TOS STANDARD OPERATING PROCEDURE: CAC – CACTUS BIOMASS AND HANDLING

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Change Record

REVISION	DATE	ECO #	DESCRIPTION OF CHANGE
A	08/04/2016	ECO-03914	Initial Release
B	03/30/2018	ECO-05527	• Added reference to mobile applications and generalized app instructions throughout. • Added tagStatus. • Updated variable names to align with ingest workbook and mobile application. • Added mapping option for D14.
C	03/10/2022	ECO-06787	• Revised logo. • Fixed formatting.
D	01/18/2023	ECO-06948	• Moved content into template Rev E. • New Appendix: Re-organized photos of common cactus shapes into photo glossary. • Added prickly pear sampling equipment (1 meter pipe/dowel/rod, sharpie, tally counter, and duct tape) to equipment list. • Added springtime prickly pear scheduling tip to contingencies and notes. • Added height and crown measurements to pad shape category. • Added section on cactus group sampling. • Added remark worthy factors contributing to death and damage in Table 5. • Added common challenges section.

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1 DESCRIPTION

1.1 Purpose

This document outlines the NEON Standard Operating Procedure (SOP) for acquiring structural measurements from members of the family Cactaceae (cacti). Structural data collected from cactus individuals may then be used to estimate volume, and in some cases, standing biomass. This SOP complements standardized structural measurements for woody plants described in the Vegetation Structure Protocol (RD[04]), and provides techniques specific to cactus growth forms. This SOP is only required at sites where qualifying cacti are present in sampling plots, and should be implemented concurrently with vegetation structure measurements.

1.2 Scope

This document provides a change-controlled version of an Observatory procedure. 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.

1.3 Applies To

The procedure described in this document is used in the following protocols:

Doc #	Title
NEON.DOC.000987	TOS Protocol and Procedure: VST – Measurement of Vegetation Structure
NEON.DOC.001573	Datasheets for TOS Protocol and Procedure: Measurement of Vegetation Structure

1.4 Acknowledgments

N/A

2 RELATED DOCUMENTS AND ACRONYMS

2.1 Applicable Documents

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

AD[01]	NEON.DOC.004300	EHS Safety Policy and Program Manual
AD[02]	NEON.DOC.004316	Operations Field Safety and Security Plan
AD[03]	NEON.DOC.000724	Domain Chemical Hygiene Plan and Biosafety Manual
AD[04]	NEON.DOC.050005	Field Operations Job Instruction Training Plan
AD[05]	NEON.DOC.004104	NEON Science Data Quality Plan

2.2 Reference Documents

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

RD[01]	NEON.DOC.000008	NEON Acronym List
RD[02]	NEON.DOC.000243	NEON Glossary of Terms
RD[03]	NEON.DOC.002652	NEON Data Products Catalog
RD[04]	NEON.DOC.000987	TOS Protocol and Procedure: VST – Measurement of Vegetation Structure
RD[05]	NEON.DOC. 001573	Datasheets for TOS Protocol and Procedure: Measurement of Vegetation Structure
RD[06]	NEON.DOC.001025	TOS Protocol and Procedure: PLT – Plot Establishment
RD[07]	NEON.DOC.001271	AOS/TOS Protocol and Procedure: DMP – Data Management
RD[08]	NEON.DOC.001717	TOS Standard Operating Procedure: LSR – TruPulse Rangefinder Use and Calibration
RD[09]	NEON.DOC.003564	Standard Operating Procedure: HRB – Plant Pressing, Mounting, and Labeling (Herbarium Techniques)
RD[10]	NEON.DOC.014042	TOS Protocol and Procedure: DIV – Plant Diversity Sampling

2.3 Acronyms

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

2.4 Definitions

Allometry: The study of the relationship between the relative size of plant structures and biomass.

Areole: An areola, especially a small area bearing spines or hairs on a cactus.

Cladode: A flattened organ of a plant; in *Opuntia* species, these are generally referred to as pads.

Glochid: A barbed bristle on the areole of cacti. Generally small and hair-like.

Pad: See cladode definition.

Fulcrum: Software tool used to create NEON electronic data entry applications.

ServiceNow: Software tool used for problem/incident tracking and resolution.

3 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.

3.1 Laser Rangefinder Safety

A laser rangefinder/hypsometer/compass instrument is used to map individual cacti (D14 only) and to measure various structural attributes (i.e., height, crown dimensions). 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.

3.2 Cactus Safety

The potential for injury exists when working with cacti due to the prevalence of spines. As a simple precautionary measure, avoid making contact with cacti. Always wear personal protective equipment such as leather boots, long pants, long sleeves, and gloves, and remain cognizant of where you walk.

Most cactus-inflicted wounds should be treated like any other scratch or puncture, that is, cleaned then bandaged if necessary. Use a comb, tweezers, or adhesive to pick out spines that break off in the skin prior to treating the affected area.

Glochids that penetrate the skin may be difficult to extract because of their barbed shafts. To remove glochids, use tweezers or adhesives. Treat any remaining glochids as a wound, keep the area clean and covered to prevent dermatitis.

Segments of Cylindropuntia species break off easily and may become attached to footwear, clothing, or skin. To remove segments, use a comb or other solid object (i.e. Leatherman, rocks, etc.) to dislodge the

segment. Symbiotic bacteria living on cactus spines may cause inflammation, which typically subsides without treatment within a few days.

4 PERSONNEL

4.1 Training Requirements

All technicians must complete protocol-specific training as required in the Field Operations Job Instruction Training Plan (AD[04]). Additional protocol-specific required skills and safety training are described here.

Technicians must be trained in the proper care of the laser rangefinder. Although this tool is resistant to dust and water, it is important to seal open ports and use lens caps when applicable. Care must also be taken to avoid scratching lenses. Finally, technicians should be trained to carefully measure the heights of cacti using the laser rangefinder.

4.2 Specialized Skills

At least one of the technicians executing this protocol must be able to identify regionally-specific cacti to species via visual inspection and use of a dichotomous key.

5 ESTIMATED TIME AND SCHEDULING

Estimated Time

The amount of time required to implement this protocol will vary depending on a number of factors, such as cactus density, skill level, species diversity, environmental conditions, and distance between plots. For a skilled two-person team, it should require no more than 4 hours to complete a single plot. If a task is taking significantly longer than the estimated time, a problem ticket should be submitted.

Scheduling Tips

Prickly pears (*Opuntia spp.*) produce new pads in the spring, while Vegetation Structure for woody individuals is typically scheduled later in the year after the growing season is complete. However, it is difficult to distinguish new *Opuntia* pads from old pads once they are fully developed later in the growing season. Therefore, if *Opuntia spp.* are present at a given site and are measured via this SOP, schedule a *Opuntia*-specific Vegetation Structure bout in addition to the woody bout later in the season. The *Opuntia*-specific bout should target the period of the year in which these cactus produce new pads (e.g., April in Domain 14).

6 STANDARD OPERATING PROCEDURES

SOP A Preparing for the field

Configure and prepare equipment in the laboratory for use in the field.

SOP B Biomass/Productivity Measurements

Techniques for measuring individual cacti and cactus groups.

