2; measure to 0.01 m. For vertical individuals, stemLength is equivalent to height. For decumbent individuals, height cannot be used to allometrically determine biomass.

## SOP F Vegetation Structure Data Collected Annually in Tower Plots

### *Overview*

In this SOP we describe measurements made annually in a subset of Tower Plots. Subsections of this SOP are focused on sites with and without dendrometer bands.

- **SOP F.1**: For relatively fast-growth increment sites without dendrometer bands.
- **SOPs F.2** and **F.3**: For relatively slow-growth increment sites with dendrometer bands.

This SOP assumes working knowledge of SOP E: 'Vegetation Structure Data Collected on a 5-year Interval'.

### *Goals*

- Collect annual Vegetation Structure data from a productivity subset of Tower Plots.
- At slow-growth increment sites, fit selected trees in the 'productivity subset' with dendrometer bands. Collect annual band gap data in addition to standard DBH data from banded trees.
- At slow-growth increment sites, fit large trees ≥ 95$^{th}$ %-tile biomass in additional Tower Plots with dendrometer bands. Collect annual band gap data in addition to standard DBH data from banded trees.

## F.1 Annual Measurements at Faster-Growth Increment Sites

- Annual Tower Plot measurement at faster-growth sites involves implementation of SOP E in a 'productivity subset' of 5-10 plots with sequential Morton Order.
- The list of plots in the productivity subset is determined by Science and the plot list is provided via the SSL.
- All qualifying woody and non-woody vegetation is measured annually within the productivity subset, *with the exception of ferns and fern allies*.
- See Appendix C for a list of faster-growth and slow-growth increment sites.

***Procedure steps:***

1. Navigate to one of the selected plots and delineate according to SOP C.
    a. Classify individuals to growth form according to SOP B when determining nested subplot size.
2. Create a record in the *VST: Plot Meta-Data [PROD]* application. Enter required information as described in SOP C.3. Ensure the following two fields are entered correctly:
    a. Enter the **eventType**:
        i. **allTowerPlots**; do NOT select. This option only applies when all Tower Plots are measured on a 5-year interval.
        ii. **distributedAndTowerSubset**; select if Distributed Plots are scheduled for measurement in the same year that the Tower Plot 'productivity subset' is measured.
        iii. **towerSubset**; select when only the productivity subset is scheduled for measurement for the current sampling year.
    b. Enter the type of **dataCollected**:
        i. **allGrowthForms**; select when all woody growth forms are measured within the plot. This is the only option to select for faster-growth sites.
        ii. **dendrometerOnly**; do NOT select. Dendrometer bands are not currently installed at faster-growth sites.
3. Survey the plot for newly qualifying woody and non-woody individuals.
    a. Tag and map (if required) according to SOP D.
    b. Do NOT consider ferns and fern allies for annual measurement in Tower Plots.
4. Collect and record required vegetation structure data for woody individuals according to SOP E.
    a. Do NOT measure ferns and fern allies annually in Tower Plots.

## F.2 Dendrometer Band Field Installation at Slow-Growth Increment Sites

***Overview***

At slow-growth increment sites, measurement of banded individuals provides high-resolution woody growth-increment data on an annual frequency that is not possible using standard DBH tapes. Annual growth increment data are used to calculate annual changes in aboveground Net Primary Productivity (NPP) for the site.

Dendrometer band installation in the field requires preparation of the tree, diameter measurements and data recording, custom fitting the tree-specific metal band prepared in the lab (SOP A.4), collar fabrication, installing the band on the tree, and finally, initial gap measurement (**Figure 21**).

Identifying Trees to Band*:*

- Trees selected for banding are initially identified by Science and a list is provided via the SSL.
- Banded trees are concentrated in a subset of spatially-balanced Tower Plots (typically n=5). The subset is chosen to match the biomass distribution from the full set of plots.
- The largest trees are banded in additional plots (those trees ≥ 95$^{th}$ percentile biomass).
- Trees with DBH < 5 cm are never banded, and the minimum banding diameter cutoff varies by site.
- When re-measuring banded trees at a site, follow the steps in this SOP to band and collect initial band data from new recruits that now meet the minimum banding diameter.

Fulcrum applications used to collect data for this SOP:

- ***VST: Mapping and Tagging [PROD]*** application. Collect dendrometer band installation data, as well as mapping, tagging, and taxonID data for individuals in the plot.
- The Vegetation Structure Fulcrum Manual on the SSL contains detailed data entry instructions.

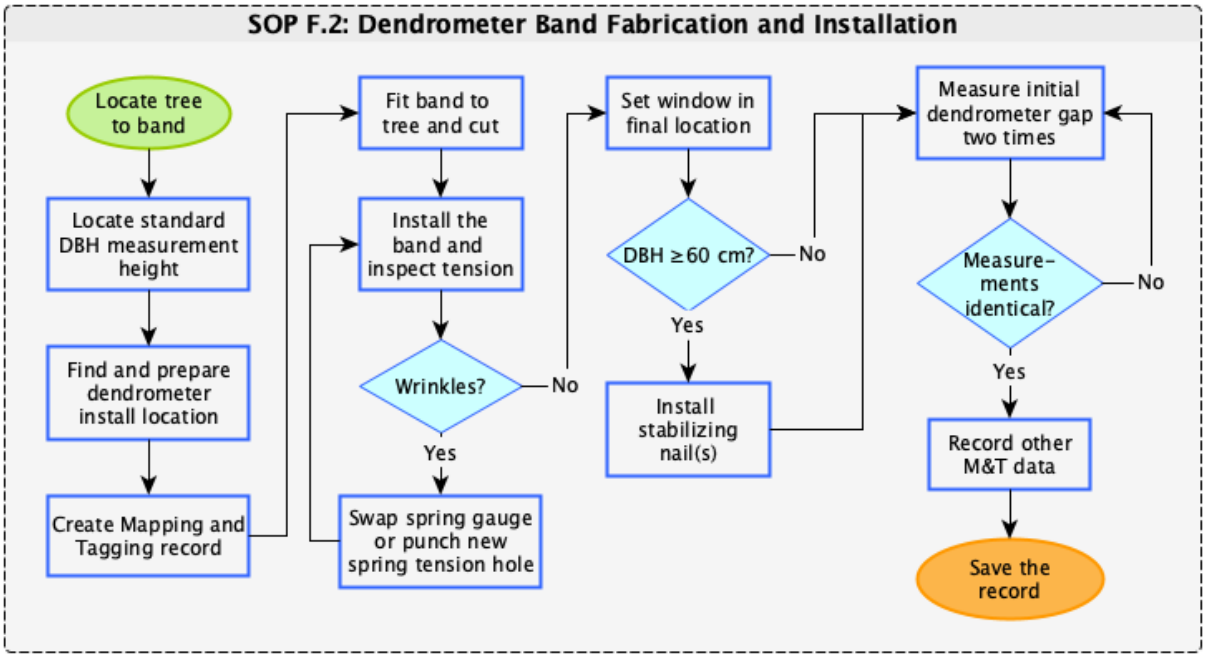



**Figure 21**. SOP F.2 workflow diagram for dendrometer band installation in the field, and initial measurements. Diagram supports and does not replace protocol text; most common workflow is outlined.

***Procedure Steps:***

1. Locate a tree to be banded. If the individual is a multi-bole tree, all boles that meet the minimum banding diameter for the site will be banded.
2. Prepare the tree for dendrometer band installation.
    a. Locate the standard DBH measurement location on the bole – i.e., the **measurementHeight**. This location is often marked with orange lumber crayon.
    b. (Optional) Tie flagging around the standard measurement location.
    c. Locate the dendrometer band installation height. The goal is to situate the band high enough above the standard DBH measurement location that bark removed during smoothing does not affect the standard DBH measurement.
        i. For smooth-barked trees that require minimal surface preparation: Situate band approximately 10 cm above the standard DBH measurement location.
        ii. For trees with rough, deeply-fissured, or loosely attached bark: Situate band approximately 20-30 cm above the standard DBH measurement location.
        iii. Assess the desired band location for branches, burls, knobs, etc. that may interfere with band placement. Move up the bole if necessary. It is possible to move below the standard DBH measurement location, but this is not desired.

d. Prepare dendrometer band location on the bole. The goal is to create as much smooth surface as possible on which the band will be flush and appressed to the bole.

   i. Use a knife to clear moss and smooth a 6-10 cm width swath around the circumference of the tree.

   ii. Inspect the bark and remove any loose pieces using either your hand and/or the knife. Smoothing the bark is an iterative process that typically requires several trips around the circumference of the tree.

   iii. For deeply fissured bark, gaps between band and bark are common and should be minimized where possible (**Figure 22**).


**Figure 22**. Preparation of the bole surface for dendrometer band installation on a deeply fissured Douglas Fir (*Pseudotsuga menziesii*) at the D16 WREF site.

3. Make initial diameter measurements and record in the *VST: Mapping and Tagging [PROD]* application. Create a new entry and record:

   a. **Dendrometer Installation Date**; *YYYYMMDD* format.

   b. **Initial Band Stem Diameter**; the diameter of the bole at the exact, smoothed location where the band will be installed, nearest 0.1 centimeters. ***!!!*** *This measurement is not the same as DBH.*

   c. **Dendrometer Height**; the height above ground at which the dendrometer band is installed, nearest 1 centimeter. For decurved stems, this is the distance along the stem rather than the height above ground.

