SOP: Cactus Biomass and Handling

PREPARED BY	ORGANIZATION	DATE
Sienna Hiebert	FOPS	06/29/2016
Katie Jones	FSU	06/29/2016
Courtney Meier	FSU	06/29/2016

APPROVALS	ORGANIZATION	APPROVAL DATE
Andrea Thorpe	SCI	07/29/2016
Rick Farnsworth	PSE	08/03/2016

RELEASED BY	ORGANIZATION	RELEASE DATE
Judy Salazar	CM	08/04/2016

See configuration management system for approval history.

The National Ecological Observatory Network is a project solely funded by the National Science Foundation and managed under cooperative agreement by NEON, Inc. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Change Record

REVISION	DATE	ECO #	DESCRIPTION OF CHANGE
A	08/04/2016	ECO-03914	Initial Release

TABLE OF CONTENTS

1 DESCRIPTION 3

1.1 Purpose 3

1.2 Scope 3

1.3 Applies To 3

1.4 Acknowledgments 3

2 RELATED DOCUMENTS AND ACRONYMS 3

2.1 Applicable Documents 3

2.2 Reference Documents 4

2.3 Acronyms 4

2.4 Definitions 4

3 SAFETY 5

3.1 Laser Rangefinder Safety 5

3.2 Cactus Safety 5

4 PERSONNEL AND EQUIPMENT 6

4.1 Equipment 6

4.2 Training Requirements 9

4.3 Specialized Skills 9

4.4 Estimated Time 9

5 CONTINGENCIES AND NOTES 9

6 STANDARD OPERATING PROCEDURES 10

SOP A PREPARING FOR THE FIELD 10

SOP B BIOMASS/PRODUCTIVITY MEASUREMENTS 11

6.1.2 Temporal Strategy 11

6.1.3 Spatial Strategy 11

7 REFERENCES 24

APPENDIX A QUICK REFERENCES 25

APPENDIX B REMINDERS 26

APPENDIX C ESTIMATED DATES FOR ONSET AND CESSATION OF SAMPLING 27

LIST OF TABLES AND FIGURES

Table 1. Equipment list – Preparing for sampling..... 6
Table 2. Equipment list – Structure measurements at one plot 7
Table 3. Cactus shape descriptions and datasheet codes. 15
Table 4. Structure Measurements. Shape determines which measurements are required. 18
Table 5. Identification qualifier codes (idQ) to designate unknown species or those species with uncertain identification in the field or after identification in the lab. 19
Table 6. List of potential structural measurements made on cactus individuals; note that not all measurements are made on a given cactus shape. 19
Table 7. Status value definitions. For damaged individuals (codes 4-7), if the source of the damage cannot be determined, record as Damaged – other, include remarks describing damage. 22
Table 8. 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. 27

Figure 1. 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. 12
Figure 2. *Cylindropuntia fulgida* in the eph shape category illustrating where to take measurements. Measure basalStemDiameter (yellow line) at the ground level; maxDiameter (black line) and ninetyDiameter across the canopy; baseCrownHeight (green line) from the ground to the beginning of the canopy. Photo by Sienna Hiebert. 20
Figure 3. *Echinocereus sp*. illustrating a multi-stem columnar cacti in which one measures the height (in this case, the average height of all stems), averageBasalDiameter, and stemCount. Photo by Sienna Hiebert. 21
Figure 4. *Opuntia sp.* with new vegetative pads growing off of an old pad. In this picture newPadCount = 3 and oldPadCount = 1. 21
Figure 5. 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 averageBranchLength data field. For cacti that have become cristate like in this picture, note “crested” in the **remarks** field. Photo by Sienna Hiebert 23

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 Measurement of Vegetation Structure (RD[04]) protocol and relies on the SOP B: Mapping and Tagging datasheet and the Biomass and Productivity Measurements- Other datasheet (RD[05]).