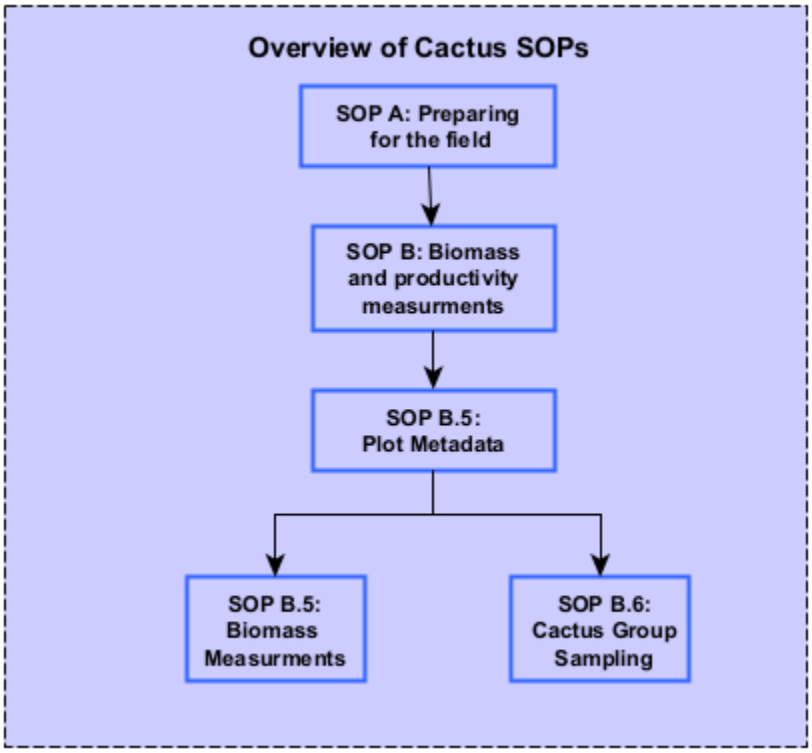


Figure 1. A high level workflow diagram that visually shows how the separate SOP sections are sequentially connected.

SOP A Preparing for the Field

A.1 Configure GPS

Transfer all required files containing plot locations to the GPS receiver.

A.2 Check the Laser Rangefinder

1. Make sure the lenses on the laser rangefinder are free of dirt and debris. Clean with a lens cloth or lens tissue if necessary.
2. Declination is different at each site, and also changes with time. Due to these factors declination should be set when moving between sites, and per site values should be looked up annually at http://www.ngdc.noaa.gov/geomag-web/
3. *Declination Offset.* Check the current declination against what is entered in the laser rangefinder unit. See RD[08] for details.
4. *Tilt-sensor Calibration.* In the rare instance that the laser rangefinder has suffered a severe drop shock, the tilt-sensor requires re-calibration prior to continued field work. See RD[08] for details. To accurately perform tilt-sensor calibration, a surface known to be perfectly flat is required.
5. *Compass Calibration.* The compass should be calibrated after the batteries are changed. Be aware that interference from local magnetic fields may prevent accurate calibration, and can cause the calibration routine to fail.

A.3 Print Field Datasheets

Print Datasheets for TOS Protocol and Procedure: Measurement of Vegetation Structure RD[05]. The preferred method of data collection through use of a mobile device running the '(TOS) VST: Apparent Individuals [PROD]' mobile application, but datasheets should always be available in the field as a backup data collection method should the mobile device fail.

A.4 Sync Mobile Device

Check that mobile devices have the required applications loaded, are fully charged, and synced before leaving the Domain Support Facility.

SOP B Cactus Vegetation Structure Measurements

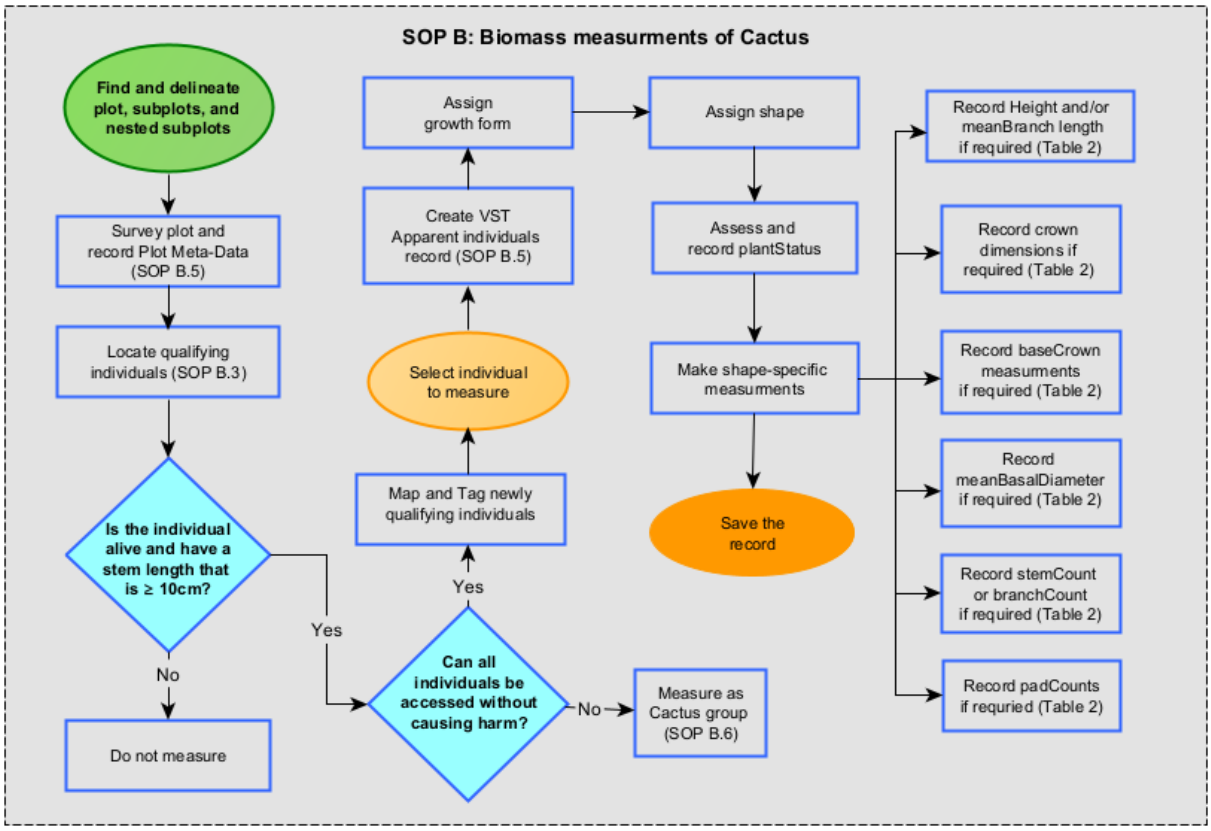


Figure 2. SOP B workflow diagram for collecting vegetation structure measurements from cactus. Diagram supports and does not replace protocol text; most common workflow is outlined.

B.1 Temporal Strategy

Most species of cactus are typically sampled concurrently with other woody and non-woody vegetation sampled via the Vegetation Structure protocol (RD[04]). That is, cactus are sampled during the dormant season after annual growth is complete. Tower plots are re-measured on either an annual or 5-year sampling interval (consult the Vegetation Structure protocol for site-specific information). Distributed plots are re-measured every 5 years. Sampling should be scheduled to begin within ± 2 weeks of the site-specific date specified in the Vegetation Structure protocol. Appendix D summarizes the sampling window for sites where cactus are expected.

B.2 Spatial Strategy

For 20 m x 20 m Tower Plots, the entire 20 m x 20 m area is sampled. At sites with 40 m x 40 m Tower Plots, only two randomly selected 20 m x 20 m subplots are sampled (see **Figure 3**). Lists of randomly selected subplots are provided by NEON Science. In Distributed Plots, Cactaceae are sampled only in the

inner 20 m x 20 m 'core' of the plot. To standardize sampling effort across plots, use nested subplots to constrain the measurement area, following the guidelines outlined in the Vegetation Structure protocol (see RD[04] for details). Briefly:

- In 20 m x 20 m plots: If nested subplots are employed, a minimum of 20 individuals, tallied across all nested subplots, must be measured in the entire 400 m^2 plot.
- In 40 m x 40 m plots: If nested subplots are employed, a minimum of 20 individuals must be measured in *at least one* of the assigned 20 m x 20 m subplots.

All cacti in the designated measurement area are identified and measured. As few established allometries are available to relate non-destructive field measurements to biomass of an individual, most cactus measurements will be used to calculate volume and will be treated in a similar fashion to shrub volume calculations described in RD[04]. In addition, structural measurements from cacti that NEON staff collects will provide a platform for potential community development of allometric biomass equations.