4. Cut the band to fit the tree.
    a. Select the labeled, pre-cut band that was sized for the current tree.
    b. In your left hand, hold the tip-punched end with the window pointing down and the tip-punch pointing to the right.
    c. Take the other end of the band and wrap it clockwise around the tree so it is taut around the prepared surface. It should overlap the tip-punched end and all of the window.
    d. Mark the overlying band approximately 1 cm left of the window. Draw a dash/dot/star just to the right of the mark to indicate the outer face of the band.
    e. Remove band.
    f. Clip the band to length at the marked location and responsibly discard the clipped waste metal.
5. Fabricate the buckle (**Figure 23**).
    a. Hold the collar perpendicular to the tree side of the band (i.e. the unmarked side) approximately 1 cm from the cut end and centered on the band (**A**).
    b. Fold each wing of the collar around the band. They should not overlap. Pinch tightly with fingers (**B, C**).
    c. Fold the cut end of the band over the collar wings so that the cut end does not extend beyond the lower edge of the collar. Make sure the fold is square with the band and tight. Use fingers to pinch tightly (**D**).
    d. Fold the cut end again, in the same direction. Make sure the fold is square and tight. Use fingers to pinch tightly (**E, F**).
        i. (*Optional*) Gloves may be worn to protect against cuts. Thin, golf-style gloves or equivalent are recommended in order to retain finger dexterity.
    e. The tip-punch end of the band should slide freely through the buckle (**G, H**).
    f. Smooth any burrs that may prevent the tip-punch end of the band from passing through the buckle.

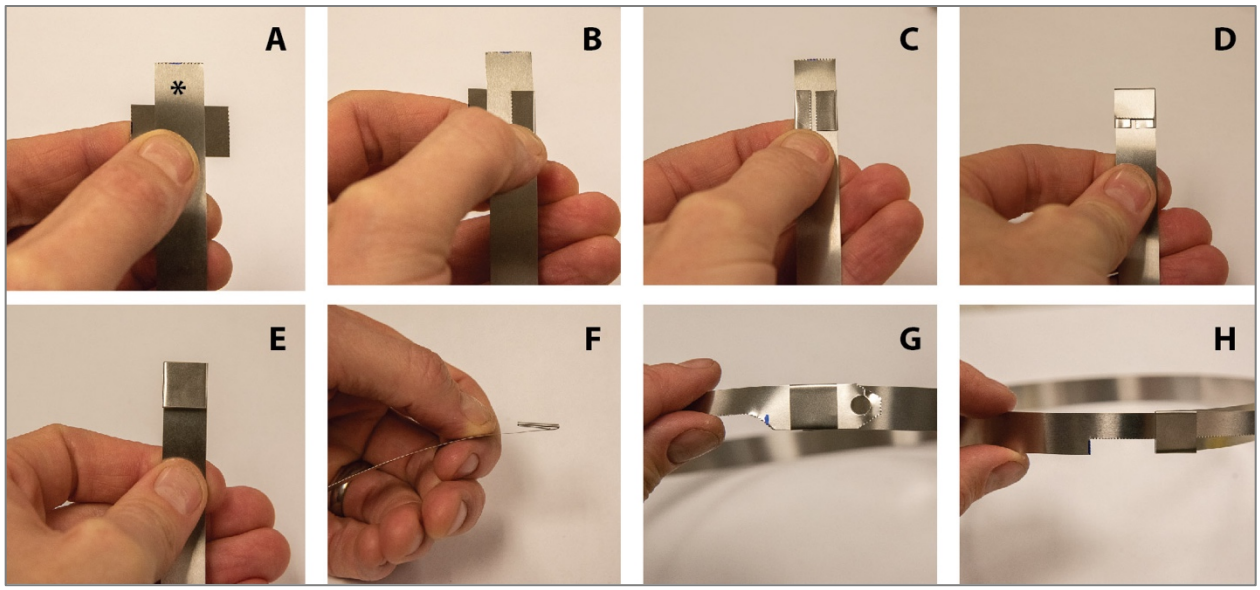



**Figure 23**. Fabricating the dendrometer band buckle with the collar after fitting the band to the tree and cutting to the desired length. The asterisk in **A** denotes the outward-facing side of the band marked in the previous step.

6. Install the band (**Figure 24**).
    a. Select a measurement location on the prepared surface of the bole where the window, buckle, and the extended spring can be fully appressed to the bark surface.
    b. Hold the leading tip-punched end with the window pointing down in your left hand, with the tip-punch end pointing to the right as you face the tree.
    c. Take the other end of the band and wrap it clockwise around the tree.
    d. Slide the tip-punched end through the buckle.
    e. Hook a spring of the required size and gauge through the tip punch from the tree side of the band (see Appendix G for spring requirements).
    f. Rotate the band to place the window, buckle, and the extended spring in the desired measurement location.
    g. Pull the band taut and stretch the spring to an appropriate tension.
        i. The spring should be tight enough that it is snug all the way around the tree, but not so tight that the band crumples or wrinkles from the tension.
        ii. Mark the band at the location where the free end of the spring will be attached.
    h. Release the band tension.
    i. Punch the hole. This may be done with the band still on the tree. Be sure to collect the chad and discard responsibly.
    j. Pull the band taut and hook the spring through the newly punched hole.
    k. Situate the band in its final location:
        i. Rotate so window, buckle, and spring are fully appressed against the bole.
        ii. Check that the entire band is perpendicular to the pith of the bole and centered within the prepared surface all the way around the tree (**Figure 22**).
        iii. Make sure the spring is resting on the band, not the bark.
    l. Check the **Initial Dendrometer Gap**. The gap between the buckle and the right-angled end of the window should be approximately 1-2 cm.
    m. Add stabilizing nail(s) if needed.
        i. Boles with DBH > 60 cm require at least one nail on the side opposite the window and underneath the band.
        ii. Tapering boles require at least one nail above the band to prevent the band from slipping upward.
        iii. ***!!!*** *Nails may be omitted for deciduous species that are known to swell around the nail.*


**Figure 24**. Installed dendrometer band with a 1-2 centimeter initial gap in the measurement window. The band is rotated such that the entirety of the measurement window and the spring are fully appressed to a smoothed section of the bole.

7. Measure and record the **Initial Dendrometer Gap**; the initial width of the dendrometer band window, nearest 0.1 mm.

   ***!!!*** *This measurement is ideally made after a settling period of approximately 4 weeks. Record on the day of installation and return and update after the settling period.*

   a. Use the inside jaws of metal calipers to measure the gap.
   b. Hold calipers level with the band and perpendicular to the bole.
   c. Place left jaw point in the upper left window corner (see **Figure 24**).
   d. Expand the caliper jaw to the upper buckle edge, stopping before the caliper dial begins to "click".
      i. Stopping before the dial clicks ensures that the caliper does not deform the window, resulting in inaccurate measurement of the growth increment.
   e. Remove caliper, read value.
   f. Reset to calipers to zero and repeat the measurement.
      i. If the two values are the same, record the **Initial Dendrometer Gap**.
      ii. If values differ, repeat measurement until obtaining two equal measurements.

8. Record **Initial Gap Measurement Date**; *YYYYMMDD* format.

   ***!!!*** *Record the current date on the day of installation and return and update after the settling period.*

9. Save the record.

10. Record standard **stemDiameter** and **measurementHeight** data for the banded individual as described in SOP E.

## F.3 Annual Measurements at Slow-Growth Increment Sites with Dendrometer Bands

***Overview***

- A spatially-balanced productivity subset of 5-10 Tower Plots is selected for sampling (based on Morton Order, same as at fast-growth increment sites).
- All qualifying woody and non-woody vegetation is measured annually within the productivity subset, *with the exception of ferns and fern allies*.
- Collect dendrometer band gap data from trees within the productivity subset that are fitted with a dendrometer band for annual measurement.
- In addition to the productivity subset, collect dendrometer band gap data from large trees with biomass ≥ 95$^{th}$ %-tile that are banded in other Tower Plots; only banded trees are measured annually in these additional plots.
- The list of banded trees is provided via the SSL. VST data are analyzed by Science every 5 y to identify any changes to per site minimum banding diameters and/or changes to the 95$^{th}$ %-tile biomass threshold.
- See Appendix C for a list of faster-growth and slow-growth increment sites.

Fulcrum applications used to collect data for this SOP:

- *VST: Apparent Individuals [PROD]* application. Collect dendrometer band gap data, as well as other required structure data for individuals in the plot.
- The Vegetation Structure Fulcrum Manual on the SSL contains detailed data entry instructions.

