

Title: Measurement of Woody Vegetation Structure		Date: 01/10/2014
NEON Doc. #: NEON.DOC.000987	Author: C. Meier	Revision: A_DRAFT

MEASUREMENT OF WOODY VEGETATION STRUCTURE

PREPARED BY	ORGANIZATION	DATE
Courtney Meier	FSU	04/01/2013
Katherine Jones	FSU	04/01/2013
Benjamin Chemel	NRCC	04/01/2013

APPROVALS	ORGANIZATION	APPROVAL DATE
Dave Tazik	CCB PROJ SCI	10/16/2013
Mike Stewart	SE	12/30/2013

RELEASED BY	ORGANIZATION	RELEASE DATE
Stephen Craft	SE	01/10/2014

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1 DESCRIPTION

1.1 Purpose

The primary purpose of this document is to provide a change-controlled version of Observatory protocols and procedures. This document provides the content for training and field-based materials for NEON staff and contractors. 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.

This document is a detailed description of the field data collection, relevant pre- and post-field tasks, and safety issues as they relate to this procedure and protocol.

1.2 Scope

This document relates the tasks for a specific field sampling or laboratory processing activity and directly associated activities and safety practices. This document does not describe:

- General safety practices
- Site-specific safety practices
- General equipment maintenance

It does identify procedure-specific safety hazards and associated safety requirements such as safe handling of small mammals or safe use of required chemicals and reagents.

2 RELATED DOCUMENTS AND ACRONYMS

2.1 Applicable Documents

Applicable documents contain information that shall be applied in the current document. Examples are higher level requirements documents, standards, rules and regulations.

AD [01]	NEON.DOC.004300	EHS Safety Policy and Program Manual
AD [02]	NEON.DOC.004316	Operations Field Safety and Security Plan
AD [03]	NEON.DOC.000724	Domain Chemical Hygiene Plan and Biosafety Manual
AD [04]	NEON.DOC.001155	NEON Training Plan
AD [05]	NEON.DOC.050005	Field Operations Job Instruction Training Plan

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2.2 Reference Documents

Reference documents contain information complementing, explaining, detailing, or otherwise supporting the information included in the current document.

RD [01]	NEON.DOC.000008	NEON Acronym List
RD [02]	NEON.DOC.000243	NEON Glossary of Terms
RD [03]	NEON.DOC.000987	NEON Science Design: Plant Biomass and Productivity
RD [04]	NEON.DOC.005003	NEON Scientific Data Products Catalog
RD [05]	NEON.DOC.014051	Field Audit Plan
RD [06]	NEON.DOC.000824	Data and Data Product Quality Assurance and Control Plan
RD [07]	NEON.DOC.014037	Measurement of Herbaceous Structure and Biomass Protocol
RD [08]	NEON.DOC.005005	Level 0 Data Product Catalog
RD [09]	NEON.DOC.014042	Plant Diversity Sampling
RD [10]	NEON.DOC.001025	Plot Establishment Protocol

2.3 Acronyms

BH	Breast height
DBH	Diameter at breast height; breast height = 130 cm above the ground
ddh	Diameter at decimeter height
ha	Hectare(s)
LAI	Leaf Area Index
LiDAR	Light Detection and Ranging
NEE	Net Ecosystem Exchange
NEP	Net Ecosystem Productivity
NPP	Net Primary Productivity

2.4 Definitions

A **protocol** is a formal summary description of a procedure and its related rationale, and includes information on knowledge and resources needed to implement the procedure. A procedure is a set of prescribed actions that must take place to achieve a certain result, and can also be called a method. It differs from a science design in that science designs provide a more complete description of the rationale for selecting specific protocols. It differs from a training manual in that training manuals provide materials in support of skills acquisition in the topic areas including information on how to best train staff rather than detailing only the steps of the procedure.

We define trees, saplings/shrubs, and lianas according to the following criteria (see RD[03] for more details):

1. *Trees*: Self-supporting woody stems with diameter at breast height (DBH) \geq 10 cm. Individuals are typically, but not always, species that are potential canopy emergents. Individuals classified as trees are mapped as points within plots.

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2. *Saplings and shrubs*: Self-supporting woody stems with DBH < 10 cm and height > 0.5 m. Woody stems < 0.5 m height are measured as part of the herbaceous plant sampling effort. Individuals may or may not be species that are canopy emergents. Saplings and shrubs may be mapped as either points or polygons within plots, depending on whether individuals are isolated or grouped.
 - a. Grouped Individuals are defined as two or more individuals in contact, or when it is difficult to discern “individuals”. Here, the word individual refers to “apparent” individuals, not “genetic” individuals.
3. *Lianas*: Non-self-supporting woody stems with DBH ≥ 1 cm. Lianas are not mapped, but the ID number of the tagged, mapped support tree is recorded during the data collection process.

3 BACKGROUND AND OBJECTIVES

3.1 Background

The measurement of vegetation structure, as well as the mapping of free-standing woody stems, is an important complement to data streams generated by the NEON AOP and TIS. These ground-collected data will validate LiDAR data used to map the structural complexity of vegetation, will enable mapping of plant biomass at the site scale, and in conjunction with carbon flux data, will facilitate understanding how biomass in different plant growth forms contributes to ecosystem level carbon flux.

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

There are numerous methods for measuring and mapping woody stems, and the recommended procedure depends greatly on the amount of labor and time available to complete the work, the equipment budget, ecosystem type, and on the scientific requirements associated with geo-registration of ground-data with approximately 1 m²-resolution airborne remote-sensing 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 that are capable of producing high-quality data.

3.2 NEON Science Requirements

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.

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3.3 NEON Data Products

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 [RD04], NEON.DOC.005003.

4 PROTOCOL

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

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

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

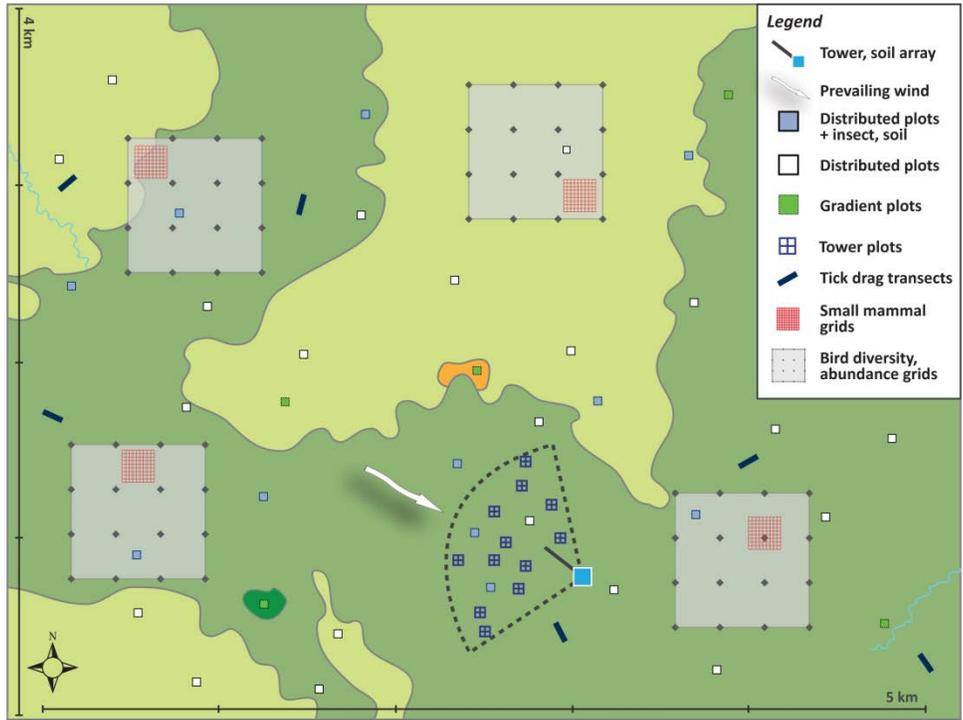


Figure 1. Generalized TOS sampling schematic, showing the placement of Distributed, Tower, and Gradient Plots

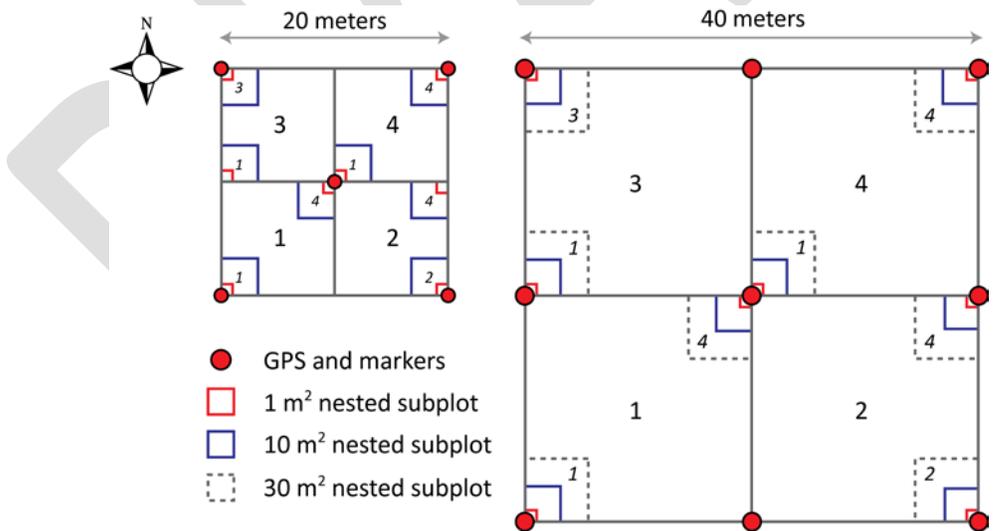


Figure 2. Illustration of a 20 m × 20 m Distributed/Gradient base plot (left), a 40 m × 40 m Tower base plot (right), and associated nested subplots used for measuring woody stem vegetation. Locations of high level subplots are numbered in plain text, and locations of lower level subplots are numbered with italics

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Additional structure and percent cover measurements will be made on herbaceous plants, and these measurements are described in RD[07] and RD[09], respectively. All of the data collected according to this protocol are acquired with hand-held tools in the field, and there is no laboratory component to the work.