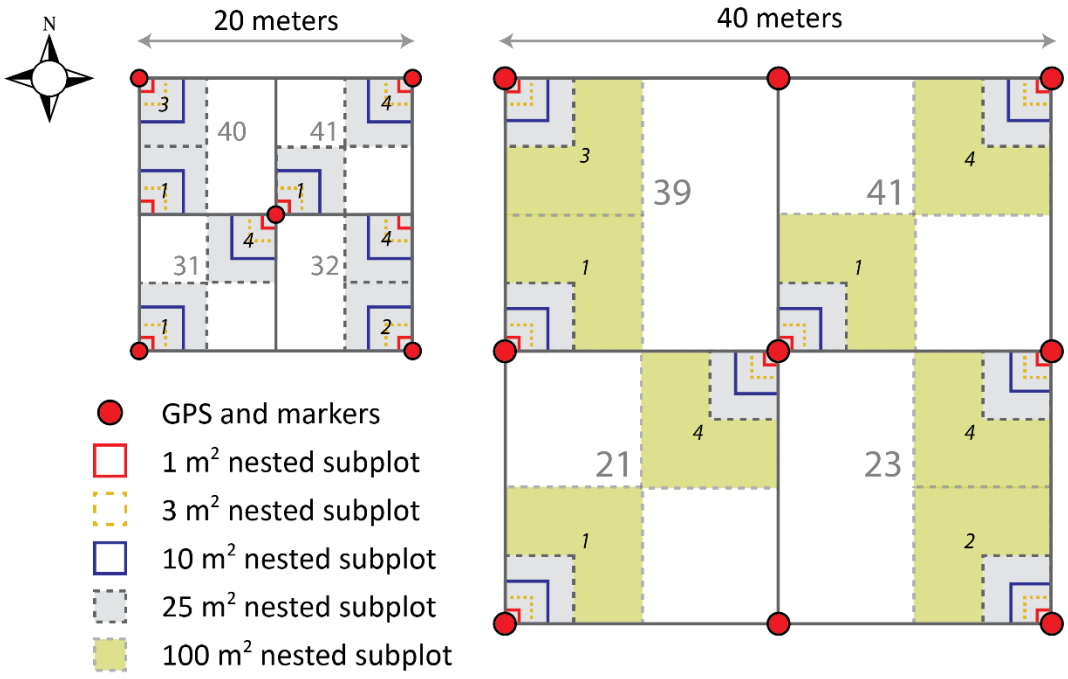


Figure 3. Illustration of a 20 m × 20 m base plot (left; larger destructive sampling portion of the plot not shown), a 40 m × 40 m base plot (right), and associated nested subplots used for measuring woody stem vegetation. The 20 m x 20 m plot size may be used for either Distributed or Tower Plots, and the 40 m x 40 m plot size is only for Tower Plots (at specific sites). Numbers in plain grey text indicate subplotIDs and numbers in italic black text indicate nested subplotIDs.

B.3 Qualifying Individuals

To qualify for measurement using this protocol, each specimen must be:

- In the Cactaceae family
- Alive **or** have a primary stem or stem segments that:
    - Are upright (with an angle that is greater than 45 degrees from the ground), **or**
    - Have a naturally decumbent growth form.
- Greater than or equal to 0.1 m stem length
    - Stem length minimum measurement applies to both upright and prostrate growth habits.
    - A minimum size is specified to constrain level of effort (LOE) for sampling activities. Cacti < 0.1 m stem length are accounted for in plant diversity sampling.

B.4 Preparing for Data Capture

Mobile applications are the preferred mechanism for data entry.

Data recording procedures are more fully described in the Vegetation Structure protocol and in the Vegetation structure Fulcrum Manual. This SOP covers information that is recorded in three different mobile applications as part of the comprehensive Vegetation Structure sampling bout:

- (TOS) VST: Plot Meta-Data [PROD]: presence/absence by growth form, nested subplot sizes, random subplot selection.
- (TOS) VST: Mapping and Tagging [PROD]: tagID, taxonID and location information (mapping cacti only occurs in D14).
- TOS) VST: Apparent Individuals [PROD]: field measurement of qualifying individuals.

Before going to the field:

- ***Double check that mobile devices are fully charged and synced***

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.

B.5 Collecting Cactus Structure Data

1. Navigate to the selected plot.
2. Delineate the plot. Use existing plot markers, the 50 m tapes, and chaining pins to carefully delineate the plot and subplots.

a. It is not necessary to pay attention to whether the plot is sloped or flat; the tape is used only to help determine the plot edges and orient 1 m^2 plot frames.

b. Refer to the Plot Establishment Protocol (RD[06]) for a review of tape wrapping techniques that can be used to delineate subplots and nested subplots.

3. Plot metadata: Determine nested subplot size. Group all forms / species of cacti together for determining nested subplot sizes. Consult the Vegetation Structure protocol (RD[04]) for a thorough explanation of requirements for nested subplot use. Record value in the *(TOS) VST: Plot Meta-Data [PROD]* mobile application or on the VST: Plot Meta-Data datasheet (RD[05]).

    a. If executing this protocol in a 20 m x 20 m plot, a sum of, at minimum, 20 cacti are required across the entire plot if nested subplot are used.

    b. If executing this protocol in a 40 m x 40 m plot, then a minimum of 20 cacti are required in at least one of the two randomly selected subplots.

4. For each plot, record in the Plot Metadata application:

    a. **plotID:** *SITE_###*

    b. **date** or **nonwoodyCollectDate:** *YYYYMMDD*. Use the **nonwoodyCollectDate** field at sites that support early-season sampling of cacti, and woody individuals are sampled at a later date. If cacti are sampled at the same time as woody individuals, use only the **date** field.

    c. **nestedSubplotAreaOther:** This is the nested subplot area as defined in SOP C in RD[04], *### m^2*

    d. **totalAreaSampledOther:** This is the subplot or nestedSubplotArea multiplied by the number of subplots surveyed. The value is auto-generated by the mobile application.

        i. **Ex.** If plotSize = 40m x 40m and no nestedSubplotArea is used, all of the two randomly selected subplot are surveyed, totalAreaSampled = 800

    e. **measuredBy:** Identifier for technician making measurements.

    f. **recordedBy:** Identifier for technician recording data.

    g. Presence/absence of all growthForms.

5. Mapping and Tagging new individuals: Tag all qualifying cacti encountered within the selected measurement area. Domain 14 tags all qualifying cacti, including those in the ‘pad’ shape category; tagging pad-shaped cacti is optional in all other domains.

    a. Tag with a unique aluminum ID tag for repeat measurements.

    b. Attach tag to a pigtail stake, and place the pigtail stake in the ground within 5 cm of the target cactus stem. To enable easily finding the tag at a later time, place pigtails on the same side of the cactus for every specimen.

c. Be consistent with tag placement for cacti. It may be useful to tag consistently with tagged woody individuals at the site.

   i. *Example*: D14 staff place the pigtail stake on the south side of cacti to avoid staring into the sun when locating a tag. Also be consistent in the spatial method you use for tagging; for example, begin in the Southwest corner of the plot and add tags as you move Northward within the plot.

d. Record new tagIDs in the *(TOS) VST: Mapping and Tagging [PROD]* Fulcrum application or the SOP B: Mapping and Tagging datasheet (RD[05]).

e. (Optional) Tagged cacti may be mapped according to guidelines in RD[04].

6. Metadata and measurements: For each qualifying cactus encountered, record:

   a. **subplotID:** number of the subplot in which the plant is located, *##*, (see **Figure 3**).

   b. **nestedSubplotID:** unique identifier of the nested subplot - assigned on a per-subplot basis, *#*, (see **Figure 3**).

   c. **tagID:** domain level unique identifier, *####* format; null for untagged individuals.

   d. **tagStatus**; description of condition of the tag. Choose one of the following options:

      i. **ok/new**; 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 cactus that do not meet tagging requirements.