1.4 Acknowledgments

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.050005	Field Operations Job Instruction Training Plan

2.2 Reference Documents

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

RD[01]	NEON.DOC.000008	NEON Acronym List
RD[02]	NEON.DOC.000243	NEON Glossary of Terms
RD[03]	NEON.DOC.005003	NEON Scientific Data Products Catalog
RD[04]	NEON.DOC.000987	TOS Protocol and Procedure: 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: Plot Establishment
RD[07]	NEON.DOC.001271	TOS Protocol and Procedure: Manual Data Transcription
RD[08]	NEON.DOC.001717	TOS Standard Operating Procedure: TruPulse Rangefinder Use and Calibration
RD[09]	NEON.DOC.001792	NEON Herbarium Specimen Label and Annotation Generation
RD[10]	NEON.DOC.014042	TOS Protocol and Procedure: 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.

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 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.

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 AND EQUIPMENT

4.1 Equipment

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

Table 1. Equipment list – Preparing for sampling

Item No.	R/S	Description	Purpose	Quantity	Special Handling
Durable Items					
MX100703	S	GPS receiver, recreational accuracy	Navigate to sampling location at sites with plot markers	1	N
	S	USB Cable	Transfer data to GPS unit	1	N
Consumable Items					
	S	Rite in the Rain paper	Printing field datasheets	1	N

R/S=Required/Suggested

Table 2. Equipment list – Structure measurements at one plot

Item No.	R/S	Description	Purpose	Quantity	Special Handling
Durable Items					
MX102540	S	GPS receiver, decimeter accuracy (e.g. GEO XH 6000, 7X)	Navigate to sampling locations at sites where markers are absent	1	N
MX100703	S	GPS receiver, recreational accuracy	Navigate to sampling location at sites with plot markers	1	N
	S	Regional flora reference guide and/or key	Identify unknown species	1	N
MX100322	S	Laser Rangefinder, ± 30 cm accuracy	Measure height	1	N
MX105823	R	Measuring stick, 2 m folding	Measure heights and widths of cacti	1	N
MX104369	R	Measuring tape, minimum 50 m	Delineate plot and subplot boundary	3	N
MX104361	R	Chaining pins or other suitable anchor	Anchor measuring tapes to delineate plot and subplot boundary	9	N
MX100320	R	Compass with mirror and declination adjustment	Determine plot boundary	1	N
Consumable Items					
RD[05]	R	Datasheets	Recording Data	1	N
	R	AA battery	Spare battery for GPS receiver	4	N

Item No.	R/S	Description	Purpose	Quantity	Special Handling
	R	CR123A battery	Spare battery for laser rangefinder	2	N
	S	Survey marking flag, PVC or fiberglass stake	Delineate sampling area and temporarily mark stems before/after measurement	50	N
MX103478 MX103477 MX103479 MX108192 MX108193 MX108194 MX108197 MX108198	R	Round numbered aluminum tag, silver; 0001-6000 and 8001-9999	Tag new qualifying stems	As needed	N
MX106345	R	Pigtail stake	Mark each specimen	As needed	N

R/S=Required/Suggested

4.2 Training Requirements

All technicians must complete required safety training and procedure-specific training for safety and implementation of this procedure as required in Field Operations Job Instruction Training Plan (AD[04]).

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.

4.3 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.

4.4 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.

5 CONTINGENCIES AND NOTES

NA

6 STANDARD OPERATING PROCEDURES

SOP A Preparing for the field

Measurements to estimate cactus biomass will be made on an individual plant basis, and the techniques used are consistent with those described in the Vegetation Structure protocol [RD(04)].

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

1. Print Datasheets for TOS Protocol and Procedure: Measurement of Vegetation Structure RD[05].

SOP B Biomass/Productivity Measurements

B.1 Introduction

This SOP is implemented at all Tower Plots and a subset of Distributed Plots, and in a manner consistent with the temporal and spatial sampling strategy outlined in AD[04].

6.1.2 Temporal Strategy

Cactus will typically be sampled concurrently with all other vegetation structure measurements, that is, during the dormant season after annual growth is complete. Tower plots are re-measured each year, Distributed plots are re-measured once every three years. Annual sampling begins ± 2 weeks of the sampling start date the preceding year. 7Appendix C summarizes the sampling window for sites where cactus are expected.

6.1.3 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 1**). Lists of randomly selected subplots are provided by Science Operations. 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.