5 QUALITY ASSURANCE AND CONTROL

The procedures associated with this protocol will be audited according to the Field Audit Plan (RD[05]). Additional quality assurance will be performed on data collected via these procedures according to the NEON Data and Data Product Quality Assurance and Control Plan (RD[06]).

A combination of hot, cold, and blind checks may be used to ensure that equipment is used properly in the field, that measurements are repeatably taken from the same locations on individual stems, and that data are recorded and reported according to established guidelines on which technicians have been trained.

5.1 Decision Tree

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

Table 1. Decision tree associated with measurement of vegetation structure, indicating how to respond to unanticipated delays in the field, and consequences of these delays

Delay	Action	Adverse outcome	Outcome for Data Product
Hours	If 1) Delay prevents completion of measuring/mapping a plot or sub-plot, use flagging to ensure it is clear which stems have been measured/mapped and resume data collection from the plot or sub-plot ASAP.	None	None
	If 2) Delay occurs between plots or sub-plots: resume data collection from the next plot or sub-plot ASAP.	None	None
1 day to 4 weeks	If 1) Delay prevents completion of measuring/mapping a plot or sub-plot, use flagging to ensure it is clear which stems have been measured/mapped and resume data collection from the plot or sub-plot ASAP.	None	None
	If 2) Delay occurs between plots or sub-plots: resume data collection from the next plot or sub-plot ASAP.	None	None

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Delay	Action	Adverse outcome	Outcome for Data Product
4 or more weeks	If 1) Delay prevents completion of measuring/mapping a plot or sub-plot, use flagging to ensure it is clear which stems have been measured/mapped and resume data collection from the plot or sub-plot ASAP.	Temporary flagging may be lost, causing duplicate measurements of individuals; significant wood growth could occur in fast-growing species.	Increased error in aboveground biomass and NPP estimates.
	If 2) Delay occurs between plots or sub-plots: resume data collection from the next plot or sub-plot ASAP.	Temporary flagging may be lost, causing duplicate measurements of individuals; significant wood growth could occur in fast-growing species.	Increased error in aboveground biomass and NPP estimates.

6 SAFETY

Personnel working at a NEON site must be compliant with safe field work practices as outlined in the Operations Field Safety and Security Plan (AD[02]) and EHS Safety Policy and Program Manual (AD[01]). Additional safety issues associated with this field procedure are outlined below. The Field Operations Manager and the Lead Field Technician have primary authority to stop work activities based on unsafe field conditions; however, all employees have the responsibility and right to stop their work in unsafe conditions.

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

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

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7 PERSONNEL REQUIREMENTS

A team of two field technicians is required for measuring and mapping woody stems, and identifying stems to species. At least one of these technicians must be able to identify regionally-specific plants to species via visual inspection and use of a dichotomous/polyclave key.

8 TRAINING REQUIREMENTS

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

Technicians must be trained in the proper care of the laser rangefinder and GeoXH 6000 GPS unit. Although these tools are resistant to dust and water, it is important to seal open ports and use lens caps when applicable. Care must also be taken to avoid scratching lenses and LCD screens.

Finally, technicians should be trained to carefully measure the heights of trees using the laser rangefinder/hypsometer. Specifically, in order to estimate tree heights accurately, it is important to understand the assumptions made by the instrument, as well as methods for dealing with situations that violate these assumptions.

9 FIELD STANDARD OPERATING PROCEDURE

9.1 Sampling Frequency and Timing

The timing of sampling onset will be determined by Field Operations. 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 ± 2 weeks.

9.1.1 Criteria for Determining Sampling Dates

Sites with distinct growing seasons

Structural measurements of woody stems should be made after annual growth in a given year has completed. For example, in a temperate forest, structural data should be collected any time between late autumn (post-senescence) and early the following spring (prior to leaf/needle expansion). At sites with pronounced wet/dry seasonality – e.g. D17 San Joaquin – structural data should be collected during the dry season when annual growth is minimal.

Once flux data indicate CO₂ source/sink transition dates for each site, Science Operations can provide more precise sampling windows on a site-by-site basis in an additional appendix to this protocol.

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Sites with no distinct growing season

For sites with no distinct growing season, sampling should begin at the same time every year \pm 2 weeks. As above, once flux data are available at each site, Science Operations can provide more precise sampling windows on a site-by-site basis in an appendix to this protocol.

9.1.2 Sampling Frequency

At each site, sampling for trees, saplings/shrubs, and lianas should take place no more than once per year.

Distributed Plots

Woody stems in Distributed Plots should ideally be surveyed annually in order to map, tag, and measure individuals recruited into the minimum size class, as well as re-measure previously mapped and tagged individuals. If logistical and budgetary constraints arise, Distributed Plots should be sampled according to a site-specific prioritized list provided by Science Operations.

Tower Plots

Woody stems in Tower Plots should be surveyed annually in order to map, tag, and measure individuals recruited into the minimum size class, as well as re-measure previously mapped and tagged individuals.

9.1.3 Sampling Timing Parameters

Following the end of a given growing season, measurement of woody stem vegetation structure must be completed before the onset of the next growing season. As a benchmark, it required 4 weeks for a team of two skilled foresters to perform plot establishment and obtain initial vegetation structure measurements from a total Tower Plot area of 3 ha at the D01 Harvard Forest site (n=30 plots of 0.1 ha each). Subsequent measurements should be more rapid than this initial effort, due to these factors: 1) plot-establishment will not be required, 2) the majority of stems in a plot will not require identification to species and tagging, and 3) the majority of stems will already have been mapped in the first sampling year.

At each site, the onset of sampling should be the same date for trees, saplings/shrubs, and lianas. That is, all growth forms should be measured at a given plot when that plot is sampled; technicians should **not** sample trees in all plots first, then re-sample plots for saplings/shrubs and lianas.

9.2 Equipment and Materials

The following equipment is sufficient for a team of two field technicians to collect vegetation structure data in ecosystems with woody-stemmed vegetation \geq 0.5 m height. For ecosystems with woody stems < 0.5 m height, see the Measurement of Herbaceous Structure and Biomass Protocol (RD[07]).

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Table 2. Field equipment required for a team of two people to record vegetation structure and spatial data for woody stems at a plot

Maximo Item No.	Item Description	Quantity	Habitat-Specific	Special Handling
MX102549	Trimble GeoXH 6000	1	No	No
MX100322	TruPulse 360R	1	No	No
MX104908	Extra battery for TruPulse (CR123A type; rechargeables are available if desired)	2	No	No
MX104381	Non-magnetic tripod with non-magnetic ¼" × 20 ball mount	1	No	No
MX100320	Mirror-site compass, declination adjusted	1	No	No
MX105397 (pvc stake) MX100317 (wire stake – but flag is only 2.5x3.5in)	4"× 5" survey flags; PVC stakes preferred, but metal stakes may be required when soils are heavily compacted (Qty includes extras)	12	No	No
MX104361	Chaining pins	4	No	No
	Tree ID books and/or local flora key	1	Yes	No
MX100318	Fiberglass tape, 50 m or longer	2	No	No
MX103227	DBH tape (not required if woody stems are all less than 5 cm DBH at a given site)	1	Yes	No
MX103225	Digital caliper (required to measure stem diameters < 5 cm; not required if there are no stems that meet this criterion)	1	Yes	No
MX100325 (tape: MX103238)	Reflective surface (3" bicycle reflector or reflective tape on back of field notebook)	1	No	No
	Rite-in-the-Rain datasheets or electronic data collection device	As needed	No	No
	QC datasheets or electronic data collection device	As needed	No	No
	Mechanical pencils (if paper datasheets are used)	3	No	No
MX103940	Brightly colored flagging, spool type	2	No	No
MX103478 (#S 1-1000) MX103477 (#S 1001-2000)	Numbered aluminum tags (for marking new individuals that meet minimum size cutoff)	100	No	No
MX103481	Un-numbered, blank aluminum tags (for marking multi-stemmed individuals)	50	No	No