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

   e. **taxonID** and **identificationQualifer** (**Table 3**) code (NB: idQ is not always needed)**:** USDA plant species code, e.g., *CAGI10 (Carnegiea gigantea), CYFU10 (Cylindropuntia fulgida), etc.* If the individual had been tagged and identified during a previous bout, this field will prepopulate in the mobile application.

i. The **taxonID** should be a code from the NEON master list of plant species codes (found in the 'taxonTables' supplied by NEON Science, and qualified according to technician confidence (**Table 3**).

ii. A searchable list of all taxonID for the selected domain is available via the *(TOS) VST: Mapping and Tagging [PROD]* mobile application.

1) If using a datasheet, should use ONLY the NEON master code. In the event that a code different from the NEON master code is used on a datasheet, the full **scientificName** associated with that code must be provided with each datasheet on which the non-NEON code is used, either via annotation or by attaching a key to the datasheet.

iii. The NEON master taxon lists provide codes for instances when identification below a given taxonomic rank (e.g., family or genus) cannot be made. These are indicated by a 'sp.' or 'spp.' in the scientific name, where the former is used when only one unknown species is involved, and the latter when a cactus group may contain multiple species from a given genus. When one of these genus-level codes is selected, an identification qualifier (idQ) is not needed, unless for example, the genus is uncertain.

1) *Example*: If you record **taxonID** = "CYLIN2" (*Cylindropuntia sp.*), 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 selected for the **taxonID**.

iv. Morphologically challenging species: It is expected that Field Science staff will encounter species that cannot confidently be identified in the field. In these cases, record morphospeciesID according to the guidelines in the Plant Diversity protocol (RD[10]).

f. **identificationReferences:** If a taxonomic key is used to identify the individual, record the last name(s) of author(s). If no references are used for identification, leave this field blank.

g. **shape:** A controlled list of cactus shapes derived from the scientific literature; the cactus shape determines the required structure measurements.

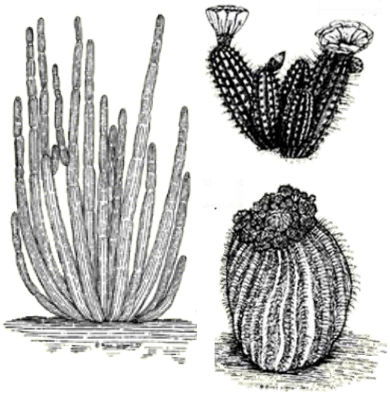
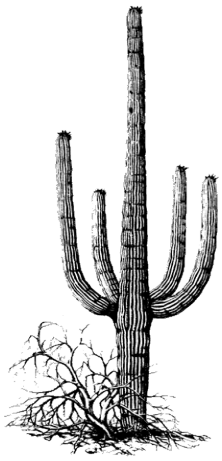
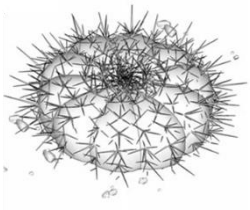
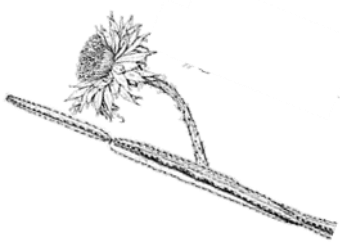
i. To determine the appropriate shape, consult **Table 1,** then match selected shape and required measurements using **Table 2**.

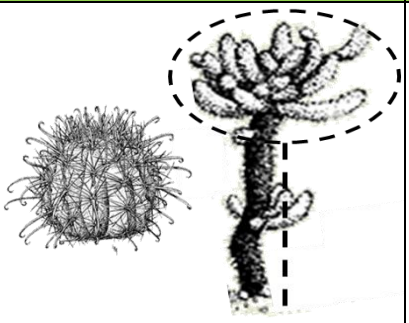
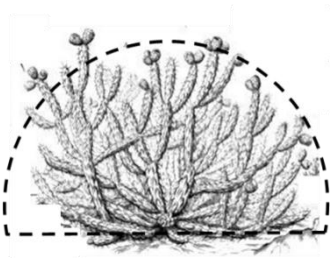
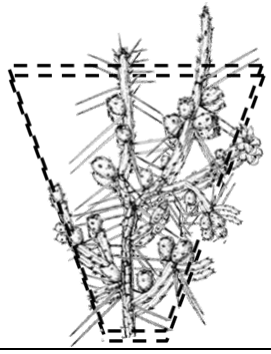
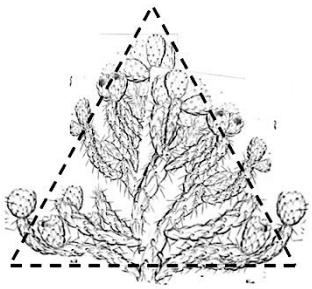
ii. Make a determination of shape based on the individual being measured; shape is not necessarily consistent within a particular species.

iii. Shape is approximate, and is used to estimate volume. It is possible that multiple shapes may be appropriate for a given individual. Be consistent and do not spend more than 30 seconds assessing shape.

7. After **shape** has been assigned, determine which of the measurements listed in **Table 4** must be recorded for the individual.

Table 1. Cactus shape descriptions and datasheet codes.

Shape	Code*	Definition	Example shapes†	Example Genera
Columnar	**col**	Non-segmented cacti that are slender in shape and erect in growth habit, may have 1 or more stems.		*Stenocereus sp.* *Lophocereus sp.* *Echinocereus sp.* *Echinocactus sp.* *Mammillaria sp.* *Pilosocereus sp.* *Leptocereus sp.* *Melocatus sp.*
Columnar **taxonID** = CAGI10	**col**	Species-specific measurements for Saguaro.		*Carnegiea gigantea*
Oblate Half Sphere	**ohs**	Single stems depressed globose in shape OR cluster of segmented stems that, as a group, form an oblate half sphere.		*Astrophytum sp.* *Escobaria sp.*
Vine	**vin**	Cacti with vine-like, non-self supporting growth forms.		*Peniocereus sp.* *Hylocereus sp.*

Shape	Code*	Definition	Example shapes†	Example Genera
Sphere or ellipsoid	**eph**	Single stems spherical in shape OR cluster of segmented stems elevated on central stalk. ***Important:*** You cannot select ellipsoid for cacti that have a base crown height the same as apex height. Choose the next best fitting shape (see **Table 6** and **Figure 10** for further clarification).		*Cylindropuntia sp.* *Ferocactus sp.* *Mammillaria sp.*
Half Sphere	**hsp**	Groups of clustered stems from a single individual that, as a group, approximately form a half sphere.		*Cylindropuntia sp.*
Inverted Cone	**icn**	Cluster of segmented stems that, as a group, approximately form an inverted cone shape.		*Cylindropuntia sp.*
Cone	**cne**	Cluster of segmented stems that, as a group, approximately form a cone shape.		*Cylindropuntia sp.*

Shape	Code*	Definition	Example shapes†	Example Genera
Cylinder	**cyl**	Cacti that grow in long cylindrical segments and approximate the form of a cylinder shape.		*Cylindropuntia sp.*
Pad	**pad**	Cacti that have flat, round cladodes (*Opuntia*).		*Opuntia sp.*

*****_Cylindropuntia_ and other segmented cacti may occur in a variety of shapes, assess each cacti individually consistent with shapes used to calculate volume of shrubs (half-sphere, cone, cylinder…)

† image credits: col, eph, icn, pad, and vin modified from Dimmitt 2000, ohs Molina-Freaner et al. 1998, cne, hsp, cyl modified from Engelmann and Bigelow 1856.

Table 2. Cactus structure measurements. Shape determines which measurements are required.