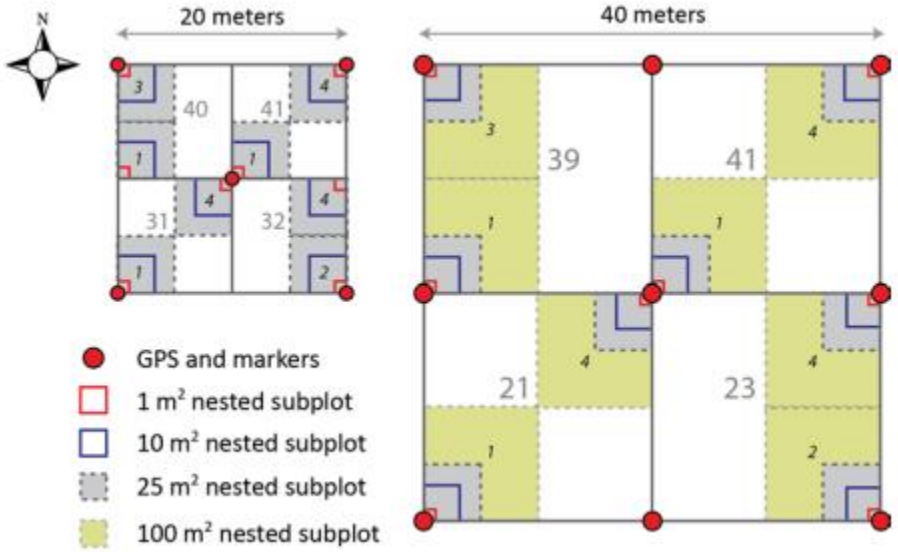


Figure 1. Illustration of a 20 m × 20 m base plot (left; larger destructive sampling portion of the plot not shown), a 40 m × 40 m base plot (right), and associated nested subplots used for measuring woody stem vegetation. The 20 m x 20 m plot size may be used for either Distributed or Tower Plots, and 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.

A.1 Qualifying Individuals

In order to qualify for measurement using this protocol, each specimen must be:

- In the Cactaceae family
- Alive **or** have a primary stem that is:
  - Woody and upright (with an angle that is greater than 45 degrees from the ground), **or**
  - Woody and with 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 will be accounted for in plant diversity sampling.

A.2 Procedure

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.
   - 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.

- 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 on plot metadata datasheet (perplotperyear table in mobile app).
    - If executing this protocol in a 20 m x 20 m plot, a sum of, at minimum, 20 cacti are required within each nested subplots for the nested subplot size chosen.
    - If executing this protocol in a 40 m x 40 m plot, then a minimum of 20 cacti are required in each of the nested subplots of at least one of the two randomly selected subplots.
4. For each plot, record:
    - **plotID:** *SITE_###*
    - **date:** *YYYYMMDD*
    - **nestedSubplotAreaOther:** This is the nested subplot area as defined in SOP C in RD[04], *### m^2*
    - **totalAreaSampledOther:** This is the subplot or nestedSubplotArea multiplied by the number of subplots surveyed.
        - **Ex.** If plotSize = 40m x 40m and no nestedSubplotArea is used, all of the two randomly selected subplot are surveyed, totalAreaSampled = 800
    - **measuredBy:** Name of the technician making measurements, email address
    - **recordedBy:** Name of the technician recording data, email address
    -
5. Tagging new individuals: Tag all qualifying cacti encountered within the selected measurement area except specimens in the `pads` shape category (see **Table 3**).
    - Tag with a unique aluminum ID tag for repeat measurements
    - Attach tag to a pigtail stake
    - Place the pigtail stake in the ground within 5 cm of a cactus stem. For the ease of finding the tag at a later time, place pigtails on the same side of the cactus for every specimen
    - Be consistent with tag placement for cacti. It may be useful to tag consistent with vegetation structure methods of tagging for your site.