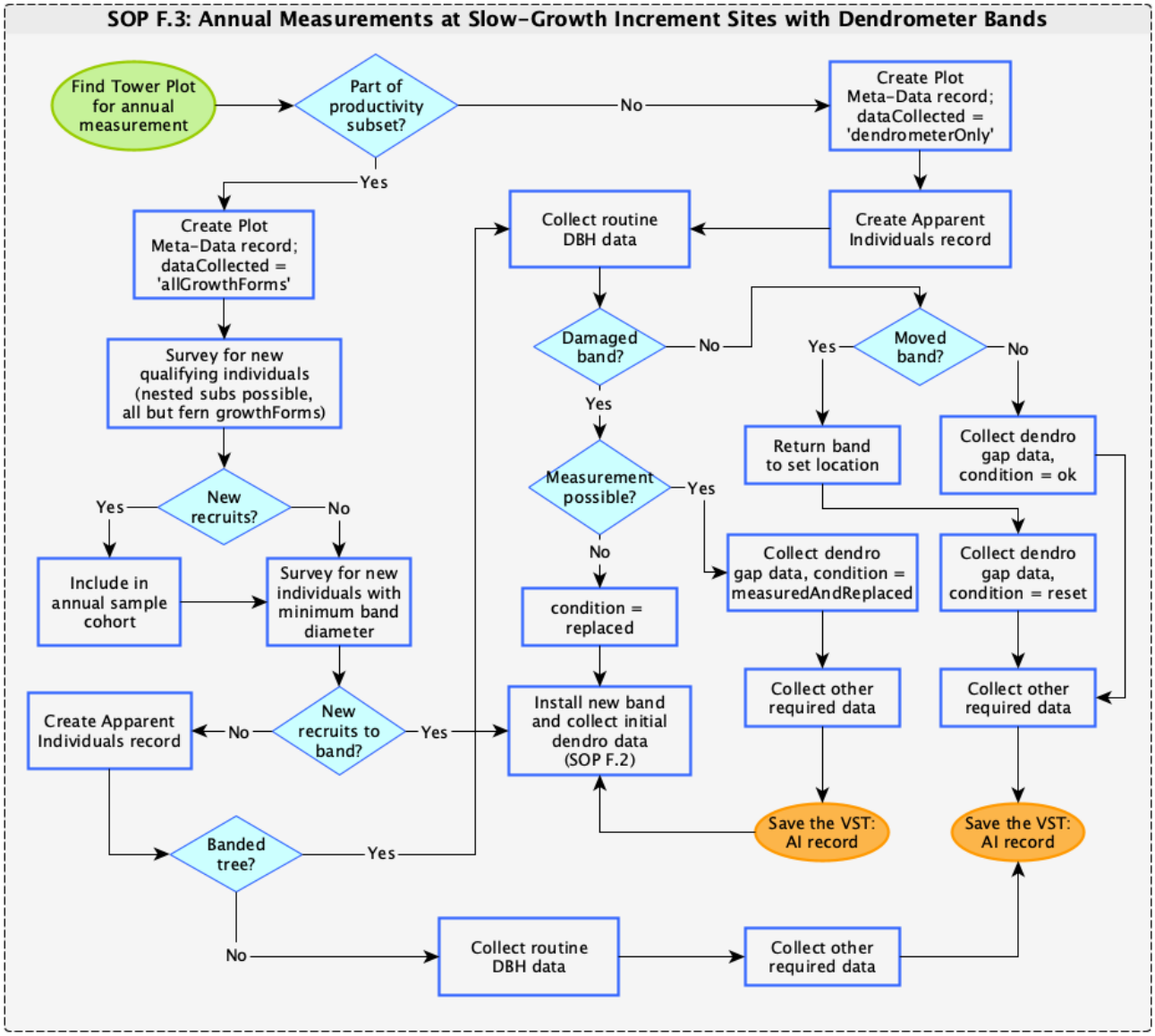



**Figure 25**. SOP F.3 workflow diagram for annual measurements in Tower Plots at slow-growth increment sites with dendrometer bands. Diagram supports and does not replace protocol text; most common workflow is outlined.

***Procedure steps:***

1. Navigate to one of the selected plots and delineate according to SOP C.
    a. Classify individuals to growth form according to SOP B when determining nested subplot size.
2. Create a record in the *VST: Plot Meta-Data [PROD]* application. Enter required information as described in SOP C.3. Specific to this SOP, ensure the following two fields are entered correctly:
    a. Enter the **eventType**:
        i. **allTowerPlots**; do NOT select. This option only applies when all Tower Plots are measured on a 5-year interval.
        ii. **distributedAndTowerSubset**; select if Distributed Plots are scheduled for measurement in the same year that the Tower Plot 'productivity subset' is measured.
        iii. **towerSubset**; select when only the productivity subset is scheduled for measurement for the current sampling year.
    b. Enter the type of **dataCollected**:
        i. **allGrowthForms**; select when all woody growth forms are measured within the plot. This option applies when the plot is part of the 'productivity subset'.
        ii. **dendrometerOnly**; select when only large, banded individuals with ≥ 95$^{th}$ %-tile biomass are measured in the plot. The 'totalSampledArea' is NULL for the plot when this value is selected because biomass data cannot be scaled to the plot level since only a subset of banded trees are measured for the bout.
3. If the plot is part of the 'productivity subset', survey the plot for newly qualifying woody and non-woody individuals.
    a. Tag and map if required (SOP D).
    b. If the individual is a tree, install a dendrometer band if the DBH now meets or exceeds the site-specific minimum banding diameter, and collect initial dendrometer band data (SOP F.2).
    c. Do NOT consider ferns and fern allies for annual measurement in Tower Plots.
4. If the plot is part of the 'productivity subset', collect and record required vegetation structure data for qualifying woody and non-woody individuals according to SOP E.
    a. Do NOT measure ferns and fern allies annually in Tower Plots.

5. For qualifying trees fitted with a dendrometer band in a previous bout:
    a. Inspect the dendrometer band for damage:
        i. If the window is damaged or the band is damaged such that it is no longer appressed flat to the bole at the set location, replace with a new band and collect **Initial Dendrometer Gap** data (SOP F.2).
        ii. If the band is damaged, a measurement is possible, and the data quality is questionable, proceed to the next step and acquire dendrometer gap data. Replace the band when finished and collect **Initial Dendrometer Gap** data (SOP F.2).
    b. Inspect the dendrometer band for movement. If the band is no longer at the original set location – i.e., the **Dendrometer Height** has changed from the initial installation height:
        i. Carefully slide the band back and forth and move the band to the bole location at which it was originally set.
        ii. If helpful, install additional nails to prevent future band movement.

        ***!!!*** *Be aware that nails may cause some deciduous species to swell around the nail, so adding nails is not universally useful.*
    c. Measure and record the **Dendrometer Gap**; the width of the dendrometer band window, nearest 0.1 mm. 'Dendrometer Gap' measurements allow precise estimation of growth increment and woody productivity.
        i. Use the inside jaws of metal calipers to measure the gap.
        ii. Hold calipers level with the band and perpendicular to the bole. In this position you will not be able to read the calipers, thus removing any visual bias from the measurement.
        iii. Place left jaw point in the upper left window corner (see **Figure 24**).
        iv. Expand the caliper jaw to the edge of the buckle, stopping before the caliper dial begins to "click".
            1. Stopping before the dial clicks ensures that the caliper does not deform the window, resulting in inaccurate measurement of the growth increment.
        v. Remove caliper, read value.
        vi. Reset to calipers to zero and repeat the measurement.
            1. If the two values are the same, record the **Dendrometer Gap**.
            2. If values differ, repeat until two equal measurements are obtained.

d. Record the **Band Condition**:

i. **ok**; select if a regular, high-quality measurement was made. That is, the band is not damaged and has not moved relative to the initial installation location.

ii. **measuredAndReplaced**; select if the band was damaged but a lower-quality measurement could be made and the band was replaced afterward.

iii. **replaced**; select if the band was damaged, a measurement could not be made, and a new band was installed. For example, the window itself was damaged by falling debris and could not be measured.

iv. **reset**; select when a band has moved from the initial **Dendrometer Height** and was undamaged; the band was moved back to the original location and a lower-quality measurement was made.

6. Record standard **stemDiameter** and **measurementHeight** data as described in SOP E.

7. Review all *VST: Apparent Individuals* record fields for completeness and accuracy.

a. It is valuable to spend a minute to identify missing data or errors while still in the field.

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

8. Save the record and repeat steps for additional qualifying individuals in the plot.

## SOP G Post-Field Sampling Tasks

### G.1 Document Incomplete Sampling Within a Site

Measurement of Vegetation Structure sampling is scheduled to occur at all prescribed sampling locations according to the frequency and timing described in Section 4 and Appendix C. The protocol should be implemented at up to 20 selected Distributed Plots, and up to the total number of Tower Plots per site. Ideally, sampling will occur at these sampling locations for the lifetime of the Observatory (core sites) or the duration of the site's affiliation with the NEON project (relocatable sites). However, sampling may be shifted from one location to another when sampling is compromised. In general, a sampling location is compromised when sampling becomes so limited that data quality is significantly reduced.

There are two main pathways by which sampling can be compromised. First, sampling locations can become inappropriately suited to answer meaningful biological questions – e.g., a terrestrial sampling plot is compromised after road-building activities, or a stream moves after a flood and the location is no longer within the stream channel. Second, sampling locations may be located in areas that are logistically impossible to sample on a schedule that that is biologically meaningful.

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

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

If sampling at a given plot is not possible during a given bout, the **Sampling Impractical** field must be populated in *VST: Plot Meta-Data [PROD]* (SOP C.3) and a problem ticket should be submitted by Field Science staff.

***To document locations not sampled during the current bout:***

1. Review Fulcrum records with a **Sampling Impractical** value to determine which locations were scheduled for sampling but were not sampled.
2. Create an incident with the following naming convention to document the missed sampling: 'TOS Sampling Incomplete: VST – [Root Cause Description]'
    a. Example: 'TOS Sampling Incomplete: VST – Could not access plot due to permanently closed road'
3. Staff scientists review incident tickets annually to determine whether a sampling location is compromised.