Measurement	Columnar	Columnar-Saguaro §	Oblate half sphere	Vine	Sphere or ellipsoid	Half sphere	Inverted cone	Cone	Cylinder	Pad * (*Opuntia*)
plantStatus	x	x	x	x	x	x	x	x	x	x
height ‡	x	x	x		x	x	x	x	x	x
maxCrown Diameter			x		x	x	x	x	x	x
ninetyCrown Diameter			x		x	x	x	x	x	x
baseCrownHeight					x					
basalStem Diameter		x			x					
measurement Height					x					
maxBaseCrown Diameter							x			
ninetyBaseCrown Diameter							x			
newPadCount										x
oldPadCount										x
stemCount	x									
branchCount		x		x						
meanBranch Length		x		x						
meanBasal Diameter	x									

‡ For multi-stem columnar species, this is the mean stem length of the cluster.

§ Required measurements are based on Steenbergh 1972, Niklas 2002, Huang 2007.

* Large-stature *Opuntia spp.* in D03, D04, and D14 have height, maxCrownDiameter, and ninetyCrownDiameter in addition to pad count. Domains without these *Opuntia spp.* measure only new and old pad counts.

Table 3. Identification qualifier codes (idQ) to designate unknown species or those species with uncertain identification in the field or after identification in the lab.

idqCode	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
CB	cf. subspecies	Roughly equals but "not sure" about the subspecies
AB	aff. subspecies	"Similar to, but is not" the subspecies
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

Table 4. List of potential structural measurements made on cactus individuals; note that not all measurements are made on a given cactus shape.

Variable	Detailed Description
Height *	Maximum height of single stem individuals, mean height for multi-stem individuals, measured using folding ruler, laser rangefinder, or measuring tape, 0.1 m, (see **Figure 5** and **Figure 8**).
maxCrownDiameter *	Largest diameter of canopy or stem, depending on which is larger, measured using calipers or folding ruler, 0.1 m, (see **Figure 5**).
ninetyCrownDiameter *	Diameter at 90˚ to maxDiameter measured using calipers or folding ruler, 0.1 m, (see **Figure 5**).
baseCrownHeight *	Use a rigid, collapsible meter stick to measure the average height above the ground for the lowest portion of the crown, 0.1 m
basalStemDiameter	Cross-sectional stem diameter at soil surface, measured using calipers or folding ruler, 0.01m
measurementHeight	The height at which the diameter is measured, soil surface = 0 cm, 1 cm
maxBaseCrownDiameter	Maximum diameter of the base of individuals in the inverted cone shape category, measuring tape, folding ruler or laser rangefinder, 1 cm
ninetyBaseCrownDiameter	90 degrees measurement of the maxBasalDiameter for individuals in the inverted cone shape category, 1 cm
newPadCount	Number of cladodes, of any size, produced in the current growing season (see **Figure 7**). Count vegetative, non-flowering, pads only.
oldPadCount	Number of cladodes produced in previous growing seasons (see **Figure 7**).
stemCount	Number of stems in a multi-stem columnar cluster (see **Figure 6**).

Variable	Detailed Description
meanBranchLength	For cacti in the columnar or vine shape that also have branches. To account for biomass in the branches in columnar or vine cacti (i.e. *Carnegiea gigantea, Peniocereus sp,* etc.) measure the length of each branch using a folding ruler, laser rangefinder, or measuring tape. Measure along the length of branches, including bends if present. If there is more than one branch length, calculate the mean of all branch lengths, and report to the nearest 0.1 m; see **Figure 8** for examples of how to measure complicated branch lengths
meanBasalDiameter	Use calipers to measure the basal diameter of each stem at ground level. Calculate the mean of all stems to the nearest 0.1 cm. For densely clustered multi-stem columnar individuals where basal diameter of interior stems cannot be measured directly, estimate basal diameter based on diameter of visible portion of the stem, assume columnar shape.
branchCount	For cacti in the columnar or vine shape that also have branch(es), the number of branches on individual cactus, (see **Figure 8**).
plantStatus	Health status of individual, if known, note the factors associated with death or damage in the notes section of the datasheet along with the corresponding tagID, #, (see **Table 5**).

* Small individuals may be measured to 1 cm accuracy (0.01 m).

Table 5. Definitions of **plantStatus** codes.

Code	Description
1	Live– any live cacti (new, re-measured or ingrowth).
2*	Standing dead – either new or re-measured, regardless of factors associated with death. The entire cacti must be dead. 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: • Unknown: It is common to have no observable evidence as to the actual cause of death. • Biotic: Suppression, animal damage, mistletoe • Disease: Rust, rot, canker, other (specify), unknown • Insect: scale, mealy bugs, termites; specify insect species if possible • Physical: Crown damage, crushed, lightning, phototoxicity, frost, other (specify if possible) • Fire: Stem scorch, stem combustion, burned through at base other (describe)
3	Removed – a cactus that has been cut and removed by direct activity to harvesting or land clearing (re-measurement plots only).
4*	Live, insect damaged - Visible damage caused by insects; note 'crown' or 'bole' damage in remarks, and indicate type of insect causing damage if possible
5*	Live, disease damaged - Visible damage cause by disease; indicate location and type of disease, in remarks, if possible
6*	Live, physically damaged – Visible damage not caused by disease or insects; indicate location and type of physical damage, in remarks, if possible
7*	Live, other damage – Note location and type of damage, in remarks, if possible
8	No longer qualifies – Note reason in remarks; record in multiple years if individual is still alive and may qualify in the future**.** Reasons for not measuring include: Individual no longer qualifies (e.g., broken and remaining live shoots do not qualify), change in nested subplot size, etc.
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 located for remeasurement
12	Lost, herbivory - A previously measured individual that is not measured in the current bout because the individual could not be located for remeasurement. 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 the individual could not be located for remeasurement, the individual is presumed dead based on evidence within the plot. Note in remarks reason (i.e. blowdown event)
15	Lost, fate unknown - A previously measured individual that is not measured in the current bout note because the individual could not be relocated
16	Downed - Part or all of previously measured individual is down, and in contact with the ground.

* For damaged individuals (codes 4-7), if the source of the damage cannot be determined, record as “Damaged – other” and include **remarks** describing damage.

B.6 Cactus Group Measurements

- 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 (available in the Sharepoint All Collaboration Library).

Classifying vegetation as a ‘group’ is a measure of last resort, as group measurements are the least useful with respect to allometric biomass estimation (see SOP E.3 in the Vegetation Structure protocol for explanation and classification guidelines). Groups are measured so that the volume of

the group may be estimated as 'canopy area' x 'average height'. Cactus groups are not mapped relative to a plot marker, and it is not required that they be tagged. You may tag cactus groups to better enable repeat measurements if you wish; however, it is not possible to enter tagged muti-species cactus groups into the *VST: Mapping and Tagging* application.