      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.
    - Record new tagIDs in the SOP B: Mapping and Tagging datasheet

6. Biomass measurements: For each qualifying cactus encountered, record:
   a. **subplotID:** number of the subplot in which the plant is located, ##, (see **Figure 1**)
   b. **nestedSubplotID:** unique identifier of the nested subplot - assigned on a per-subplot basis, #, (see **Figure 1**)
   c. **tagID:** domain level unique identifier, ####, null for untagged individuals.
   d. **taxonID** and **identificationQualifer (Table 5)** code if needed**:** USDA plant species code, e.g., *OPPO (Opuntia polyacantha), CYFU10 (Cylindropuntia fulgida), etc.*

      - The **taxonID** should be a code from the NEON master list of plant species codes (found in the 'taxonTables' supplied by NEON Science Operations, and qualified according to technician confidence (**Table 5**).
      - Technicians are strongly encouraged to use ONLY the NEON master code on all datasheets. 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.
      - 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 shrub group may contain multiple species from a given genus. When one of these genus-level codes is selected, an identification qualifier is not needed, unless for example, the genus is uncertain.
        - 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 reported in **taxonID**.
      - Morphospecies:
        - The use of morphospecies IDs is expected during the course of this work. If the domain staff are able to identify a morphospecies at a later time, the full scientific name associated with that ID must be provided with the data sheet, either via attaching a key, or via annotation (see RD[07]).
        - If domain staff is not able to identify a given morphospecies prior to data entry, the morphospecies ID must be recorded in the controlled morphospecies ID list.
      - Cryptic species:
        - Issues with cryptic species may arise if two morphologically similar species may co-occur at a given site. To account for this, members of cryptic pairs or groups should

be added to NEON master taxon lists. New pairs / groups must be entered in the 'crypticSpeciesGroups' controlled spreadsheet.

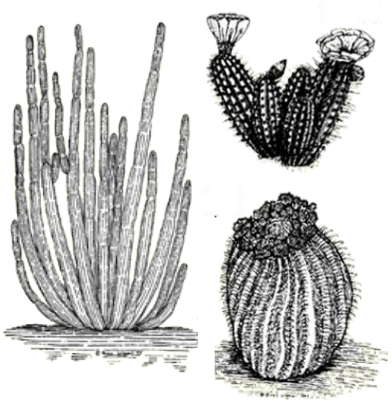
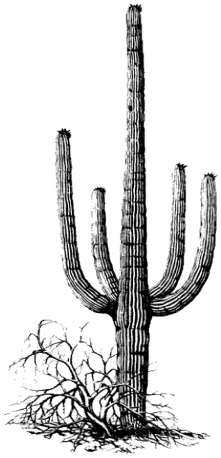
e. **identificationReferences:** If a taxonomic key is used to identify the individual, record, last name(s) of author(s)

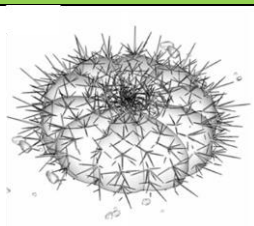
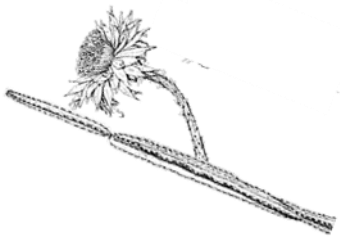
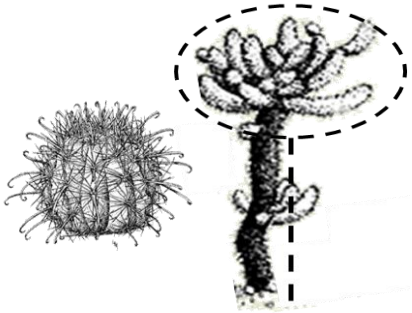
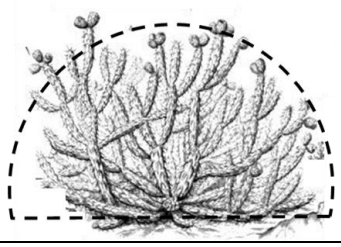
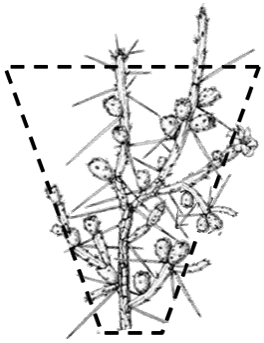
- if no references are used for identification, leave this field blank