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Maximo Item No.	Item Description	Quantity	Habitat-Specific	Special Handling
MX103224	Aluminum nails (for affixing tags to those stems with DBH ≥ 5 cm)	100	Yes	No
MX105666 (0.064 diameter)	Aluminum wire, spool (for fixing tags to stems with DBH < 5 cm)	1	No	No
MX101593	Wire cutters	1	No	No
MX103480	Hand stamp steel die set (for labeling blank aluminum tags)	1 set	No	No
	Hammer (for labeling blank aluminum tags)	1	No	No
MX104546	Markal Fluorescent Lumber Crayon	1	Yes	No
Plant press (MX100316 – press; MX100312 – blotting paper);	Clear plastic bags and/or plant press for plant voucher collection	20	No	No
MX104512	First aid kit	1	No	No

9.3 Preparation

- 1) **Check the QA/QC datasheet to determine whether a plot has been measured before, and if so, which subplot size must be used.** If a plot has been measured before, it is important to use the same subplot size each year, so that tagged, mapped individuals can be tracked through time.
- 2) Transfer all required Data Dictionary files, and files containing plot marker locations to the high-resolution GPS unit.
 - a) Connect the GPS unit to the computer via a USB cable.
 - b) Launch Windows Mobile Device Center to ascertain that the device is communicating properly with the PC.
 - c) Open Pathfinder Office: without a license it will default to opening in Viewer Mode, which is sufficient for performing file-transfer tasks.
 - d) Within Pathfinder Office, open the Data-Transfer Utility to transfer the desired files (click “Utilities → Data Transfer”). DO NOT use Windows Explorer to copy/paste files.
 - e) The “Help” button within the Data Transfer Utility provides detailed instructions for carrying out file transfer.
- 3) Check the TruPulse 360R laser rangefinder
 - a) Make sure the lenses on the TruPulse 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 at <http://www.ngdc.noaa.gov/geomag-web/>

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- c) *TruPulse Declination Offset*. Check the current declination against what is entered in the TruPulse. See Appendix A for details.
- 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. See Appendix A below for details.

9.4 Data Collection in the Field

Vegetation structure data are collected systematically from all woody stems rooted inside subplots of various sizes within each plot (Figure 2). High-level subplots may be either 10 m × 10 m (for 20 m × 20 m plots) or 20 m × 20 m (for 40 m × 40 m or larger plots). High-level subplots are numbered in sequence beginning with the SW corner of the plot; when the end of a row is reached, a new row of subplots is numbered starting from the western edge of the plot (Figure 2). Stems must be ≥ 50% rooted in the plot/subplot in order to be measured.

Team Duties:

- Person 1: Identify stems to species, measure stem properties, and record sampling metadata.
- Person 2: Use TruPulse 360R to map and measure stems, and call out data for recording by Person 1.

The procedure is organized into three sections according to the specific measurements that must take place for each plant growth form – i.e. trees, saplings/shrubs, and lianas. **Each plot that is visited must be assessed for the presence of these growth forms, and measured accordingly.** Assessments should take place every time a plot is measured.

9.4.1 File Naming

When mapping shrub polygons with the Trimble GeoXH running TerraSync, create a new, appropriately named TerraSync data file for each plot module – this ensures that few data will be lost should the PDA crash or should batteries fail during data collection. Name files according to the following convention:

- 1) Filename begins with the **plot_ID**: E.g. “HARV_001” for a plot at the D01 Harvard Forest core site.
- 2) The plot_ID code is followed by an underscore and two digits denoting the high-level **subplot number** within the plot.
 - a) Example of an acceptable filename: HARV_001_02
- 3) Once the file is properly named, it is important to select the “Woody Veg Structure” Data Dictionary.

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9.4.2 Determining and Marking the Appropriate Point(s) for Stem Diameter Measurement [begin again here]

Trees, saplings, shrubs, and lianas exhibit numerous growth forms – from single, straight boles to multiple curved, branched stems, to stems with adventitious roots that emerge some distance from the ground. Because of this variety, consistently choosing the appropriate measurement point is paramount. For the most part, this protocol adopts guidelines established by Gerwing et al. (2006) and Schnitzer et al. (2008).

Guidelines for Trees and Lianas (DBH \geq 10 cm and DBH \geq 1 cm, respectively)

- 1) For straight, single-bole stems growing on level ground, a meter tape or pre-marked staff can be used to straightforwardly measure 130 cm above the ground (i.e. Breast Height).
- 2) For stems growing on a slope or uneven terrain, measure 130 cm above the ground from the uphill side of the stem.
- 3) For leaning stems, measure the diameter 130 cm along the stem, rather than perpendicular to the ground. In this case the DBH tape should be wrapped at an angle so that it is perpendicular to the bole axis, and should represent an accurate cross-section of the stem.
- 4) For stems with anomalies at 130 cm (e.g. a big bulge, node/branch, or damage), measure DBH 5 cm below the anomaly where the stem becomes “normal” again. Record the alternate measurement height in the “Measurement_height” field.
- 5) Stems that branch or split into multiple boles below 130 cm should be measured 20 cm below the branch/split point, where the stem is regular. Record the alternate measurement height in the “Measurement_height” field.
 - a) Where the stem is regular but the distance between the branch/split point and the ground is < 40 cm, measure half way between the branch/split and the ground, where the stem is regular.
 - b) If the stem is deformed between the branch/split point and the ground, and it is not possible to make a single diameter measurement because the stem is not regular at any point between the branch/split and the ground (e.g. there is a high root collar), measure each qualifying bole 130 cm from the main rooting point, and tag and record data for each bole separately.
 - c) Exclude the tree from the census if there is a split within 130 cm of the roots, the main stem is not regular and cannot be measured, and none of the stem diameters beyond the branch/split is \geq 10 cm DBH at 130 cm.
- 6) For all stems, the measurement location should be marked so that repeat measurements at exactly the same location are possible:
 - a) For stems with $10 \text{ cm} \leq \text{DBH} < 30 \text{ cm}$, mark the measurement point on the main stem with a lumber crayon, and mark 10 cm above the measurement point with a single aluminum nail and an ID tag.
 - b) For stems with $\text{DBH} \geq 30 \text{ cm}$, mark the measurement location as in (a) above, and make an additional mark with the lumber crayon on the opposite side of the trunk to ensure that the tape is placed at the desired height all the way around the bole.

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- c) For multi-stemmed individuals for which it is impossible to find a single measurement location (i.e. stems described in 5b above), additional boles with DBH \geq 10 cm should be marked and tagged with a custom tag. To make the custom tag, label a blank aluminum tag with the steel die and hammer. The tag ID for secondary stems should be “a”, “b”, “c”, etc.
 - i) Record the secondary tag IDs in the “stem_ID” field (i.e. stem_ID = 1234a).
- 7) When measuring DBH, place the DBH tape directly over the lumber crayon marking(s). For large boles, the tape must not slip above or below the desired measurement point.

Guidelines for Saplings and Shrubs (1 cm \leq DBH < 10 cm)

Because woody stems with DBH < 10 cm represent a variety of growth forms, including single and multi-stemmed individuals, the marking and diameter measurement strategy for stems in the 1 cm \leq DBH < 10 cm size class depends on stem number (sensu Dahlin et al. 2011).

- 1) *For individuals with < 5 stems with qualifying diameter at breast height:* Measure the diameter of each qualifying stem, and select and mark the appropriate measurement height using the same guidelines employed for trees (described above).
 - a) Tag the largest stem with a unique ID, and mark the diameter measurement location with a lumber crayon.
 - b) The largest stem may be the only stem in some cases.
 - c) Mark secondary qualifying stems with a lumber crayon according to the guidelines above.
 - d) Tag secondary stems with a custom tag. Make and label the custom tags as indicated above.
- 2) *For individuals with > 5 stems with qualifying diameter at breast height:* Measure the diameter at decimeter height (i.e. the diameter at 10 cm aboveground), and record in the “stem_diameter” field. Tag the largest stem with a unique ID, and mark the diameter measurement location 10 cm aboveground.
 - a) Mark and measure secondary qualifying stems 10 cm aboveground with a lumber crayon. Record the diameter in the “stem_diameter” field, and use the same “stem ID”.
 - b) DO NOT tag and label secondary qualifying stems.

For all stems, labeled tags may be attached at the measurement location either with aluminum nails or with aluminum wire.

Best practice tip: Use aluminum wire for stems with DBH < 5 cm, and do not wrap the wire so tightly that it will cut into the stem as it grows.