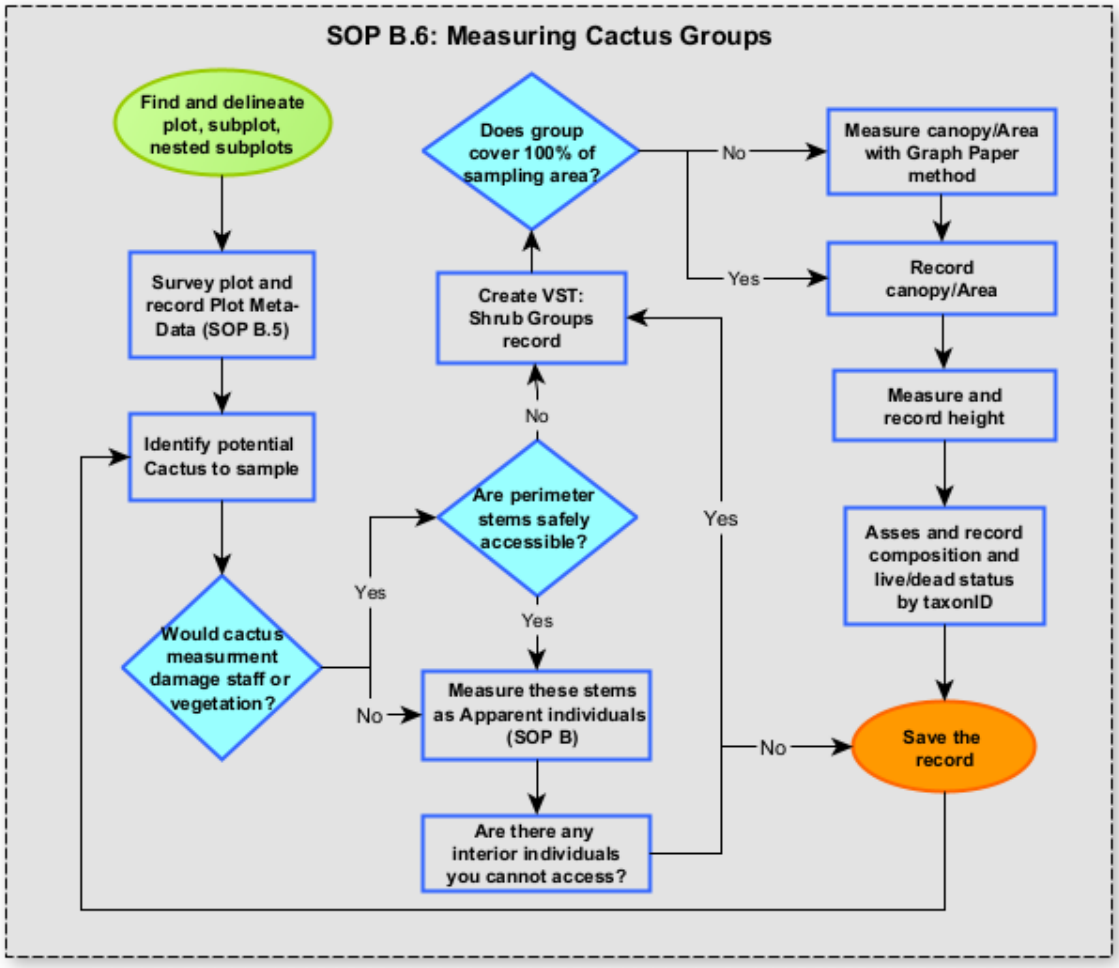


Figure 4. SOP B.6 workflow diagram for measuring cactus groups. Diagram supports and does not replace protocol text; most common workflow is outlined.

For each cactus group:

1. Measure the accessible individuals around the perimeter of the group as you would any other qualifying cacti.
2. Measure inaccessible cacti as part of the Cactus Group.
3. 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.

4. Measure Cactus Group canopyArea with the graph paper method:

    a. Label plotID, subplotID, nestedSubplotID, and nestedSubplotArea (if applicable) on the graph paper.

    b. Draw the measurement area boundaries, (1 cm2 = 1 m2).

    c. Draw the shape of the grid cells contained within the sketched group, begin with whole cells then add up partial cells: the sum is the **canopyArea** for the group.

    d. See SOP E.3 in RD[04] for more detail.

5. Measure Cactus Group average height:

    a. Use either the laser rangefinder (>2m), a meter tape (<2m) or a collapsible meter stick (<2m).

    b. Measure the height at 5 locations (**aGroupHeight, bGroupHeight,** etc.); nearest 0.1m

    c. Choose heights that you feel best represent the average maximum height of the cactus group. Bear in mind that the goal is to estimate the volume of the entire group as accurately as possible.

    d. For vining cacti, measure the height for the majority of the group, do not account for climbing stems extending to the canopy.

6. 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 a 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 cactus group is located, and if applicable, the nestedSubplotID within the subplot. These data can aid in re-finding cactus group 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 **yearBoutBegan**. If an auto-populated value is incorrect, return to the *VST: Plot Meta-Data* app 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 cactus 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 cactus group, nearest 1 square meter.

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

7. Assess the cactus group to determine taxonomic composition, create a child record in the *VST: Shrub Groups* app for each taxonID within the cactus group, and for each taxon in the cactus group record:

   a. **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. If **taxonID** is unknown and the stem is alive, assign a morphospecies ID as indicated in steps below, take photos and obtain reproductive parts (if useful) to bring back to the lab to identify.

   b. **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.

   c. **identificationQualifier**; select the appropriate qualifier when identification below a given taxonomic rank cannot be made – e.g., taxonID = family- or genus-level (**Table 3**).

   d. **morphospeciesID** (if applicable); enter a concise, descriptive ID that will be possible to link to this species at a later time. Refer to RD[10] for more detail processing morphospecies.

   e. **volumePercent**; visually estimate the % volume for the taxonID within the cactus group, nearest 10% (sum of all live + dead biomass for the taxonID). If a taxonID is < 5% of total cactus group volume, record volumePercent = 1%.

   f. **livePercent**; the estimated percent of the biomass that is alive for a taxonID in the cactus group, nearest 10%. The sum of % live and % dead should = 100 for each taxonID.

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

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

8. Save the parent cactus group record and proceed to the next group.

B.7 Common Challenges

Table 6. Common challenges encountered in the field.

Challenge	Action
Prickly pear pads that detach from an individual will re-root. Due to the proximity of the original individual, it can be confusing whether to call the newly rooted pads its own individual or not.	Map and tag new individual if it meets qualifications (greater than 0.1m stem length, alive, rooted).
Cylindropuntia or other cacti clones that are 0.1m in height and have a few arms that are at the apex. The best fitting shape is ellipsoid, but the baseCrownHeight and apex height cannot be the same value.	Choose the next best fitting shape category with biomass measurements in mind. For *Cylindropuntia* species this size, cylinder should be used.
Cannot access individuals for measurement due to density of cacti.	Measure as a cactus group.

7 REFERENCES

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APPENDIX A QUICK REFERENCES

Quick Reference: Collecting Quality Cactaceae Measurements

Step 1 – Calibrate laser rangefinder compass.

Step 2 – Delineate measurement area.

Step 3 - Assess need for nested subplots (new plots only).

Step 4 – Identify qualifying species.

Step 5 - Record metadata.

Step 6 – Tag qualifying species.

Step 7 – Collect and record shape-specific structure measurements.

Step 8 – Remove temporary flagging.

For directions on using the laser rangefinder, see TOS Standard Operating Procedure: TruPulse Rangefinder Use and Calibration (RD[08]).

APPENDIX B REMINDERS

Collecting quality Vegetation Structure data

Measurement Area: Make sure you know …

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

Taking measurements: Remember to…

- ✓ Carefully record all metadata, measurements, and observations in mobile application or on datasheet.
- ✓ Create plot-specific checklists of previously measured individuals.

Using the laser rangefinder: Pay close attention to …

- ✓ Declination – Is it set for your current location?
- ✓ Battery charge – Replace when low-charge indicated and bring back-up batteries.
- ✓ Transcription of measurements onto datasheet.
- ✓ Metal objects – Keep them at least 2 feet away from instrument when using internal compass.

APPENDIX C EQUIPMENT

The following equipment is needed to implement the procedures in this document. Equipment lists are organized by task. They do not include standard field and laboratory supplies such as charging stations, first aid kits, drying ovens, ultra-low refrigerators, etc.

Table 7. Equipment list – Preparing for sampling.

Supplier/ Item No.	Exact Brand	Description	Purpose	Quan-tity
Amazon Cabela's REI; IK270217 895022	N	GPS receiver, recreational accuracy	Navigate to sampling location at sites with plot markers	1
	N	USB Cable	Transfer data to GPS unit	1
	N	Rite in the Rain paper	Printing field datasheets	1

Table 8. Equipment list – Structure measurements at one plot.