### G.2 Sample Preservation

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

### G.3 Refreshing the Sample Kit

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

### G.4 Equipment Maintenance, Cleaning, and Storage

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

## SOP H Data Entry and Verification

Mobile applications are the preferred mechanism for data entry. Data should be entered into the protocol-specific application as they are being collected, whenever possible, to minimize data transcription and improve data quality. Mobile devices should be synced at the end of each field day, where possible; alternatively, devices should be synced immediately upon return to the Domain Support Facility.

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

### H.1 QA/QC and Digital Data Workflow

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

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

3. ***VST: Apparent Individuals***

    a. Records created here rely on previously created **plotID** and **tagID** records in upstream applications – *VST: Plot Meta-Data* and *VST: Mapping and Tagging*, respectively.

4. ***VST: Shrub Groups***

    a. Records created here rely on previously created **plotID** records in the upstream *VST: Plot Meta-Data* application.

    b. The **groupID** does NOT need to be created first in *VST: Mapping and Tagging*.

### H.2 Field Data Sheets

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

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

**SOP I Sample Shipment**

Not applicable to the Measurement of Vegetation Structure protocol.

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## APPENDIX A QUICK REFERENCES

### Making Quality Measurements of Vegetation Structure

**Step 1** – Calibrate laser rangefinder compass.

**Step 2** – Carefully delineate measurement area and ensure all tagged individuals fall within plot boundaries.

**Step 3** – Survey vegetation for presence/absence of growth forms and assess need for nested subplots (typically for new plots only).

**Step 4** – Record Plot Meta-Data and save.

**Step 5** – Tag and identify each newly qualifying individual (new plots and as needed in existing plots), and map individuals as required.

**Step 6** – Record Mapping and Tagging data.

**Step 6** – Take and record Apparent Individual and Shrub Group measurements, using temporary flagging as you go to mark progress.

**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 B 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, and how to determine whether a new nested subplot size is warranted.

**Taking Measurements**: Remember to…

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

**Using the laser rangefinder**: Pay close attention to…

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

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

## APPENDIX C SITE-SPECIFIC SCHEDULING INFORMATION

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

> ***"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. Unless indicated otherwise, "End Date" values are in the next calendar year.

**Table 19.** Site-specific scheduling information for vegetation structure measurements.

| Domain Number | Site ID | Site Type | Start Date | End Date | Protocol Scheduling by Plot Type | Dendro-bands | Remarks |
|---|---|---|---|---|---|---|---|
| 01 | BART | Faster-growth | 08/09 | 04/28 | Dist = Yes<br>Tower = Yes | N | Access problems may exist during proposed measurement window. |
| | HARV | Faster-growth | 08/07 | 04/22 | Dist = Yes<br>Tower = Yes | N | Access problems may exist during proposed measurement window. |
| 02 | BLAN | Faster-growth | 07/13 | 03/13 | Dist = Yes<br>Tower = Yes | N | |
| | SCBI | Faster-growth | 08/03 | 03/27 | Dist = Yes<br>Tower = Yes | N | |
| | SERC | Faster-growth | 08/09 | 03/17 | Dist = Yes<br>Tower = Yes | N | |
| 03 | DSNY | Faster-growth | 07/19 | 03/04 | Dist = Yes<br>Tower = No | N | |
| | JERC | Faster-growth | 08/10 | 03/23 | Dist = Yes<br>Tower = Yes | N | |

| Domain Number | Site ID | Site Type | Start Date | End Date | Protocol Scheduling by Plot Type | Dendro-bands | Remarks |
|---|---|---|---|---|---|---|---|
| | OSBS | Faster-growth | 07/15 | 03/05 | Dist = Yes<br>Tower = Yes | N | Not all Distributed plots may have qualifying stems. |
| 04 | GUAN | Faster-growth | 12/01 | 03/01 | Dist = Yes<br>Tower = Yes | N | Dates correspond to the dry season, and are derived from Ensenada precipitation data (1980-2015). |
| | LAJA | Faster-growth | 12/01 | 03/01 | Dist = Yes<br>Tower = No | NA | Dates correspond to the dry season, and are derived from Ensenada precipitation data (1980-2015). |
| 05 | STEI | Faster-growth | 08/08 | 04/29 | Dist = Yes<br>Tower = Yes | N | Not all Tower plots may have qualifying stems. |
| | TREE | Faster-growth | 08/07 | 04/27 | Dist = Yes<br>Tower = Yes | N | |
| | UNDE | Faster-growth | 08/08 | 04/30 | Dist = Yes<br>Tower = Yes | N | |
| 06 | KONA | Not scheduled | NA | NA | Dist = No<br>Tower = No | NA | Ag site, no qualifying individuals |
| | KONZ | Survey (D)<br>Faster-growth (T) | 07/30 | 04/02 | Dist = No<br>Tower = Yes | N | Dist: Survey indicates no qualifying individuals; schedule survey every 5 y. |
| | UKFS | Faster-growth | 07/28 | 03/22 | Dist = Yes<br>Tower = Yes | N | |
| 07 | GRSM | Faster-growth | 08/03 | 04/02 | Dist = Yes<br>Tower = Yes | N | |
| | MLBS | Faster-growth | 08/08 | 04/17 | Dist = Yes<br>Tower = Yes | N | |
| | ORNL | Faster-growth | 07/24 | 03/17 | Dist = Yes<br>Tower = Yes | N | |
| 08 | DELA | Faster-growth | 07/17 | 03/01 | Dist = Yes<br>Tower = Yes | N | |
| | LENO | Faster-growth | 07/17 | 03/09 | Dist = Yes<br>Tower = Yes | N | |
| | TALL | Faster-growth | 07/14 | 03/16 | Dist = Yes<br>Tower = Yes | N | |
| 09 | DCFS | Survey | 07/28 | 04/30 | Dist = No<br>Tower = No | NA | Survey indicates no qualifying individuals; schedule survey every 5 y |
| | NOGP | Survey | 07/19 | 04/25 | Dist = No<br>Tower = No | NA | Survey indicates no qualifying individuals; schedule survey every 5 y |

| Domain Number | Site ID | Site Type | Start Date | End Date | Protocol Scheduling by Plot Type | Dendro-bands | Remarks |
|---|---|---|---|---|---|---|---|
| | WOOD | Survey | 07/29 | 04/30 | Dist = No<br>Tower = No | NA | Survey indicates no qualifying individuals; schedule survey every 5 y |
| 10 | CPER | Survey | 07/29 | 03/31 | Dist = No<br>Tower = No | NA | Survey indicates no qualifying individuals; schedule survey every 5 y; *Opuntia* cover is critical for Tower Plot survey. |
| | RMNP | Slow-growth | 08/02 | 05/09 | Dist = Yes<br>Tower = Yes | Y | |
| | STER | Not scheduled | NA | NA | Dist = No<br>Tower = No | NA | Ag site, no qualifying individuals |
| 11 | CLBJ | Faster-growth | 08/28 | 02/27 | Dist = Yes<br>Tower = Yes | N | MODIS-EVI may reflect herbaceous community rather than trees; adjust if necessary using on-the-ground observations. |
| | OAES | Survey | NA | NA | Dist = No<br>Tower = No | NA | Survey indicates no qualifying individuals; schedule survey every 5 y |
| 12 | YELL | Slow-growth | 07/12 | See Remarks | Dist = Yes<br>Tower = Yes | Y | For Tower Plots: Measurements must be completed before Bear Management closure. |
| 13 | MOAB | Sensitive | 08/13 | 03/15 | Dist = Yes<br>Tower = Yes | N | Short shrubs, widely spaced; many may not be qualifying stems. Sensitive soil/veg site: No annual Tower Plot measurement, every 5-year for all plots only. |
| | NIWO | Slow-growth | 08/10 | 05/30 | Dist = Yes<br>Tower = Yes | Y | Complete data collection before snowfall and road closure. Tower Plots meet Science Design criteria for implementation. |
| 14 | JORN | Sensitive | 09/03 | 03/21 | Dist = Yes<br>Tower = Yes | N | Sensitive soil/veg site: No annual Tower Plot measurement, every 5-year for all plots only. |

| Domain Number | Site ID | Site Type | Start Date | End Date | Protocol Scheduling by Plot Type | Dendro-bands | Remarks |
|---|---|---|---|---|---|---|---|
| | SRER | Sensitive | 09/07 | 03/01 | Dist = Yes<br>Tower = Yes | N | Dist Plots: Schedule survey every 5 y in year before anticipated VST effort. Sensitive soil/veg site: No annual Tower Plot measurement, every 5-year for all plots only. |
| 15 | ONAQ | Sensitive | 06/15 | 03/17 | Dist = Yes<br>Tower = Yes | N | Sensitive soil/veg site: No annual Tower Plot measurement, every 5-year for all plots only. |
| 16 | ABBY | Faster-growth | 07/23 | 04/18 | Dist = Yes<br>Tower = Yes | N | Not all plots may have qualifying stems due to logging management. |
| | WREF | Slow-growth | 07/27 | 04/21 | Dist = Yes<br>Tower = Yes | Y | Not technically a slow-growth site but large trees lead to small growth increment. |
| 17 | SJER | Slow-growth | 07/01 | 04/30 | Dist = Yes<br>Tower = Yes | Y | Tree senescence does not align with Mediterranean rainy season. |
| | SOAP | Slow-growth | 07/08 | 03/30 | Dist = Yes<br>Tower = Yes | Y | |
| | TEAK | Slow-growth | 07/27 | 05/04 | Dist = Yes<br>Tower = Yes | Y | Access problems may exist during proposed measurement window. |
| 18 | BARR | Survey | 07/27 | 06/26 | Dist = No<br>Tower = No | NA | Survey indicates no qualifying individuals; schedule survey every 5 y |
| | TOOL | Survey | 07/26 | 06/06 | Dist = No<br>Tower = No | NA | Survey indicates no qualifying individuals; schedule survey every 5 y |
| 19 | BONA | Slow-growth | 07/26 | 05/13 | Dist = Yes<br>Tower = Yes | Y | Complete data collection before snowfall and road closure. |
| | DEJU | Slow-growth | 07/27 | 05/12 | Dist = Yes<br>Tower = Yes | Y | Complete data collection before snowfall and road closure. |
| | HEAL | Slow-growth | 07/28 | 05/18 | Dist = Yes<br>Tower = Yes | Y | Complete data collection before snowfall and road closure. |
| 20 | PUUM | Faster-growth | Any | 60 d after start | Dist = Yes<br>Tower = Yes | N | Start Date should be consistent from year to year (± 2 weeks). |