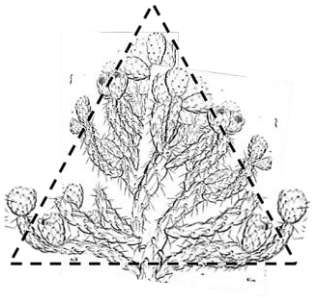
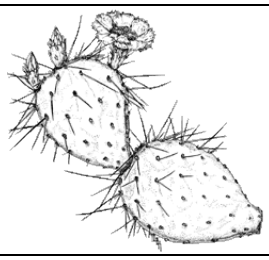
f. **shape:** the form that the cactus takes that determines the required measurements.

- To determine the appropriate shape, consult **Table 3,** then match selected shape and required fields in **Table 4**.
- Make a determination of shape based on the individual being measured; shape is not necessarily consistent within a particular species.

Table 3. 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.*
Columnar **taxonID** = CAGI10	**col**	Species-specific measurements for Saguaro.		*Carnegiea gigantea*

shape	Code*	Definition	Example shapes†	Example Genera
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.*
Sphere or ellipsoid	**eph**	Single stems spherical in shape OR cluster of segmented stems elevated on central stalk		*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.*

shape	Code*	Definition	Example shapes†	Example Genera
Cone	**cne**	Cluster of segmented stems that, as a group, approximately form a cone shape.		*Cylindropuntia sp.*
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 4. Structure Measurements. Shape determines which measurements are required.

Shape	status	height‡	maxDiameter	ninetyDiameter	baseCrown Height	basalStem Diameter	measurement Height	baseCrown MaximumDiam	baseCrown NinetyDiameter	newPadCount	oldPadCount	stemCount	branchCount	averageBranch Length	averageBasal Diameter
Columnar	x	x										x			x
Columnar Saguaro§	x	x				x							x	x	
Oblate half sphere	x	x	x	x											
Vine	x												x	x	
Sphere or ellipsoid	x	x	x	x	x	x	x								
Half sphere	x	x	x	x											
Inverted cone	x	x	x	x				x	x						
Cone	x	x	x	x											
Cylinder	x	x	x	x											
Pad (*Opuntia*)	x									x	x				

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

§ Required measurements are based on (Steenbergh 1972, Niklas 2002)

Table 5. 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

7. After **shape** has been assigned, determine which of the measurements listed in **Table 6** must be recorded for the current individual:

Table 6. 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, average height for multi-stem individuals, measured using folding ruler, laser rangefinder, or measuring tape, 0.1 m, (see **Figure 5**).
maxDiameter	Largest diameter of canopy or stem, depending on which is larger, measured using calipers or folding ruler, 0.1 m, (see **Figure 2**)
ninetyDiameter	Diameter at 90˚ to maxDiameter measured using calipers or folding ruler, 0.1 m, (see **Figure 2**)
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, 0.1m
measurementHeight	The height at which the diameter is measured, soil surface = 0 cm, 1 cm
baseCrownMaximumDiameter	Maximum diameter of the base of individuals in the inverted cone shape category, measuring tape, folding ruler or laser rangefinder, 1 cm,(see **Figure 2**)
baseCrownNinetyDiameter	90 degrees measurement of the maxBasalDiameter for individuals in the inverted cone shape category, 1 cm, (see **Figure 2**)
newPadCount	Number of cladodes, of any size, produced in the current growing season (see **Figure 4**). Count vegetative, non-flowering, pads only.
oldPadCount	Number of cladodes produced in previous growing seasons (see **Figure 4**)

Variable	Detailed description
stemCount	Number of stems in a multi-stem columnar cluster (see **Figure 3**)
averageBranchLength	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 average of all branch lengths, and report to the nearest 0.1 m; see **Figure 5** for examples of how to measure complicated branch lengths
averageBasalDiameter	Use calipers to measure the basal diameter of each stem at ground level. Calculate the average 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, nearest 0.1 m, (see **Figure 5**)
status	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 7**)