Stems with DBH < 1 cm and height \geq 0.5 m

- 1) Measure the diameter at decimeter height (ddh), and record in the “stem_diameter” field. Also record the “Measurement height”.
- 2) Attach the tag to the stem at decimeter height (i.e. 10 cm above the ground), and mark the measurement point with a lumber crayon.

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- 3) Mark and measure secondary qualifying stems 10 cm aboveground with a lumber crayon. Record the diameter in the “stem_diameter” field, and use the same “stem ID”.
 - a) DO NOT tag and label secondary qualifying stems.

9.4.3 Mapping and Measurement of Saplings and Shrubs

Saplings and shrubs are self-supporting woody stems with $1 \text{ cm} \leq \text{DBH} < 10 \text{ cm}$, and/or height $\geq 0.5 \text{ m}$.

Saplings and shrubs are mapped and measured on a per subplot basis within plots in order to facilitate tracking individuals that have and have not been measured. Because saplings and shrubs can attain very high stem densities, even within a single subplot, it may be necessary to employ a nested subplot approach in order to keep the number of mapped and measured individuals manageable (Figure 2). To be consistent within plots, the same size measurement unit (e.g. the chosen nested subplot size) should be used for the entire plot, and the same size subplots within a given plot should be used from year to year (see Section 9.3.1).

- 1) Determine the appropriate measurement area
 - a) Upon arriving at the specified plot, check the QA/QC datasheet to determine whether the plot has been measured in a prior year, and if so, which subplot size was used.
 - b) If a plot has NOT been measured previously:
 - i) Survey the entire plot and visually assess the stem density of those stems that meet the definition of sapling/shrub to determine whether to map and measure all stems within each high-level subplot, or whether a nested subplot of appropriate size is warranted.
 - (1) For $20 \text{ m} \times 20 \text{ m}$ plots, it is desirable to measure no more than approximately $n=30$ to 50 individuals per $10 \text{ m} \times 10 \text{ m}$ subplot (100 m^2).
 - (2) For $40 \text{ m} \times 40 \text{ m}$ plots, there should be no more than approximately $n=120$ to 200 individuals per $20 \text{ m} \times 20 \text{ m}$ subplot (400 m^2).
 - ii) Based on the visual survey, choose an appropriate measurement area. If it is determined that a nested subplot is required, keep in mind that two subplots of a given size are always measured per module.
 - iii) Record the **shrub/sapling subplot size** in the QA/QC datasheet.
 - c) **If a plot HAS been measured previously** use the same measurement area each year in order to ensure that repeat measurements are made on tagged stems.
 - d) Once a measurement area has been determined, use existing plot markers, the 50 m tapes, and chaining pins to carefully delineate the desired module or subplot. In this case, it is not necessary to pay attention to whether the plot is sloped or flat: the tape is used only to help determine which stems are “in” versus “out” of the plot.
 - i) Refer to the Plot Establishment Protocol (RD [10]) for a review of tape wrapping techniques that can be used to delineate modules or subplots.
 - ii) The one-sided length of the subplots shown in Figure 2 are as follows:
 - (1) 1 m^2 red subplot = 1 m

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- (2) m² blue subplot = 3.16 m
- (3) 30 m² dashed grey subplot = 5.48 m
- iii) Map and measure stems where $\geq 50\%$ of the individual (or $\geq 50\%$ of the stems, for a multi-stemmed individual) are rooted within the measurement area.

9.4.3.1 Mapping and Measurement of Individuals and Groups

Saplings and shrubs can exist either as isolated individuals (with either single or multiple stems) that are not in contact with other individuals, or as groups of individuals in contact with each other (e.g. a continuous shrub thicket). Based on this “isolated” versus “grouped” dichotomy, there are two strategies for measuring these plants (see sections below).

Isolated individuals are mapped as points and tagged with a unique aluminum ID tag for repeat measurements. Groups of individuals are mapped with polygons, but not tagged. If a group is dense and covers an entire measurement area, there is no need to map or tag individual stems: simply record that cover is 100% of the measurement area.

Isolated Saplings/Shrubs

Measure isolated individuals (with either single or multiple stems) that are not in contact with other individuals.

- 1) For individuals that have not been previously mapped, tagged, and measured:
 - a) Record stem map data in the **Mapping Isolated Stems** datasheet.
 - b) Record stem measurement data in the **Isolated Stem Structure** datasheet.
- 2) For individuals that have been previously mapped, tagged, and measured:
 - a) Record stem measurement data in the **Isolated Stem Structure** datasheet.
- 3) If collecting data electronically using the TerraSync software:
 - a) Make sure the file from the previous subplot has been closed, and create a new file for each high-level subplot.
- 4) Name the file according to the convention described in Section 9.4.1 above. Record the **plot ID**.
- 5) Record the **module number**, and record the **subplot number** and **subplot size** (if applicable).
- 6) Record the **stem ID** from the aluminum tag. If the individual has not been previously tagged, tag and mark the stem(s) according to the guidelines in Section 9.4.2 above.
- 7) If stem was not previously tagged:
 - a) Mount the TruPulse on the non-magnetic tripod. Position the TruPulse directly over an existing plot marker for which high-resolution GPS coordinates have already been recorded, and from which the stem of interest is visible via direct line of sight.
 - b) Record the plot **marker ID** number over which the TruPulse is standing. Plot markers are associated with high-resolution GPS coordinates and provide a known reference point for the stem.

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- c) Record the **stem distance** to the nearest 0.1 m using the TruPulse in **HD** mode (see Appendix A). This is the distance from the TruPulse to the base of the stem. Stems are not mapped to the center of the bole.
- d) Record the **stem azimuth** to the nearest 0.1 degree from the TruPulse (see Appendix A). This is the angle relative to True North from the chosen plot marker to the base of the stem.
- e) Record the **species ID**. This should be either a binomial latin name or an accepted USDA NRCS code.
 - i) When **stem status** = dead (see below), assign to species if possible. If it is not clear what species a dead stem is, assign to genus, family, or unknown, in that order of preference.
 - ii) If **species ID** = unknown and the stem is alive, obtain leaf samples according to the guidelines in RD [09] and bring back to the lab to identify.
 - (1) Place collected unknown specimens in sealable plastic bags.
 - (2) Label plant with a unique (to the technician) unknown name, number, description, botanist, date, and plot number.
 - iii) For all stems, labeled tags may be attached 10cm above the measurement location either with aluminum nails or with aluminum wire.
 - iv) Best practice tip: Use aluminum wire for stems with DBH < 5 cm, and do not wrap the wire so tightly that it will cut into the stem as it grows.
- 8) Record the **stem diameter** (or stems, for multi-stemmed individuals):
- 9) For individuals with $1 \text{ cm} \leq \text{DBH} < 10 \text{ cm}$: Record the appropriate diameter (DBH or ddh) to the nearest 0.1 cm. Follow the guidelines in Section 9.4.1.3 to determine where stems should be measured.
 - a) Record the measurement height
 - b) Use a DBH tape for stems with $\text{DBH} \geq 5 \text{ cm}$.
 - c) Use calipers for stems with $\text{DBH} < 5 \text{ cm}$.
- 10) For individuals with height $\geq 0.5 \text{ m}$, but that do not meet the above DBH requirement: Use calipers and measure the ddh to the nearest 0.1 cm.
- 11) If an individual has been previously tagged, marked, and measured, it is important to measure at the same location in subsequent years.
- 12) Record **canopy diameters** to the nearest 0.1 meter. **Diameter_max** = the diameter at the greatest canopy extent. **Diameter_90** = the diameter approximately perpendicular to Diameter_max. Canopy diameters can be measured via either of the two techniques outlined in Appendix A.
- 13) Record **height** values to the nearest 0.1 meter. Height can be measured via either of the following two techniques:
 - a) *For individuals with height > approximately 2 m*: Use the TruPulse 360R (see Appendix A). Record both **height_VD1** (vertical distance from observer to top of canopy) and **height_VD2** (vertical distance from observer to base of stem).
 - b) *For individuals with height < approximately 2 m*: Use a meter tape.
 - i) Manually stretch the tape from the ground to the top of the canopy.

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- ii) If the individual is growing on uneven or sloped terrain, measure from the uphill side of the stem(s).
 - iii) Record the value from the meter tape as **height_VD1**, and enter a “0” (zero) for **height_VD2**.
- 14) Record the **stem status** – i.e. healthy, dead, damaged, or “other”.
- a) If “damaged” or “other”, describe with one or two words in the “**Status Notes**” field.

Grouped Stems: Group-Level Measurements

For grouped individuals, data are recorded in two places:

- Attributes measured for the entire group of stems are recorded digitally using the “**Woody Veg Structure**” Data Dictionary in TerraSync.
- Attributes of individual stems within the group are recorded on paper using the **Group Stems** datasheet.