# APPENDIX D SITE-SPECIFIC SAMPLING INFORMATION

## D.1 D03 – DSNY – Disney Wilderness Preserve

| Modification Type | Modification | Standard Rule | Rationale for Change |
|---|---|---|---|
| Tagging requirements | Root (re)sprouts from some species are only tagged once they graduate to 'smt' or 'sis'. DSNY species are:<br>• *Quercus spp.*<br>• *Lyonia spp.*<br>• *Ilex glabra*<br>• *Vaccinium spp.*<br>• *Diospyros virginiana*<br>• *Rhus copallinum*<br>• *Sassafras albidum*<br>• *Cratagus spp.*<br>Create *VST: Mapping and Tagging* record with **recordType** = 'temporary' to record taxon data. | Tag qualifying 'sap' and 'sms' with DBH < 1 cm and ddh ≥ 1 cm. | • Implementation of standard guidance does not result in longitudinal data per tagID.<br>• Fire management results in repeat tagging of resprouts with little data value.<br>• Protocol clarification: Apparent individuals drive nested subplot size, not number of resprouts from same individual. |

### D.2 D03 – OSBS – Ordway Swisher Biological Station

| Modification Type | Modification | Standard Rule | Rationale for Change |
|---|---|---|---|
| Tagging requirements | Root (re)sprouts from some species are only tagged once they graduate to 'smt' or 'sis'. DSNY species are:<br>• *Quercus spp.*<br>• *Lyonia spp.*<br>• *Ilex glabra*<br>• *Vaccinium spp.*<br>• *Diospyros virginiana*<br>• *Rhus copallinum*<br>• *Sassafras albidum*<br>• *Cratagus spp.*<br>Create *VST: Mapping and Tagging* record with **recordType** = 'temporary' to record taxon data. | Tag qualifying 'sap' and 'sms' with DBH < 1 cm and ddh ≥ 1 cm. | • Implementation of standard guidance does not result in longitudinal data per tagID.<br>• Fire management results in repeat tagging of resprouts with little data value.<br>• Protocol clarification: Apparent individuals drive nested subplot size, not number of resprouts from same individual. |

### D.3 D06 – KONZ – Konza Prairie

| Modification Type | Modification | Standard Rule | Rationale for Change |
|---|---|---|---|
| Tagging requirements | Root (re)sprouts from some species are only tagged once they graduate to 'smt' or 'sis'. KONZ species are:<br>• *Cornus drummondii*<br>Create *VST: Mapping and Tagging* record with **recordType** = 'temporary' to record taxon and mapping data. | Tag qualifying 'sap' and 'sms' with DBH < 1 cm and ddh ≥ 1 cm. | • Implementation of standard guidance does not result in longitudinal data per tagID.<br>• Fire management results in repeat tagging of resprouts with little data value.<br>• Protocol clarification: Apparent individuals drive nested subplot size, not number of resprouts from same individual. |

### D.4 D10 – RMNP – Rocky Mountain National Park

| Modification Type | Modification | Standard Rule | Rationale for Change |
|---|---|---|---|
| Measurement method | Annual measurement of qualifying stems in Tower Plot 'productivity subset', including banded trees. Dendrometer band measurements in additional Tower Plots for large trees (≥ 95$^{th}$ percentile biomass). | DBH tape used for annual measurement of diameter in Tower Plot subset. | • Annual measurement frequency in Tower Plot 'productivity subset' plus dendrometer band measurements required to estimate annual aboveground net primary productivity for slow-growth-increment site. |

### D.5 D12 – YELL – Yellowstone National Park

| Modification Type | Modification | Standard Rule | Rationale for Change |
|---|---|---|---|
| Measurement method | Annual measurement of qualifying stems in Tower Plot 'productivity subset', including banded trees. Dendrometer band measurements in additional Tower Plots for large trees (≥ 95$^{th}$ percentile biomass). | DBH tape used for annual measurement of diameter in Tower Plot subset. | • Annual measurement frequency in Tower Plot 'productivity subset' plus dendrometer band measurements required to estimate annual aboveground net primary productivity for slow-growth-increment site. |

### D.6 D13 – NIWO – Niwot Ridge

| Modification Type | Modification | Standard Rule | Rationale for Change |
|---|---|---|---|
| Measurement method | Annual measurement of qualifying stems in Tower Plot 'productivity subset', including banded trees. Dendrometer band measurements in additional Tower Plots for large trees (≥ 95$^{th}$ percentile biomass). | DBH tape used for annual measurement of diameter in Tower Plot subset. | • Annual measurement frequency in Tower Plot 'productivity subset' plus dendrometer band measurements required to estimate annual aboveground net primary productivity for slow-growth-increment site. |

### D.7 D13 – MOAB

| Modification Type | Modification | Standard Rule | Rationale for Change |
|---|---|---|---|
| Measurement frequency | All Tower Plots measured on 5 y interval; no annual measurements | Annual measurements in a subset of Tower Plots. | • Dendrometer band installation not applicable for vegetation.<br>• Annual measurement with calipers causes adverse site impacts due to sensitive vegetation, soils. |

### D.8 D14 – JORN – Jornada LTER

| Modification Type | Modification | Standard Rule | Rationale for Change |
|---|---|---|---|
| Measurement frequency | All Tower Plots measured on 5 y interval; no annual measurements | Annual measurements in a subset of Tower Plots. | • Dendrometer band installation not applicable for vegetation.<br>• Annual measurement with calipers causes adverse site impacts due to sensitive vegetation, soils. |

### D.9 D14 – SRER – Santa Rita Experimental Range

| Modification Type | Modification | Standard Rule | Rationale for Change |
|---|---|---|---|
| Mapping guidelines | Map large-stature cacti | Cacti not mapped | • Ensure data completeness.<br>• Speed locating individuals for repeat measurements. |
| Measurement frequency | All Tower Plots measured on 5 y interval; no annual measurements | Annual measurements in a subset of Tower Plots. | • Dendrometer band installation not applicable for vegetation.<br>• Annual measurement with calipers causes adverse site impacts due to sensitive vegetation, soils. |
| Measurement guidelines | 2020 onward: *Prosopis velutina* and *Parkinsonia florida* measured as 'sis' | 2019 and prior: These two species measured as 'sbt' or 'mbt' | • Published biomass allometries for these two species require basal diameter as input.<br>• Both 'shrub' and 'tree' growth forms are consistent with USDA Plants designation. |
| eventID | | Same eventID for *Opuntia* measured in spring as for woody vegetation measured in autumn | • Clarification of standard rule, given large temporal gap between *Opuntia* and woody measurement events in same calendar year. |

### D.10 D15 – ONAQ – Onaqui / Ault

| Modification Type | Modification | Standard Rule | Rationale for Change |
|---|---|---|---|
| Measurement frequency | All Tower Plots measured on 5 y interval; no annual measurements | Annual measurements in a subset of Tower Plots. | • Dendrometer band installation not applicable for vegetation.<br>• Annual measurement with calipers causes adverse site impacts due to sensitive vegetation, soils. |

### D.11 D16 – WREF – Wind River Experimental Forest

| Modification Type | Modification | Standard Rule | Rationale for Change |
|---|---|---|---|
| Measurement method | Annual measurement of qualifying stems in Tower Plot 'productivity subset', including banded trees. Dendrometer band measurements in additional Tower Plots for large trees (≥ 95$^{th}$ percentile biomass). | DBH tape used for annual measurement of diameter in Tower Plot subset. | • Annual measurement frequency in Tower Plot 'productivity subset' plus dendrometer band measurements required to estimate annual aboveground net primary productivity for slow-growth-increment site. |

### D.12 D17 – SJER – San Joaquin Experimental Range

| Modification Type | Modification | Standard Rule | Rationale for Change |
|---|---|---|---|
| Measurement method | Annual measurement of qualifying stems in Tower Plot 'productivity subset', including banded trees. Dendrometer band measurements in additional Tower Plots for large trees (≥ 95$^{th}$ percentile biomass). | DBH tape used for annual measurement of diameter in Tower Plot subset. | • Annual measurement frequency in Tower Plot 'productivity subset' plus dendrometer band measurements required to estimate annual aboveground net primary productivity for slow-growth-increment site. |