Supplier/ Item No.	Exact Brand	Description	Purpose	Quan-tity
Compass Tools; 88180-04	N	GPS receiver, decimeter accuracy (e.g. GEO XH 6000, 7X)	Navigate to sampling locations at sites where markers are absent	1
Amazon Cabela's REI; IK270217 895022	N	GPS receiver, recreational accuracy	Navigate to sampling location at sites with plot markers	1
	N	Backup mobile data recorder battery, fully charged	Continue data collect in the event tablet loses charge	1
	N	Regional flora reference guide and/or key	Identify unknown species	1
Forestry Suppliers; 91567	Y	TruPulse 360 Laser Rangefinder, ± 30 cm accuracy	Measure height	1

Supplier/ Item No.	Exact Brand	Description	Purpose	Quan-tity
Forestry Suppliers; 71112	N	Measuring stick, 2 m folding	Measure heights and widths of cacti	1
	N	Rod, dowel, pipe, or equivalent; 1 m length	Used for marking prickly pear during pad counts	1
Ben Meadows 84516, 230916; Grainger 9TA07	N	Fluorescent lumber crayon	Used for marking prickly pear during pad counts	1
	N	Duct tape	Used to attach lumber crayon to marking implement.	1 roll
Forestry Suppliers; 53029 53031	N	Tally counter	Used for counting cacti when determining nested subplot size and prickly pear pads when completing pad counts.	1
Ben Meadows Forestry Suppliers; 122732 39945	N	Measuring tape, minimum 50 m	Delineate plot and subplot boundary	3
Ben Meadows Forestry Suppliers; 100952 39167	N	Chaining pins or other suitable anchor	Anchor measuring tapes to delineate plot and subplot boundary	9
Ben Meadows Forestry Suppliers; 213379 37184	N	Compass with mirror and declination adjustment	Determine plot boundary	1
RD[05]	N	Datasheets	Recording Data	1
	N	AA battery	Spare battery for GPS receiver	4

Supplier/ Item No.	Exact Brand	Description	Purpose	Quan-tity
	N	CR123A battery	Spare battery for laser rangefinder	2
	N	Survey marking flag, PVC or fiberglass stake	Delineate sampling area and temporarily mark stems before/after measurement	50
Ben Meadows Forestry Supplier; Varies depending on numerical sequence	N	Round numbered aluminum tag, silver; 0001-6000 and 8001-9999	Tag new qualifying stems	As needed
Paragon Spring; Pig Tail Stakes	N	Pigtail stake	Mark each specimen	As needed

APPENDIX D ESTIMATED DATES FOR ONSET AND CESSATION OF SAMPLING

The dates in **Table 9** below are based on historic records and estimated from MODIS-EVI phenology data averaged from 2005-2014 (Didan 2015), and are therefore estimates for the average start and stop dates of sampling. It is essential that domain staff monitor real-time conditions to determine when to start (and stop) sampling. Unless indicated otherwise, "End Date" values are in the next calendar year. The sites included in **Table 9** are only sites where cacti are expected to be. If cacti exist at a site that is not included in **Table 9**, see the Vegetation Structure Protocol (RD[04]) for start and end dates, and issue a problem ticket.

> ***"Start Date" definition***: Below, values in the "Start Date" field correspond to the average day of year at which greenness begins to decrease.

"Start Date" and "End Date" fields are relevant to cacti 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. If you feel this assessment is inaccurate for your site, please submit a problem ticket to Science Operations. If provided measurement windows are not logistically feasible, changes to "Start Date" may be made in consultation with Science Operations.

Table 9. Site-specific sampling start and end dates for cacti biomass measurements. See the Vegetation Structure Protocol (RD[04]) for start and end dates if they are not included in this table.

Domain Number	Site ID	Start Date	End Date	Tower plot sampling interval	Additional Sampling Information
03	DSNY	07/19	03/04	Annual	Target taxa present.
	JERC	08/10	03/23	Annual	Target taxa present.
	OSBS	07/15	03/05	Annual	Target taxa present.
04	GUAN	12/01	03/01	Annual	Dates correspond to the dry season, and are derived from Ensenada precipitation data (1980-2015).
10	CPER	07/29	03/31	Annual	Target taxa present.
	RMNP	08/02	05/09	Annual	
11	CLBJ	08/28	02/27	Annual	Target taxa present.
	OAES	NA	NA	Annual	
13	MOAB	08/13	03/15	5-year	Target taxa present.
14	JORN	09/03	03/21	5-year	Target taxa present.
	SRER	09/07	03/01	5-year	Target taxa present.
		4/15	5/15		Prickly pear
15	ONAQ	06/15	03/17	5-year	Target taxa present.

APPENDIX E CACTUS SHAPE PHOTO GLOSSARY

Ellipsoid

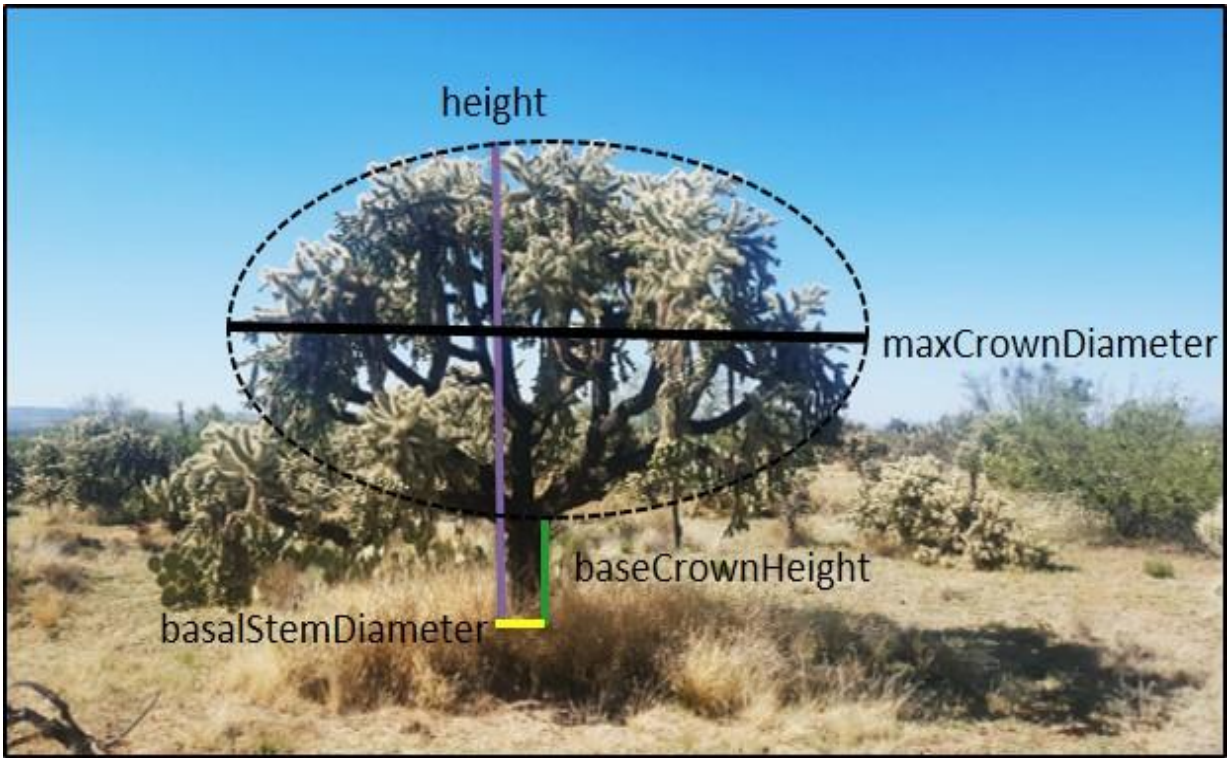

Figure 5. *Cylindropuntia fulgida* in the ellipsoid shape category illustrating where to take measurements. Measure basalStemDiameter (yellow line) at the ground level; maxCrownDiameter (black line) and ninetyDiameter across the canopy (black dotted circle); baseCrownHeight (green line) from the ground to the base of the crown and total height (purple line). Photo by Sienna Hiebert.