To measure grouped stems:

- 1) Assess the % cover of the group relative to the measurement area:
 - a) If cover is 100% - i.e. stems are very dense, and a more-or-less continuous group covers the entire measurement area – skip to step g) below. There is no need to map the group of stems.
 - b) If the group does not cover the entire measurement area, then map the area of the group according to the steps immediately below.
 - c) Turn on the high-resolution GPS unit (GeoXH 6000 or equivalent), and open the TerraSync software. See the Plot Establishment Protocol (RD [10]) for best practice tips when using the high-resolution GPS unit.
- 2) Within TerraSync, create and name a data file for the current plot module using the appropriate naming conventions described above.
- 3) You **MUST** select the “Woody Veg Structure” Data Dictionary at the time of file creation.
- 4) Walk to the edge of the group to be mapped, and create a new “Group Stem Area” feature.
- 5) Record the **plot ID**.
- 6) Record the **module number**, and record the **subplot number** and **subplot size** (if applicable).
- 7) The **Group ID** for the group of stems being measured should be populated automatically by TerraSync.
- 8) Record the **Mapped Area** of the group of stems.
 - a) If the group covers the entire measurement area, record **Mapped Area** = “100 percent”.
 - b) If the group does NOT cover the entire measurement area, map the area of the group with a polygon in TerraSync, and record **Mapped Area** = “Polygon”. To map the group of stems with TerraSync:
 - i) Press the “Log” button to begin recording GPS data, and walk around the outside perimeter of the shrub group with the GPS unit.
 - ii) Press “Done” once the group has been circumnavigated.

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- iii) If the group of stems crosses the boundary of the measurement area (i.e. plot, module, or subplot), only map the portion of the group that falls inside the measurement area, and walk along the plot boundary to close the polygon.
 - 9) Record the **height** of each of the tallest 5 stems within the group, to the nearest 0.1 m:
 - a) Depending on the height of the stems within the group, use either the TruPulse or a meter tape to measure height, as described above.

Grouped Stems: Within-Group Measurements

For each stem within the mapped group that falls within the measurement area, record the following data. Use a separate datasheet for each unique **Group ID**:

- 1) Record the plot ID, module number, subplot number, subplot size, and Group ID.
- 2) Record the species ID. This should be either a binomial Latin name or an accepted USDA NRCS code.
 - a) When stem status = dead, follow the guidelines above.
- 3) Record the stem diameter.
 - a) For individuals with $1 \text{ cm} \leq \text{DBH} < 10 \text{ cm}$: Record the diameter at the appropriate point based on the guidelines above. Use a DBH tape for stems with $\text{DBH} \geq 5 \text{ cm}$. Use calipers for stems with $\text{DBH} < 5 \text{ cm}$.
 - b) For individuals with height $\geq 0.5 \text{ m}$, but that do not meet the above DBH requirement: Use calipers and measure the ddh to the nearest 0.1 cm.
- 4) Record the stem diameter measurement height.
- 5) Record the stem status – i.e. healthy, dead, damaged, or other.
 - a) If “damaged” or “other”, describe with one or two words in the “Status Notes” field.
- 6) It is helpful to mark stems you have just measured with a small length of temporary flagging in order to track work progress.
 - a) All temporary flagging must be removed once data have been collected from all stems within a given module.

9.4.4 Mapping and Measurement of trees (DBH $\geq 10 \text{ cm}$)

All standing woody stems in each module of each plot with $\text{DBH} \geq 10 \text{ cm}$ are mapped, measured, and marked with a unique aluminum ID tag. This approach enables repeat measurements of individual stems, and provides a detailed picture of forest structure and composition. For each stem, the following variables are recorded:

- Distance and azimuth from a known GPS reference point.
- Species ID
- Diameter at Breast Height
- Maximum canopy height
- Status (i.e. alive, dead, damaged, other)

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Additionally, in one randomly selected “Intensive” 20 m × 20 m subplot per plot, each stem is measured for:

- Maximum canopy diameter (Diameter_max)
- Canopy diameter at 90° to Diameter_max (Diameter_90)

The identity of the randomly selected Intensive subplot(s) is/are provided in the “**Tower Plot Intensive**” datasheet. When plot size = 20 m × 20 m, the “Intensive” subplot corresponds to the entire plot, and all stems are measured for canopy diameters.

- 1) Careful attention should be paid to: 1) map, measure, and tag new stems that now meet the minimum 10 cm DBH cutoff; and 2) identify previously tagged stems that have died since the last measurement. For individuals that have not been previously mapped, tagged, and measured:
 - a) Record stem map data in the **Mapping Isolated Stems** datasheet.
 - b) Record stem measurement data in the **Isolated Stem Structure** datasheet.
- 2) For each stem with DBH ≥ 10 cm, do the following:
 - a) If collecting data electronically using the TerraSync software, make sure the file from the previous subplot has been closed, and create a new file for each high-level subplot. If a file is already open because sapling/shrub data were just collected from the current high-level subplot, you may continue to collect data in the same file.
 - b) Name the file.
- 3) Record the **plot ID** and the **subplot number** (the “subplot number” and “subplot size” fields on the datasheet are left blank for stems with DBH ≥ 10 cm).
- 4) (Skip if stem was previously tagged). Tag, mark, and map the tree.
 - a) Mark the measurement location so that repeat measurements at exactly the same location are possible (see Section 9.4.2 above).
 - b) Mount the TruPulse on the non-magnetic tripod. Position the TruPulse directly over an existing plot marker for which high-resolution GPS coordinates have already been recorded.
 - c) Record the **TruPulse location**. This is the plot marker number over which the TruPulse is standing.
 - d) Record the **stem distance** to the nearest 0.1 m using the TruPulse. This is the distance from the TruPulse to the base of the stem.
 - i) Press “Power/Fire” to turn on the TruPulse.
 - ii) Set the unit to Target Mode = Filter. Press either the ▲ or ▼ button until **HD** (i.e. Horizontal Distance) appears in the viewfinder.
 - iii) Person 1: Hold the reflective surface at the base of the stem so that it is visible to Person 2.
 - iv) Person 2: Look through the TruPulse viewfinder, aim the crosshairs at the reflective surface held by Person 1, and press and hold “Power/Fire” until the distance is displayed in the viewfinder; **record this distance**.

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- e) Record the **stem azimuth** to the nearest 0.1 degree. This is the angle relative to True North from the chosen plot marker to the base of the stem.
 - i) After recording the **HD** to the stem above, press ▲ three times until **AZ** (i.e. azimuth from True North) appears in the viewfinder and the angle in degrees is displayed; record this angle.
 - ii) The angle should be preceded by a “**d**” indicating that declination has been set for the TruPulse at your current location (as described in Appendix A).
- f) Record the **species ID**. This should be either a binomial latin name or an accepted USDA NRCS species code.
 - i) When **stem status** = dead (see below), assign to species if possible. If it is not clear what species a dead stem is, assign to genus, family, hardwood/softwood, or unknown, in that order of preference.
 - ii) If **species ID** = unknown and the stem is alive, obtain leaf samples and bring back to the lab to identify.
 - (1) Place collected unknown specimens in sealable plastic bags.
 - (2) Label plant with a unique (to the technician) unknown name, number, description, botanist, date, and plot number.
- 5) Record the **stem ID** from the aluminum tag.
- 6) Record the **stem diameter** (or stems, for qualifying multi-stemmed individuals) to the nearest 0.1 cm.
- 7) Record the **measurement height** to the nearest 0.1 cm.
- 8) If the plot is a 20 m × 20 m plot, or you are surveying a randomly selected “Intensive” high-level subplot in a larger plot, record the **canopy diameters** below to the nearest 0.1 m, using the TruPulse (see Appendix A).
 - a) **Diameter_max** = the maximum extent of the canopy
 - b) **Diameter_90** = the diameter at 90° to Diameter_max
- 9) Record the **stem height** at the highest canopy point to the nearest 0.1 meter, using the TruPulse. Stem height is always height above the ground, not length of the stem – i.e. for leaning stems, measure the highest point above the ground.
 - a) Record VD1: The vertical distance from the highest canopy point to the observer, typically a positive number.
 - b) Record VD2: The vertical distance from the base of the stem where it meets the ground to the observer, typically a negative number.
 - c) For stems growing on uneven or sloped terrain, measure VD2 from the uphill side of the stem base.
- 10) Record the **stem status** – i.e. healthy, dead, damaged, or “other”.
 - a) If “damaged” or “other”, describe with one or two words in the “**Status Notes**” field.
- 11) It is helpful to mark trees you have just measured with a small length of flagging in order to track work progress.

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- a) All temporary flagging must be removed once data have been collected from all trees within a given module.

9.4.5 Measurement of Lianas (DBH \geq 1 cm)

Lianas are defined as woody stems that ascend up off the forest floor with the aid of mechanical support from another stem – i.e. lianas are non-self-supporting woody stems. The support stem is typically a tree with DBH \geq 10 cm. Lianas may not always be associated with a support tree if an individual has yet to begin climbing, or if an individual has recently fallen from the canopy.

All lianas that meet or exceed the diameter cutoff are measured and marked with a unique aluminum ID tag. This approach enables repeat measurements of individual lianas, and provides a detailed picture of forest structure and composition.