### D.13 D17 – SOAP – Soaproot Saddle

| Modification Type | Modification | Standard Rule | Rationale for Change |
|---|---|---|---|
| Measurement method | Annual measurement of qualifying stems in Tower Plot 'productivity subset', including banded trees. Dendrometer band measurements in additional Tower Plots for large trees (≥ 95$^{th}$ percentile biomass). | DBH tape used for annual measurement of diameter in Tower Plot subset. | • Annual measurement frequency in Tower Plot 'productivity subset' plus dendrometer band measurements required to estimate annual aboveground net primary productivity for slow-growth-increment site. |

### D.14 D17 – TEAK – Teakettle

| Modification Type | Modification | Standard Rule | Rationale for Change |
|---|---|---|---|
| Measurement method | Annual measurement of qualifying stems in Tower Plot 'productivity subset', including banded trees. Dendrometer band measurements in additional Tower Plots for large trees (≥ 95$^{th}$ percentile biomass). | DBH tape used for annual measurement of diameter in Tower Plot subset. | • Annual measurement frequency in Tower Plot 'productivity subset' plus dendrometer band measurements required to estimate annual aboveground net primary productivity for slow-growth-increment site. |

### D.15 D18 – BARR – Utqiagvik (Barrow)

| Modification Type | Modification | Standard Rule | Rationale for Change |
|---|---|---|---|
| Diameter cutoff | Reduce ddh cutoff from 1 cm to 0.7 cm. | For apparent individuals with no DBH, measure basal stem diameter for all individuals with ddh ≥ 1 cm. | • The mean ddh of the dominant small shrubs at the site (*Betula nana*) is approximately 1 cm, with a significant number of individuals having ddh smaller than 1 cm.<br>• Using a 1 cm ddh cutoff at this site therefore arbitrarily splits the *B. nana* population such that roughly half is measured via the VST protocol, and half is measured via the HBP protocol.<br>• Reducing the ddh cutoff from 1 cm to 0.7 cm ensures that > 90% of the 'sms' individuals are measured with only the VST protocol. |
| Mapping requirements | Do not map 'sms' growth forms even if trees with DBH ≥ 10 cm are not present (mainly applies to *Betula nana*). | Map 'sis' and 'sms' if no trees with DBH ≥ 10 cm are present in the plot. | • Mapping *B. nana* is not consistent with the goals of the Plant Productivity Science Design (NEON.DOC.000914) |

### D.16 D18 – TOOL – Toolik LTER

| Modification Type | Modification | Standard Rule | Rationale for Change |
|---|---|---|---|
| Diameter cutoff | Reduce ddh cutoff from 1 cm to 0.7 cm. | For apparent individuals with no DBH, measure basal stem diameter for all individuals with ddh ≥ 1 cm. | • Mean ddh of the dominant small shrubs at the site (*Betula nana*) is approximately 1 cm, with a significant number of individuals having ddh smaller than 1 cm.<br>• A 1 cm ddh cutoff at this site arbitrarily splits the *B. nana* population such that roughly half is measured via the VST protocol, and half is measured via the HBP protocol.<br>• Reducing the ddh cutoff from 1 cm to 0.7 cm ensures that > 90% of the 'sms' individuals are measured with only the VST protocol. |
| Mapping requirements | Do not map 'sms' growth forms even if trees with DBH ≥ 10 cm are not present (mainly applies to *Betula nana*). | Map 'sis' and 'sms' if no trees with DBH ≥ 10 cm are present in the plot. | • Mapping *B. nana* is not consistent with the goals of the Plant Productivity Science Design (NEON.DOC.000914) |
| **measurement Height** | When thick bryophytes form the ground layer, the mean height of the bryophyte layer surrounding the base of the stem is used as the zero-point for determining **measurement Height**. | Mounded or heaped organic material around the base of a stem is removed, and the 'true' ground surface is exposed before determining **measurement Height**. | • Bryophytes grow in a mounded, clustered manner around the base of stems, and often grow up stems 10 cm+<br>• It is destructive and not possible to remove bryophytes and uncover the 'true' surface of the ground because of the mat-like bryophyte growth form that slowly transitions to peat with depth.<br>• It is functionally consistent with other sites to consider the surface of the bryophyte layer the ground, and the zero-point for determining **measurementHeight**. |

### D.17 D19 – BONA – Bonanza Creek LTER

| Modification Type | Modification | Standard Rule | Rationale for Change |
|---|---|---|---|
| Mapping requirements | Do not map 'sms' growth forms even if trees with DBH ≥ 10 cm are not present (mainly applies to *Betula nana*). | Map 'sis' and 'sms' if no trees with DBH ≥ 10 cm are present in the plot. | • Mapping *B. nana* is not consistent with the goals of the Plant Productivity Science Design (NEON.DOC.000914) |
| **measurement Height** | When thick bryophytes form the ground layer, the mean height of the bryophyte layer surrounding the base of the stem is used as the zero-point for determining **measurement Height**. | Mounded or heaped organic material around the base of a stem is removed, and the 'true' ground surface is exposed before determining **measurement Height**. | • Bryophytes grow in a mounded, clustered manner around the base of stems, and often grow up stems 10 cm or more.<br>• It is destructive and not possible to remove bryophytes and uncover the 'true' surface of the ground because of the mat-like bryophyte growth form that slowly transitions to peat with depth.<br>• It is functionally consistent with other sites to consider the surface of the bryophyte layer the ground, and the zero-point for determining **measurementHeight**. |
| Measurement method | Annual measurement of qualifying stems in Tower Plot 'productivity subset', including banded trees. Dendrometer band measurements in additional Tower Plots for large trees (≥ 95$^{th}$ percentile biomass). | DBH tape used for annual measurement of diameter in Tower Plot subset. | • Annual measurement frequency in Tower Plot 'productivity subset' plus dendrometer band measurements required to estimate annual aboveground net primary productivity for slow-growth-increment site. |

### D.18 D19 – DEJU – Delta Junction

| Modification Type | Modification | Standard Rule | Rationale for Change |
|---|---|---|---|
| Mapping requirements | Do not map 'sms' growth forms even if trees with DBH ≥ 10 cm are not present (mainly applies to *Betula nana*). | Map 'sis' and 'sms' if no trees with DBH ≥ 10 cm are present in the plot. | • Mapping *B. nana* is not consistent with the goals of the Plant Productivity Science Design (NEON.DOC.000914) |
| **measurement Height** | When thick bryophytes form the ground layer, the mean height of the bryophyte layer surrounding the base of the stem is used as the zero-point for determining **measurement Height**. | Mounded or heaped organic material around the base of a stem is removed, and the 'true' ground surface is exposed before determining **measurement Height**. | • Bryophytes grow in a mounded, clustered manner around the base of stems, and often grow up stems 10 cm or more.<br>• It is destructive and not possible to remove bryophytes and uncover the 'true' surface of the ground because of the mat-like bryophyte growth form that slowly transitions to peat with depth.<br>• It is functionally consistent with other sites to consider the surface of the bryophyte layer the ground, and the zero-point for determining **measurementHeight**. |
| Measurement method | Annual measurement of qualifying stems in Tower Plot 'productivity subset', including banded trees. Dendrometer band measurements in additional Tower Plots for large trees (≥ 95$^{th}$ percentile biomass). | DBH tape used for annual measurement of diameter in Tower Plot subset. | • Annual measurement frequency in Tower Plot 'productivity subset' plus dendrometer band measurements required to estimate annual aboveground net primary productivity for slow-growth-increment site. |

### D.19 D19 – HEAL – Healy

| Modification Type | Modification | Standard Rule | Rationale for Change |
|---|---|---|---|
| Mapping requirements | Do not map 'sms' growth forms even if trees with DBH ≥ 10 cm are not present (mainly applies to *Betula nana*). | Map 'sis' and 'sms' if no trees with DBH ≥ 10 cm are present in the plot. | • Mapping *B. nana* is not consistent with the goals of the Plant Productivity Science Design (NEON.DOC.000914) |
| **measurement Height** | When thick bryophytes form the ground layer, the mean height of the bryophyte layer surrounding the base of the stem is used as the zero-point for determining **measurement Height**. | Mounded or heaped organic material around the base of a stem is removed, and the 'true' ground surface is exposed before determining **measurement Height**. | • Bryophytes grow in a mounded, clustered manner around the base of stems, and often grow up stems 10 cm or more.<br>• It is destructive and not possible to remove bryophytes and uncover the 'true' surface of the ground because of the mat-like bryophyte growth form that slowly transitions to peat with depth.<br>• It is functionally consistent with other sites to consider the surface of the bryophyte layer the ground, and the zero-point for determining **measurementHeight**. |
| Measurement method | Annual measurement of qualifying stems in Tower Plot 'productivity subset', including banded trees. Dendrometer band measurements in additional Tower Plots for large trees (≥ 95$^{th}$ percentile biomass). | DBH tape used for annual measurement of diameter in Tower Plot subset. | • Annual measurement frequency in Tower Plot 'productivity subset' plus dendrometer band measurements required to estimate annual aboveground net primary productivity for slow-growth-increment site. |

### D.20 D20 – PUUM – Pu'u Maka'ala

| Modification Type | Modification | Standard Rule | Rationale for Change |
|---|---|---|---|
| Measurement guidelines | Uluhe (*Dicranopteris emarginata*) and group-forming fern allies (e.g., *Lycopodiella spp.*) are measured as shrub groups. | Ferns and fern allies are measured as apparent individuals. | • Dense groups of Uluhe and other fern allies are impenetrable without significant damage to the vegatation.<br>• Lack of physical access to individuals of these species makes Apparent Individual measurements impractical. |

## APPENDIX E EQUIPMENT

- Equipment in the tables below 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.
- Item quantities are provided for a single team of two people collecting data.