Columnar

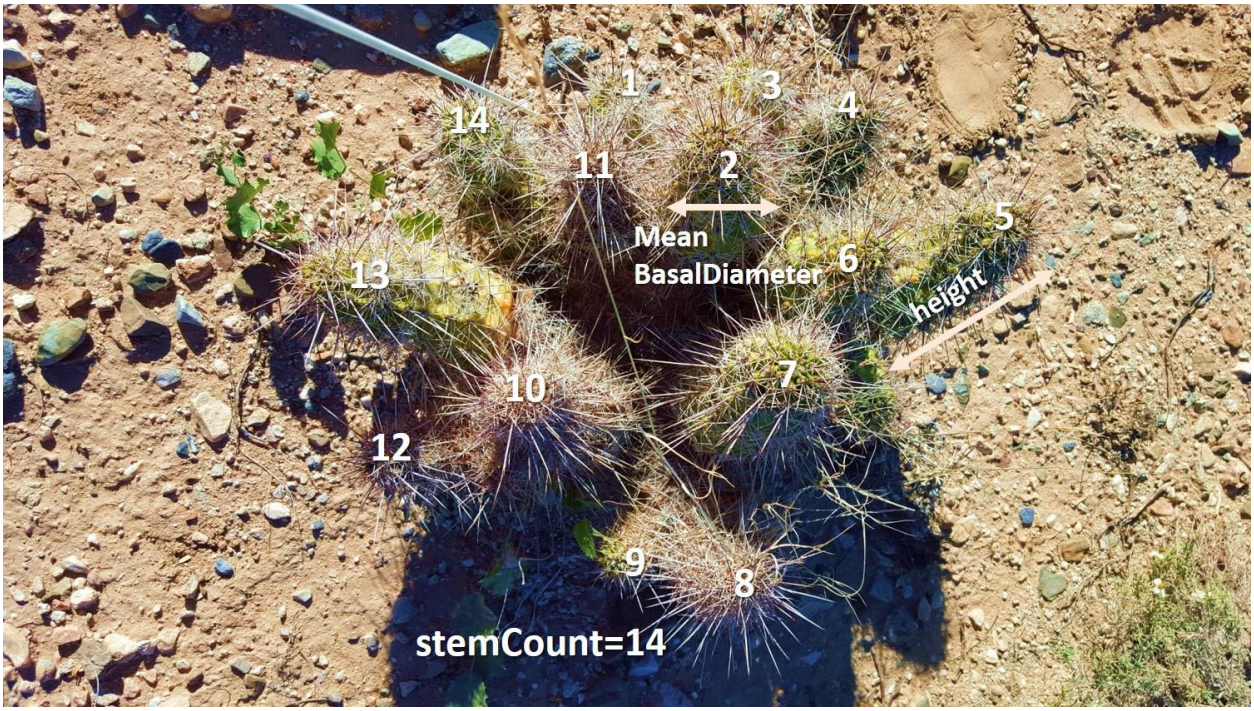

Figure 6. *Echinocereus sp*. illustrating a multi-stem columnar cacti in which one measures the height (in this case, the mean height of all stems), meanBasalDiameter, and stemCount. Photo by Sienna Hiebert.

Pad

Figure 7. *Opuntia sp.* with new vegetative pads growing off of an old pad. In this picture newPadCount = 3 and oldPadCount = 1.

Columnar – Saguaro

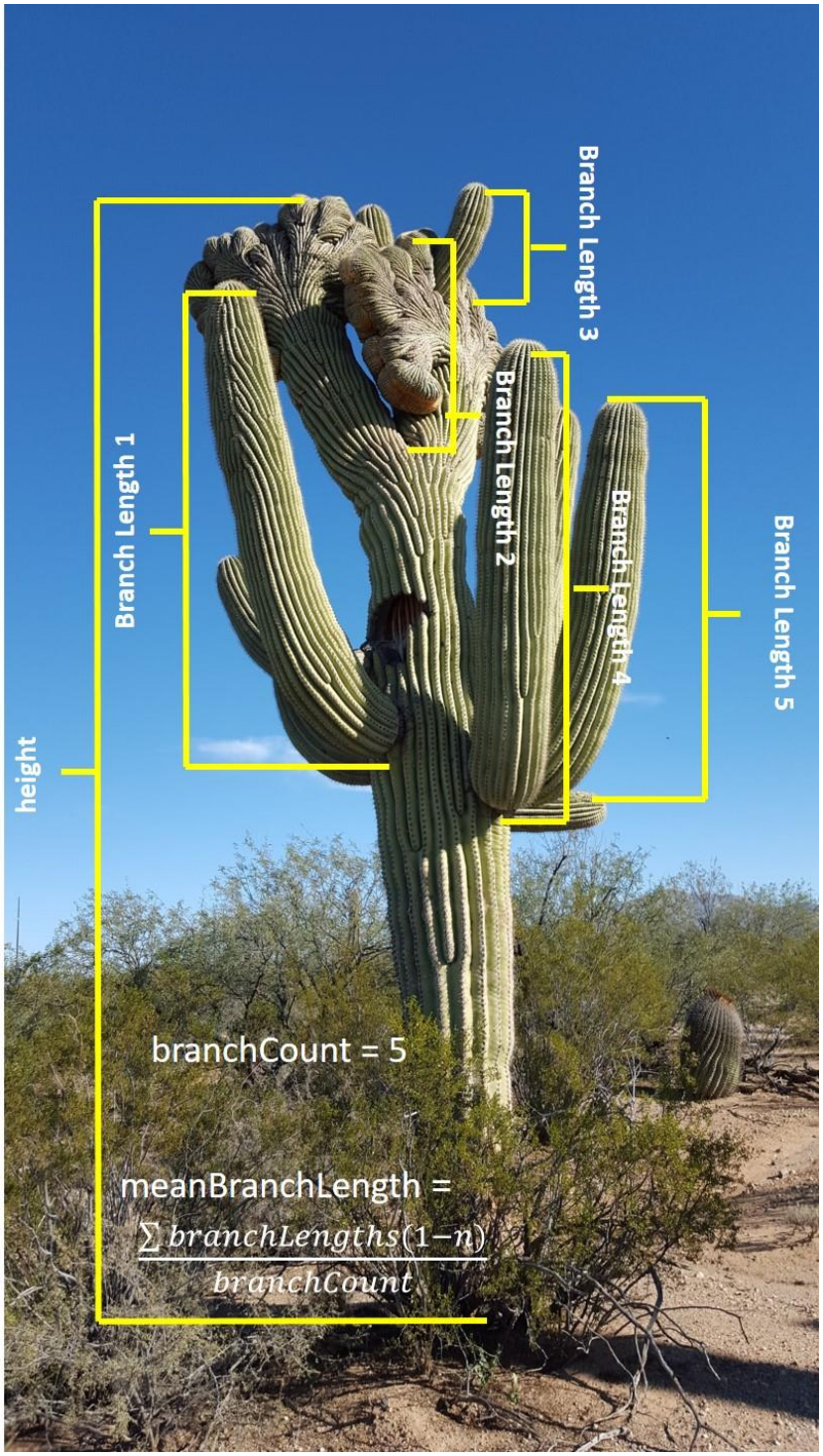

Figure 8. Branch length measurement (measure along the stem) in *Carnegiea gigantea*. Measure each branch then average the length of all branches. Enter that value in the meanBranchLength data field. For cacti that have become cristate like in this picture, note "crested" in the **remarks** field. Photo by Sienna Hiebert.

Cactus Group

Figure 9. Group of 20 + *Leptocereus quadricostatus* individuals measured as a shrub group at the NEON Domain 04 GUAN site. The density of this group made it impossible to access each individual without causing harm to field staff and/or vegetation. Photo by Wilmarie Plaza-Muniz.

Half Sphere

Figure 10. This *Cylindropuntia fulgida* specimen illustrates the necessity of accounting for current size and volume when assigning a shape. This individual is 0.1 m in height, with a shape that best resembles an ellipsoid. However, the baseCrownHeight would also be 0.1 m (due to unit of measurement minimums), thus leading to an inaccurate volume calculation. In this situation, when apexHeight and baseCrownHeight are the same, choose the next best fitting shape for the individual. For this cholla shape = 'half sphere'. Photo by Danielle Steinberg.