Similar to measurement of saplings and shrubs, it may be necessary to choose a subplot measurement area so that the number of stems measured is logistically feasible (Figure 2). To be consistent within plots, the same size measurement unit (i.e. the chosen nested subplot size, or the entire module) should be used for the entire plot, and the same size subplots within a given plot should be used from year to year (see Section 9.3.1 above).

- 1) Determine measurement area:
 - a) Upon arriving at the specified plot, check the QA/QC datasheet to determine whether the plot has been measured for lianas in a prior year, and if so, what size subplot was used.
 - b) **If a plot has NOT been measured previously** survey the entire plot and visually assess the stem density of those stems that meet the definition of liana to determine whether to map and measure all stems within each high-level subplot, or whether a nested subplot of appropriate size is warranted,.
 - i) For 20 m \times 20 m plots, it is desirable to measure no more than approximately n=30 to 50 individuals per 10 m \times 10 m high-level subplot (100 m²).
 - ii) For 40 m \times 40 m plots, there should be no more than approximately n=120 to 200 individuals per 20 m \times 20 m high-level subplot (400 m²).
 - c) Based on the visual survey, choose an appropriate measurement area. If it is determined that a nested subplot is required, keep in mind that two subplots of a given size are always measured per high-level subplot.
 - d) The measurement area selected for liana measurements may differ from measurement area selected for other vegetation components.
 - e) Record the **liana subplot size** in the QA/QC datasheet.
- 2) **If a plot HAS been measured previously:** Use the same measurement area each year in order to ensure that repeat measurements are made on tagged stems.
- 3) Record data from all measured liana individuals in the **Liana Stems** datasheet.
- 4) For each liana with DBH \geq 1 cm, do the following:

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- a) If collecting data electronically using the TerraSync software, make sure the file from the previous high-level subplot has been closed, and create a new file for each high-level subplot.
 - i) Name the file according to the convention described in Section 9.4.1 above.
- b) Record the plot ID, module number, subplot number, and subplot size.
- c) If the liana has not been previously tagged:
 - i) Affix a unique aluminum ID tag to the stem using a small length of aluminum wire.
 - ii) Record the **species ID**.
 - (1) When **stem status** = dead (see below), assign to species if possible. If it is not clear what species a dead stem is, assign to genus, family, or unknown, in that order of preference.
 - (2) If **species ID** = unknown and the stem is alive, obtain leaf samples and bring back to the lab to identify.
 - (a) Place collected unknown specimens in sealable plastic bags.
 - (b) Label plant with a unique (to the technician) unknown name, number, description, botanist, date, and plot number.
- d) Record the **liana ID**.
- e) Record the **stem ID**; this is the stem ID of the support stem (if applicable).
- f) (Re)Mark the correct measurement location using a fluorescent lumber crayon. The measurement location should be determined according to the following guidelines:



Figure 3. Situations that determine the location at which liana DBH should be measured

Lines A through G below describe common situations presented by the same letter in Figure 3 (excerpted from Gerwing et al. 2006). (H through R): Situations that may affect location of the DBH measurement point for lianas; see Schnitzer et al. (2008) for a full description of these less common scenarios.

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- A. Lianas that simply ascend into the canopy are measured 130 cm along the stem from the main rooting point.
- B. Twining lianas are measured 130 cm along the stem from the rooting point, including all twists and curves.
- C. Lianas that branch 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. Lianas 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 a clonal stem with the same **liana ID**.
- F. Lianas with rooted adventitious roots further than 80 cm from the main rooting point are measured 50 cm past the last root.
- G. Lianas 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 data with the same **liana ID**.
- g) Using calipers, measure and record the **stem diameter** to the nearest 0.1 cm at the marked measurement point.
- h) Record the **measurement height** to the nearest 0.1 meter.
- i) Record the **stem status**, along with any relevant **status notes**.

9.5 Sample Preservation

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

9.6 Data Handling

Upon returning to the Domain Support Facility lab, data collected in the field should be transferred to NEON servers.

Stem Data Collected Digitally with TerraSync Software

- 1) If they do not exist already, create the following folders and sub-folders: “Veg_structure_data → Site_name → YYYY”, where “Site_name” is the four-letter site code, and “YYYY” is the current year.
- 2) Connect the high-resolution GPS unit to a PC, power on the GPS unit, and make sure the GPS unit is connected in the Windows Mobile Device Center.

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- 3) Launch the Trimble GPS Pathfinder Office software, and open the Data Transfer Wizard.
- 4) Use the Transfer Wizard to copy any files created in TerraSync to NEON servers.
- 5) Once you have confirmed that the transfer was successful, files may be deleted from the GPS unit, and the GPS may be powered down.

Stem Data Collected Manually with Paper Datasheets

If data were collected manually, transcribe into the appropriate Excel spreadsheet.

- 1) There should be one Excel file containing vegetation structure ingest datasheets for all of the plots measured in a given year, and this file should have multiple tabs for each of the types of stems measured and mapped.
 - a) Enter data into tabs with “csv” in the tab name. Choose the appropriate tab for the field datasheets at hand.
 - b) Once data have been entered from all plots, save the “csv” tab as a .csv file for CI ingest.

9.7 Refreshing the Sampling Kit

- 1) Recharge batteries on the high-resolution GPS unit.
- 2) 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.
- 3) Check that supplies of lens tissue are adequate.
- 4) Check that supplies of consumable materials listed in Table 2 are adequate.

9.8 Equipment Maintenance, Cleaning and Storage

- 1) If necessary, clean the lenses on the TruPulse with a lens cloth or lens tissue.
- 2) Remove Data Dictionary and plot location files that are no longer needed from the high-resolution GPS unit.

10 REFERENCES

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Gerwing, J. J., S. A. Schnitzer, R. J. Burnham, F. Bongers, J. Chave, S. J. DeWalt, C. E. N. Ewango, R. Foster, D. Kenfack, M. Martínez-Ramos, M. Parren, N. Parthasarathy, D. R. Pérez-Salicrup, F. E. Putz, and D. W. Thomas. 2006. A standard protocol for liana censuses. *Biotropica* **38**:256-261.

Schnitzer, S. A., S. Rutishauser, and S. Aguilar. 2008. Supplemental protocol for liana censuses. *Forest Ecology and Management* **255**:1044-1049.

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APPENDIX A USING AND CALIBRATING THE TRUPULSE 360R

Set the declination of the TruPulse 360R Laser Rangefinder internal compass.

Declination changes with time and space so must be looked up annually for a given location. Positive declination values are East, negative values are West. Obtain the current declination values for your location from <http://www.ngdc.noaa.gov/geomag-web/#declination> and be sure to note the positive or negative sign before heading into the field.

The following procedure can be used to check and set the declination (if necessary) on the TruPulse 360R Laser Rangefinder:

- 1) Press the “Power/Fire” button to turn on the unit. The viewfinder will display the main “Measurement Mode” screen.
- 2) Press and hold ▼ for 4 s to enter “System Setup Mode”. Units will appear in the Main Display.
- 3) Press ▼ until H_Ang is displayed in the viewfinder, then press “Power/Fire”.
- 4) dECLn will be displayed in the viewfinder, press “Power/Fire”.
- 5) no and dECLn will blink. Press ▼ until YES and dECLn blink, then press “Power/Fire” again. The current declination is shown in the viewfinder (**Error! Reference source not found.**).
- 6) If this is the correct value, press and hold ▲ to return to the main “Measurement Mode” screen.

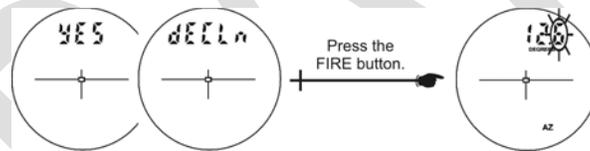


Figure 4. TruPulse 360R Laser Rangefinder viewfinder showing a user-entered declination value

- 7) If the displayed value is incorrect for your current location:
 - a) Press either ▲ or ▼ to change the tenths value, press “Power/fire”.
 - b) Press either ▲ or ▼ to change first integer value, press “Power/fire”.
 - c) Press either ▲ or ▼ to change second integer value, press “Power/fire”.
 - d) The value just entered will blink. Press “Power/fire” to confirm and return to the “Measurement Mode” screen.

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Calibrating the tilt sensor of the TruPulse 360R Laser Rangefinder

In the rare case that the TruPulse 360R Laser Rangefinder suffers severe drop shock, the following procedure can be used to calibrate the tilt sensor (vertical angle) on the TruPulse 360R Laser Rangefinder:

- 1) Press the “Power/Fire” button to turn on the unit. The viewfinder will display the main “Measurement Mode” screen.
- 2) Press and hold ▼ for 4 s to enter “System Setup Mode”. UnitS will appear in the Main Display.
- 3) Press ▼ until inC is displayed in the viewfinder, then press “Power/Fire” (Figure 5).
- 4) no and CAL will blink. Press ▼ until yes and CAL blink, then press “Power/Fire” again.
 - a) Calibration can be aborted by pressing “Power/Fire” when no and CAL are alternately displayed.