**Table 20.** Equipment list – Preparing for Sampling (SOP A).

| Supplier / Item No. | Exact Brand | Description | Purpose | Quan-tity |
|---|---|---|---|---|
| Amazon 0100078101 | N | GPS receiver, recreational accuracy | Pre-load sampling locations | 1 |
| Forestry Suppliers 91567 | Y | TruPulse 360R Laser Rangefinder, ± 30 cm accuracy | Map and measure apparent individuals and shrub groups. | 1 |
| | N | Hammer | Label blank tags | 1 |
| Forestry Suppliers 57522 | N | Hand stamp steel die set | Label blank tags | 1 set |
| Ben Meadows 010510-1 | N | All weather copy paper | Print datasheets | As needed |
| Ben Meadows 152499 | N | Round unnumbered aluminum tag, silver | Pre-label for tagging multi-stemmed individuals. | 50 |

**Table 21**. Equipment list – Field Sampling: Classification, Plot Meta-Data, Mapping and Tagging (SOP C and SOP D).

| Supplier / Item No. | Exact Brand | Description | Purpose | Quan-tity |
|---|---|---|---|---|
| | N | Mobile data collection device (tablet or equivalent), and spare battery | Collect and record data in the field. | 1 |
| Bioquip 3127 | N | Cardboard ventilator | Press collected individuals for identification | |
| Ben Meadows 100952 | N | Chaining pins or other suitable anchor | Anchor measuring tapes | 4 |
| Ben Meadows 213379 | N | Compass with mirror and declination adjustment | Determine nested subplot boundary | 1 |
| | N | Cooler | Chill perishable samples in field | 1 |
| Forestry Suppliers 59422 | N | Diameter tape, 200 cm | Measure stem diameter. Stems present with diameter > 64 cm | 1 |
| Ben Meadows 122117 | N | Diameter tape, 64 cm | Measure stem diameter. Stems present with 5 cm < diameter < 64 cm | 1 |
| | N | Field guide, regional flora reference guide and/or key | Identify unknown species | 1 |
| Compass Tools 703512; Forestry Suppliers 90998 | Y | TruPulse 360R Foliage filter | Allow laser rangefinder use in dense vegetation | 1 |
| Amazon 0100078101 | N | GPS receiver, recreational accuracy | Navigate to sampling location | 1 |
| | N | Site map | Navigate to sampling location | 1 |
| | N | Hammer | Nail tags to trees, label blank tags | 1 |

| Supplier / Item No. | Exact Brand | Description | Purpose | Quan-tity |
|---|---|---|---|---|
| Forestry Suppliers 57522 | N | Hand stamp steel die set | Label blank tags | 1 set |
| | N | Block of wood or equivalent hard surface | Tag stamping | 1 |
| | N | Handheld caliper, 0.1 cm precision | Measure stem diameter < 5 cm; lianas prevent accurate diameter measurement with tape | 1 |
| Fisher 19067113 | N | Ice pack | Chill perishable samples in field | As needed |
| Forestry Suppliers 91567 | Y | TruPulse 360R Laser Rangefinder, ± 30 cm accuracy | Determine nested subplot boundary; map stems; measure stem height and crown diameter. Individuals with relatively large canopies; plots with slopes > 20% | 1 |
| Ben Meadows 122732 | N | Measuring tape, minimum 50 m | Determine nested subplot, subplot boundary | 4 |
| Herbarium Supply 223 | N | Paper blotters | Press collected individuals for identification | As needed |
| Bioquip 3115 | N | Plant press | Press collected individuals for identification | As needed |
| Compass Tools 7024901 | N | Tripod, non-magnetic | Hold laser rangefinder directly over plot marker | 1 |
| Grainger 5B317 | N | White reflector or reflective tape | Reflective target for laser rangefinder; aids in measuring distance to target accurately | 1 |
| | N | Wire cutter | Cut wire to desired length | 1 |
| | N | Rod, dowel, pipe, or equivalent; 1.4 m length, max 1” diameter, marking at 1.3 m | Quickly find measurementHeight and tag height for straight boles | 1 |
| | N | Rod, dowel, pipe, or equivalent; 0.1 m length, max 1” diameter | Quickly find measurementHeight for ddh | 1 |

| Supplier / Item No. | Exact Brand | Description | Purpose | Quan-tity |
|---|---|---|---|---|
| | N | AA battery | Spare battery for GPS receiver | 4 |
| Forestry Suppliers 79121 | N | Aluminum nail | Affix tag to stems with DBH ≥ 5 cm | As needed |
| Grainger 16Y067 | N | Aluminum wire, 20 gauge | Affix tag to stems with DBH ≥ 5 cm | As needed |
| | N | CR123A battery | Spare battery for laser rangefinder | 2 |
| Forestry Suppliers 57880; Grainger 9WKP4, 3JVZ5 | N | Flagging tape | Temporarily mark stems after measurement | 2 |
| Ben Meadows 84516, 230916; Grainger 9TA07 | N | Fluorescent lumber crayon | Mark DBH measurement location on stem | 1 |
| Grainger 8YAT5, 5CNK5 | N | Resealable plastic bag, 1 gal | Collect voucher specimens | 20 |
| Ben Meadows 152580 | N | Round numbered aluminum tag, silver; 0001-6000 and 8001-9999 | Tag qualifying stems | As needed |
| Ben Meadows 152499 | N | Round unnumbered aluminum tag, silver | Tag multi-stemmed individuals. | 50 |
| | N | Survey marking flag, PVC or fiberglass stake | Delineate sampling area | 12 |
| | N | Tabloid newspaper pages | Press collected individuals for identification | As needed |
| | N | Field datasheet | Record data | As needed |

**Table 22**. Equipment list – Dendrometer band fabrication and installation (SOP A.4and SOP F.2).

| Supplier / Item No. | Exact Brand | Description | Purpose | Quan-tity |
|---|---|---|---|---|
| McMaster 1598T62 | Y | ½" stainless steel label tape, 21 foot length | Band material | per SSL |
| Amazon | N | Small plastic bucket with slit cut in side at ground level – e.g., large yogurt container or equivalent | Organize and dispense band material for initial cutting and prep | 2 |
| Lee Spring LE 026C 05 S | Y | 1.5" stainless steel spring | Band 5-10 cm DBH trees | per SSL |
| Lee Spring LE 026C 11 S | Y | 3" stainless steel spring, wire diameter = 0.026 inch | Band 10-50 cm DBH trees | per SSL |
| Lee Spring LE 031C 11 S | Y | 3" stainless steel spring, wire diameter = 0.031 inch | Band DBH > 50 cm trees | per SSL |
| Roper Whitney | Y | Heavy duty metal hole punch | Punch spring attachment points in band material | 2 |
| Amazon | N | Tin snips | Cut band material to length | 2 |
| Knife Center | N | Mora knife | Prepare tree bole surface for band | 8 |
| Forestry Suppliers | N | Hatchet; use existing CDW equipment if available | Prepare tree bole surface for band if knife is inadequate | 2 |
| McMaster 2325A55 | Y | Stainless steel Mitutoyo dial caliper, 0-150 mm measuring range, 0.025 mm increment | Measure dendrometer band gap | 4 |

Table 23. Equipment list – Measuring Apparent Individuals (SOP E).

| Supplier / Item No. | Exact Brand | Description | Purpose | Quan-tity |
|---|---|---|---|---|
| | N | Mobile data collection device (tablet or equivalent), and spare battery | Collect and record data in the field. | 1 |
| Bioquip 3127 | N | Cardboard ventilator | Press collected individuals for identification | |
| Ben Meadows 100952 | N | Chaining pins or other suitable anchor | Anchor measuring tapes | 4 |
| | N | Cooler | Chill perishable samples in field | 1 |
| Forestry Suppliers 59422 | N | DBH tape, 200 cm | Measure stem diameter. Stems present with diameter > 64 cm | 1 |
| Ben Meadows 122117 | N | DBH tape, 64 cm | Measure stem diameter. Stems present with 5 cm < diameter < 64 cm | 1 |
| Forestry Suppliers 59763 | Y | 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 |
| Forestry Suppliers 59714 | Y | 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 | Field guide, regional flora reference guide and/or key | Identify unknown species | 1 |
| Compass Tools 703512; Forestry Suppliers 90998 | Y | TruPulse 360R Foliage filter | Allow laser rangefinder use in dense vegetation | 1 |
| Amazon 0100078101 | N | GPS receiver, recreational accuracy | Navigate to sampling location | 1 |
| | N | Site map and plot list | Navigate to sampling location | 1 |
| | N | Hammer | Nail tags to trees, label blank tags | 1 |