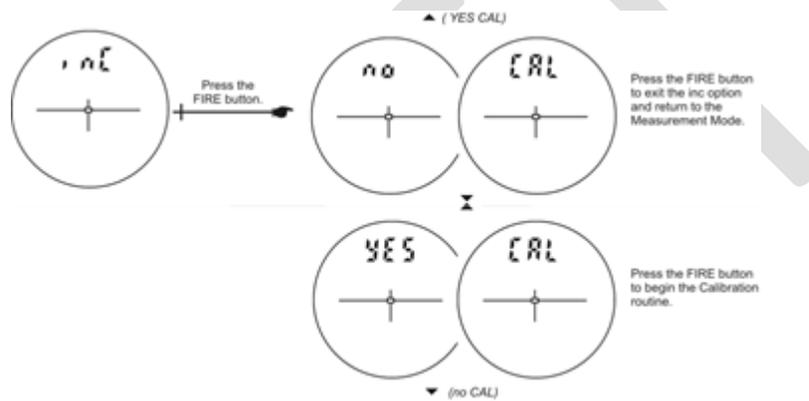


Figure 5. TruPulse 360R Laser Rangefinder viewfinder when initiating the tilt-sensor calibration routine

- 5) C1_Fd will be displayed in the view finder.
- 6) Place the TruPulse 360R Laser Rangefinder on a relatively flat surface (within 15deg of level), and follow the sequence outlined in Figure 6 below.
 - a) At each step wait approximately 1 second before pressing “Power/fire”, then wait another second before moving to the next position. It is important that the unit is held steady when you press “Power/fire”.
 - b) To abort and return to previous calibration at any point hold ▲ or ▼ for 4 sec.

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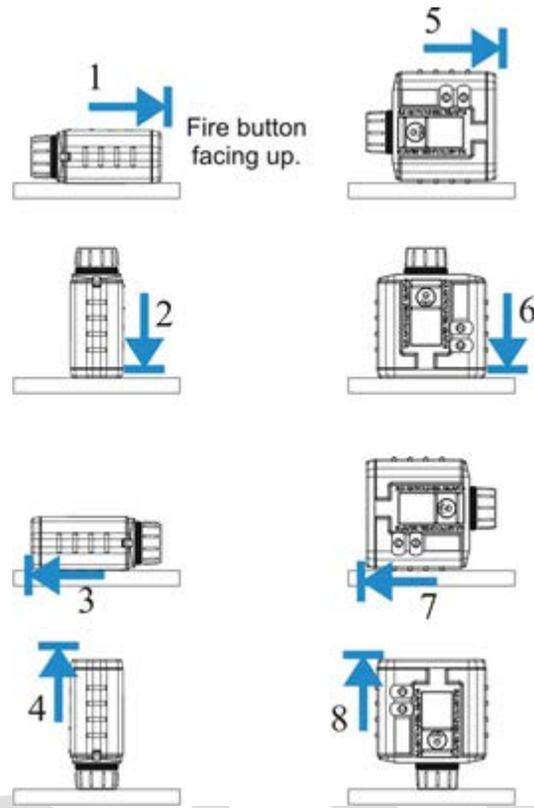


Figure 6. TruPulse 360R Laser Rangefinder tilt-sensor calibration routine

- 7) After all 8 positions have been run through, look through the eyepiece. Either a PASS or FAiL message appears in the view finder.
 - a) PASS: Press the “Power/Fire” Button to return to the measurement mode.
 - b) FAiL1: Excessive motion during calibration. Unit was not held steady.
 - c) FAiL2: Magnetic saturation error. Local magnetic field too strong.
 - d) FAiL3: Mathematical fit error.
 - e) FAiL4: Calibration convergence error.
 - f) FAiL6: Orientations were wrong during the calibrations.
- 8) If FAiL appears, press the “Power/Fire” button. No and CAL will alternately blink allowing you to do a new calibration. IF the calibration fails, the unit reverts to the previous calibration.

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Calibrating the internal compass of the TruPulse 360R Laser Rangefinder

The internal compass of the TruPulse 360R Laser Rangefinder is susceptible to error. When beginning a new plot, the TruPulse 360R Laser Rangefinder should be checked against an actual compass or a previously established plot line. ALWAYS CHECK AND RECALIBRATE THE COMPASS AFTER CHANGING THE BATTERIES! It is not uncommon for the compass calibration to be inaccurate when the low battery indicator is displayed in the view finder, and you should replace the batteries when this indicator appears.

To calibrate the internal compass of the TruPulse 360R Laser Rangefinder, use the following procedure:

- 1) Before calibrating the internal compass, take the TruPulse 360R Laser Rangefinder outside (away from local electromagnetic interference) and at least 2 feet away from all (magnetic) metal objects (including watches, etc.).
- 2) Press the “Power/Fire” button to turn on the unit. The viewfinder will display the main “Measurement Mode” screen.
- 3) Press and hold ▼ for 4 s to enter “System Setup Mode”. UnitS will appear in the Main Display.
- 4) Press ▼ until H_Ang is displayed in the viewfinder, then press “Power/Fire”.
- 5) dECLn is displayed. Press ▼ to display the HACAL option, then press “Power/Fire” again (Figure 7).
- 6) No and HACAL will alternately blink. Press ▲ or ▼ to display yES and CAL, then press “Power/Fire” to begin calibration.
 - a) Calibration can be aborted by pressing “Power/Fire” when no and CAL are alternately displayed.

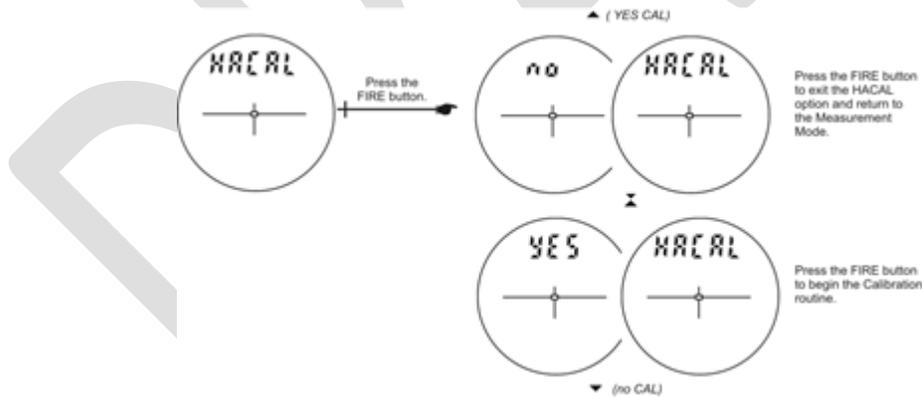


Figure 7. TruPulse 360R Laser Rangefinder viewfinder during compass calibration procedure

- 7) C1_Fd will be displayed in the view finder.
- 8) Place the TruPulse 360R Laser Rangefinder facing magnetic North (within 15 deg of N) on a relatively flat surface, or hold it while maintaining it flat (within 15 deg of level). To calibrate the compass, follow the sequence outlined in Figure 8 below. The TruPulse 360R Laser Rangefinder provides confirmation after each step.

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- a) At each step, wait approximately 1 second before pressing “Power/fire”, then wait another second before moving to the next position. It is important that the unit is held steady when you press “Power/fire”.
- b) To abort and return to previous calibration at any point hold ▲ or ▼ for 4 sec.

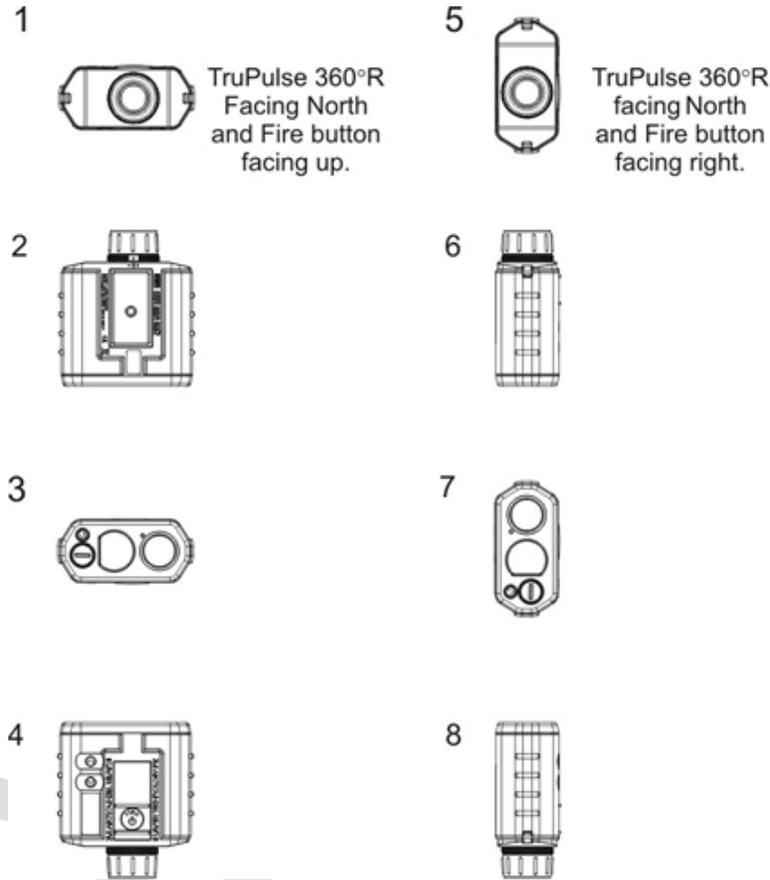


Figure 8. TruPulse 360R Laser Rangefinder compass calibration routine

- 9) After all 8 positions have been run through, look through the eyepiece. Either a PASS or FAiL message appears in the view finder.
 - a) PASS: Press the “Power/Fire” Button to return to the measurement mode.
 - b) FAiL1: Excessive motion during calibration. Unit was not held steady.
 - c) FAiL2: Magnetic saturation error. Local magnetic field too strong.
 - d) FAiL3: Mathematical fit error.
 - e) FAiL4: Calibration convergence error.
 - f) FAiL6: Orientations were wrong during the calibrations.
- 10) If FAiL appears, press the “Power/Fire” button. No and CAL will alternately blink allowing you to do a new calibration. IF the calibration fails, the unit reverts to the previous calibration.

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Measuring Distance from a Known Point

- 1) Press “Power/Fire” to turn on the TruPulse.
- 2) Set the unit to Target Mode = Filter
 - a) Press ▲ for 4 seconds. The active Target Mode appears in the viewfinder. Press ▲ or ▼ to cycle through available Target Modes. Available Target Modes are:
 - i) Std = Standard; Single-shot mode. The laser will acquire data from one target.
 - ii) Con = Continuous; In this mode, by pressing and holding “Power/Fire” the unit will acquire a target, and will continue to acquire additional targets for a maximum of 10 s. The most recently acquired target is displayed in the viewfinder. Useful for scanning trees in order to find the highest point.
 - iii) CLO = Closest; Press and hold the “Power/Fire” button in this mode. Once the initial target is acquired, the unit will acquire additional targets. The **MULTI** indicator in the viewfinder denotes additional targets have been acquired. The closest acquired target is displayed in the viewfinder. Useful with narrow targets in the foreground.
 - iv) FAr = Farthest; Identical to CLO above, but the farthest target is displayed in the viewfinder. Useful with a target partially obscured by brush, or for finding the highest point of a tree.
 - v) Flt = Filter; In this mode, the laser’s sensitivity is reduced to only detect pulses returned from a reflective surface. Useful when attempting to measure targets through thick brush.
In very heavy brush, the optional foliage filter can be used in this mode, but is not required. In this mode, an ‘F’ appears at the left of the viewfinder.
 - b) Choose “Flt” and press “Power/Fire” to make the chosen Target Mode active.
- 3) Press either the ▲ or ▼ button until **HD** (i.e. Horizontal Distance) appears in the viewfinder.
- 4) Person 1: Hold the reflective surface at the base of the stem so that it is visible to Person 2.
- 5) Person 2: Look through the TruPulse viewfinder, aim the crosshairs at the reflective surface held by Person 1, and press and hold “Power/Fire” until the distance is displayed in the viewfinder; record this distance.

Measuring Azimuth from a Known Point

- 1) After recording the **HD** to the stem above, press ▲ three times until **AZ** (i.e. azimuth from True North) appears in the viewfinder and the angle in degrees is displayed; record this angle.
- 2) The angle should be preceded by a “d” indicating that declination has been set for the TruPulse at your current location (as described previously).

Measuring the Canopy Diameter of Woody Stems

- 1) *For individuals with height > approximately 2 m:* Use the TruPulse 360R in **HD** (Horizontal Distance) mode.
 - a) Person 1 and Person 2 should position themselves below the edges of the canopy corresponding to either Diameter_max or Diameter_90 above.

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- b) Person 1 should hold a reflective surface, and Person 2 should shoot a **HD** to Person 1 using the TruPulse. Record this distance to the nearest 0.1 meter.
- 2) For individuals with height < approximately 2 m: Use a meter tape.
 - a) Person 1 and Person 2 stretch a meter tape to measure the desired diameters, and record the distance to the nearest 0.1 meter.

Measuring the Height of Woody Stems

First measure the vertical distance from the TruPulse to the top of the canopy (this is VD1; this number is typically positive). Next, use the TruPulse to measure the vertical distance from the TruPulse to the base of the stem (this is VD2; this number should be negative, since the base of the stem is typically below the height of the observer's eyes). The height of the stem is then, Height = VD1–VD2.

To start, the TruPulse should be set with Target Mode = Continuous, so that when “Power/Fire” is continuously depressed (for up to 10 s), the observer can scan and search for the **VD** value that represents the highest canopy point or the stem base. It is critical to ascertain that the observed **VD** values are associated with the stem of interest, and not any interfering or background vegetation.

In cases where the desired **VD** cannot be measured in Continuous mode (e.g. foliage or branches obstruct the target), set the TruPulse with Target Mode = Farthest (FAR), so that the unit reports **VD** from the furthest laser return from the observer. If the observer is positioned carefully, the furthest return should correspond either to the base of the stem (i.e. the ground) or the highest canopy point.

The steps required to record VD1 and VD2 are as follows:

- 1) Select a location from which the likely canopy peak(s) and the base of the stem are visible. It is critical that the observer measure both VD1 and VD2 from the same location.
- 2) Press “Power/Fire” to power on the TruPulse.
- 3) Set the Target Mode to either Continuous (Con) or Farthest (FAR); use your best judgement as to which mode is most appropriate for the stem of interest. Press ▲ for 4 s, then press ▲ or ▼ until either “Con” or “FAR” is displayed, and press “Power/Fire” to select.
- 4) Press ▲ or ▼ until **VD** (Vertical Distance) is displayed in the viewfinder.
- 5) Look through the viewfinder and aim the cross-hairs at what appears to be the highest point of the canopy. If the TruPulse is in Continuous mode, “Power/Fire” may be pressed for up to 10 s, and “Laser” will display in the viewfinder and the **VD** value in the upper-right will update in real-time as the cross-hairs are aimed at targets. When “Laser” disappears, the unit will display the most recent **VD** in the upper-right.
 - a) If it is necessary to move around while locating the highest canopy point, make sure that the base of the stem is still visible from the new location.

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- b) If it is unclear which point in the canopy is the highest, press “Power/Fire” and use the TruPulse to explore potential peaks until the highest point is found. **Once the highest point is located, record this value as VD1.**
- 6) Look through the viewfinder and aim the cross-hairs at the base of the stem. Press and hold “Power/Fire” for at least 1 s. The **VD** value in the upper-right of the viewfinder should blink when “Power/Fire” is released. **Record this value as VD2.**

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APPENDIX C INTENSIVE PLOT MODULES

Woody Vegetation

Designated "Intensive" plot modules for Tower Plots 40m x 40m and larger (not all sites v

- Step 1 Find the appropriate site below.
- Step 2 Enter the actual Tower Plot IDs for the site.
- Step 3 Record the Plot ID and the Intensive Module number on the QA/QC da
- Step 4 Measure canopy diameters for stems with DBH \geq 10 cm in the designat

40m x 40m plots: D01 HARV

Generic Plot ID	Actual Plot ID (e.g. HARV_001)	Intensive Module
plot_1		3
plot_2		1
plot_3		1
plot_4		3
plot_5		3
plot_6		1
plot_7		3
plot_8		1
plot_9		1
plot_10		2
plot_11		3
plot_12		1
plot_13		4
plot_14		4
plot_15		2
plot_16		3
plot_17		2
plot_18		1
plot_19		2
plot_20		2

40m x 40m plots: D03 OSBS

Generic Plot ID	Actual Plot ID (e.g. OSBS_001)	Intensive Module
plot_1		4
plot_2		2
plot_3		1
plot_4		4

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plot_5	3
plot_6	2
plot_7	1
plot_8	2
plot_9	3
plot_10	4
plot_11	3
plot_12	2
plot_13	2
plot_14	4
plot_15	4
plot_16	3
plot_17	1
plot_18	3
plot_19	2
plot_20	3

40m x 40m plots: D10 RMNP

Generic Plot ID	Actual Plot ID (e.g. RMNP_001)	Intensive Module
plot_1		3
plot_2		3
plot_3		4
plot_4		2
plot_5		1
plot_6		3
plot_7		4
plot_8		1
plot_9		2
plot_10		1
plot_11		4
plot_12		1
plot_13		1
plot_14		2
plot_15		3
plot_16		4
plot_17		4
plot_18		2
plot_19		3
plot_20		4