| Supplier / Item No. | Exact Brand | Description | Purpose | Quan-tity |
|---|---|---|---|---|
| Forestry Suppliers 57522 | N | Hand stamp steel die set | Label blank tags for multi-stem trees | 1 set |
| | N | Handheld caliper, 0.1 cm precision | Measure stem diameters < 5 cm | 1 |
| Fisher 19067113 | N | Ice pack | Chill perishable samples in field | As needed |
| Forestry Suppliers 91567 | Y | TruPulse 360R Laser Rangefinder, ± 30 cm accuracy | Map stems recruited into the minimum size class; measure stem height, crown diameter. Brushy; trees with relatively large canopy diameters; slopes ≥ 20% | 1 |
| Ben Meadows SPSO1722151; Forestry Suppliers 71112 | N | Measuring stick, 2 m folding | Measure heights of small-stature woody vegetation | 1 |
| | N | Aluminum or fiberglass measuring rod, 5 m telescoping | Measure heights of medium-stature woody vegetation, measure crown dimensions for some shrubs | 1 |
| Ben Meadows 122732; Forestry Suppliers 39945 | N | Measuring tape, minimum 50 m | Determine nested subplot, subplot boundary | 4 |
| Forestry Suppliers 53740 | N | Paper blotters | Press collected individuals for identification | As needed |
| Bioquip 3115 | N | Plant press | Press collected individuals for identification | 1 |
| Grainger 5B317 | N | White reflector or reflective tape | Reflective target for laser rangefinder; aids in measuring distance to target accurately | 1 |
| | N | Wire cutter | Cut wire to desired length. Stems present with DBH < 5 cm | 1 |

| Supplier / Item No. | Exact Brand | Description | Purpose | Quan-tity |
|---|---|---|---|---|
| Ben Meadows 213379 | N | Compass with mirror and declination adjustment | Delineate nested subplots if markers are removed or disturbed | 1 |
| | N | Rod, dowel, pipe, or equivalent; 1.4 m length, max 1” diameter, marking at 1.3 m | Quickly find measurementHeight and tag height for straight boles | 1 |
| | N | Rod, dowel, pipe, or equivalent; 0.1 m length, max 1” diameter | Quickly find measurementHeight for ddh | 1 |
| | N | Retractable metal measuring tape, 25 mm W x 10 m L, metric demarcations | Quickly measure mid-stature shrub crown dimensions | 1 |
| | N | AA battery | Spare battery for GPS receiver | |
| Forestry Suppliers 79121 | N | Aluminum nail | Affix tag to stems with DBH ≥ 5 cm | As needed |
| Grainger 16Y067 | N | Aluminum wire, 20 gauge | Affix tag to stems with DBH ≥ 5 cm | As needed |
| | N | CR123A battery | Spare battery for laser rangefinder | 2 |
| Forestry Suppliers 57880; Grainger 9WKP4, 3JVZ5 | N | Flagging tape | Temporarily mark stems after measurement | 2 |
| Ben Meadows 84516, 230916; Grainger 9TA07 | N | Fluorescent lumber crayon | Mark DBH measurement location on stem | 1 |
| | N | Graph paper | Estimate area of shrub groups | As needed |

| Supplier / Item No. | Exact Brand | Description | Purpose | Quan-tity |
|---|---|---|---|---|
| Ben Meadows 152580, 152581, 152582, 152583, 227423, 227426, 227427 | N | Round numbered aluminum tag, silver; 0001-6000 and 8001-9999 | Tag new qualifying stems | As needed |
| Ben Meadows 152499 | N | Round unnumbered aluminum tag, silver | Tag new multi-stemmed individuals | 50 |
| | N | Survey marking flag, PVC or fiberglass stake | Delineate sampling area | 12 |
| | N | Newspaper pages, tabloid size | Press collected individuals for identification | As needed |
| | N | Cordless Power drill, 18V Li-ion | Pre-drill nail holes into trees with dense wood; prevent bending of aluminum nails | 1 |
| | N | Field data sheets | Record data in event of device failure | As needed |

**Table 24**. Equipment and materials required for a team of two to minimize exposure to toxic oils from *Toxicodendron spp.*

| Supplier / Item No. | Exact Brand | Description | Purpose | Quan-tity |
|---|---|---|---|---|
| Forestry Suppliers 59763 | Y | Haglof Mantax Black calipers, 95 cm | Measure stem diameters up to 95 cm when lianas are attached; label for use with *Toxicodendron* to minimize spread of oils. Accurate enough to also measure *Toxicodendron* diameter. | 1 |
| Forestry Suppliers 59714 | Y | Haglof Mantax Black calipers, 50 cm | Measure supporting stem diameters up to 50 cm when lianas are attached; label for use with *Toxicodendron* spp. to minimize spread of oils to other equipment. | 1 |
| | N | Pruning shear | Label for use with *Toxicodendron* spp. to minimize spread of oils to other equipment. Used to gain access to woody stems surrounded by *Toxicodendron*. | 1 |
| Ben Meadows 32577 | N | Cleanser, urushiol-specific, Tecnu or equivalent | Clean equipment after use with *Toxicodendron* spp. | As needed |
| | N | Nitrile or cotton gloves | Prevent oil contact with skin | As needed |
| | N | PPE outer-wear | Prevent oil contact with skin, normal clothing | As needed |
| | N | Trash bag | Dispose of used gloves and PPE to minimize toxic oil transfer | 2 |
| | N | Cleanser, urushiol-specific, Tecnu or equivalent | Clean equipment after use with *Toxicodendron* spp. | As needed |

## 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 is defined for every point on a 10 m grid within this framework; this design is used in initial plot establishment, but permanent, primary, and secondary markers are placed at 20 meter intervals. During stem mapping, technicians will only use the points that have permanent markers in place. Plot subplotIDs are determined by the pointID of the SW corner of the subplot area. Plot center will always be pointID 41.

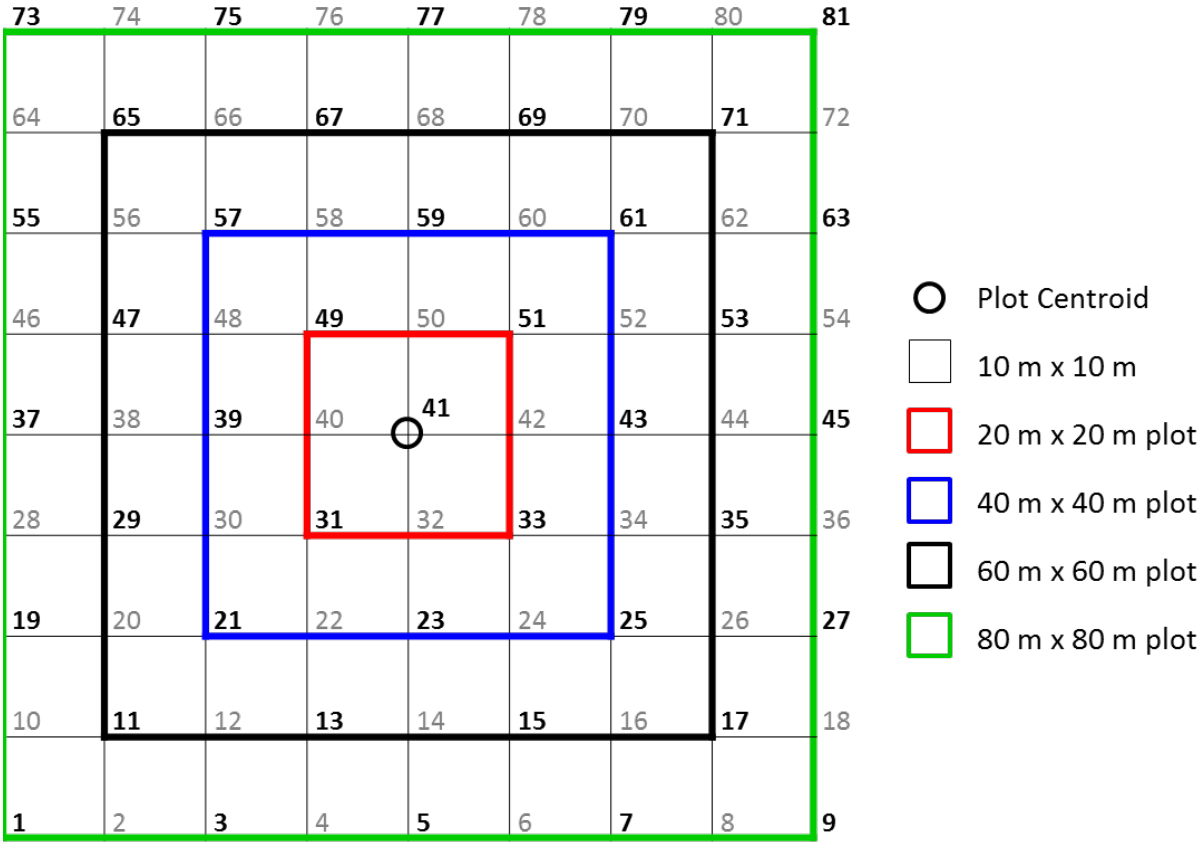


**Figure 26**. Plot map, illustrating how NEON base plots of various sizes are constructed from 10 m x 10 m 'modules.' The SW corner of each 'module' receives a pointID number; bold numbers indicate pointIDs that may receive physical markers and for which high-resolution GPS data may be collected.

## APPENDIX G DENDROMETER BAND CUTTING TEMPLATE