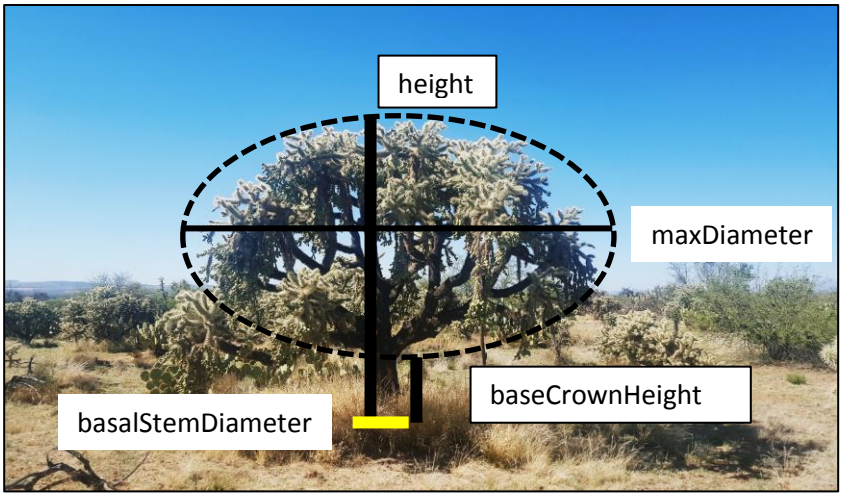


Figure 2. *Cylindropuntia fulgida* in the eph shape category illustrating where to take measurements. Measure basalStemDiameter (yellow line) at the ground level; maxDiameter (black line) and ninetyDiameter across the canopy; baseCrownHeight (green line) from the ground to the beginning of the canopy. Photo by Sienna Hiebert.

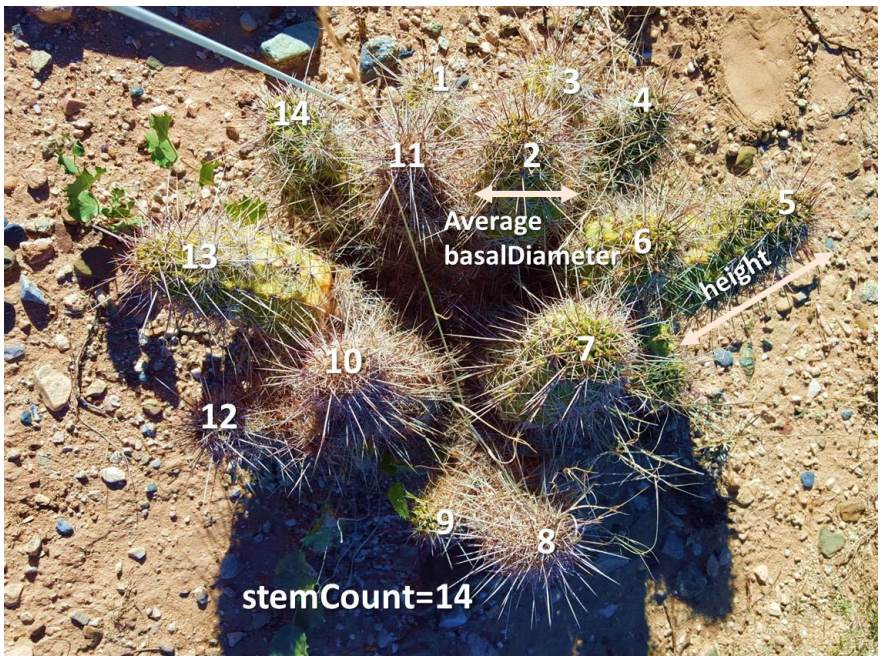


Figure 3. *Echinocereus sp*. illustrating a multi-stem columnar cacti in which one measures the height (in this case, the average height of all stems), averageBasalDiameter, and stemCount. Photo by Sienna Hiebert.

Figure 4. *Opuntia sp.* with new vegetative pads growing off of an old pad. In this picture newPadCount = 3 and oldPadCount = 1.

Table 7. Status value definitions. For damaged individuals (codes 4-7), if the source of the damage cannot be determined, record as Damaged – other, include remarks describing damage.

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

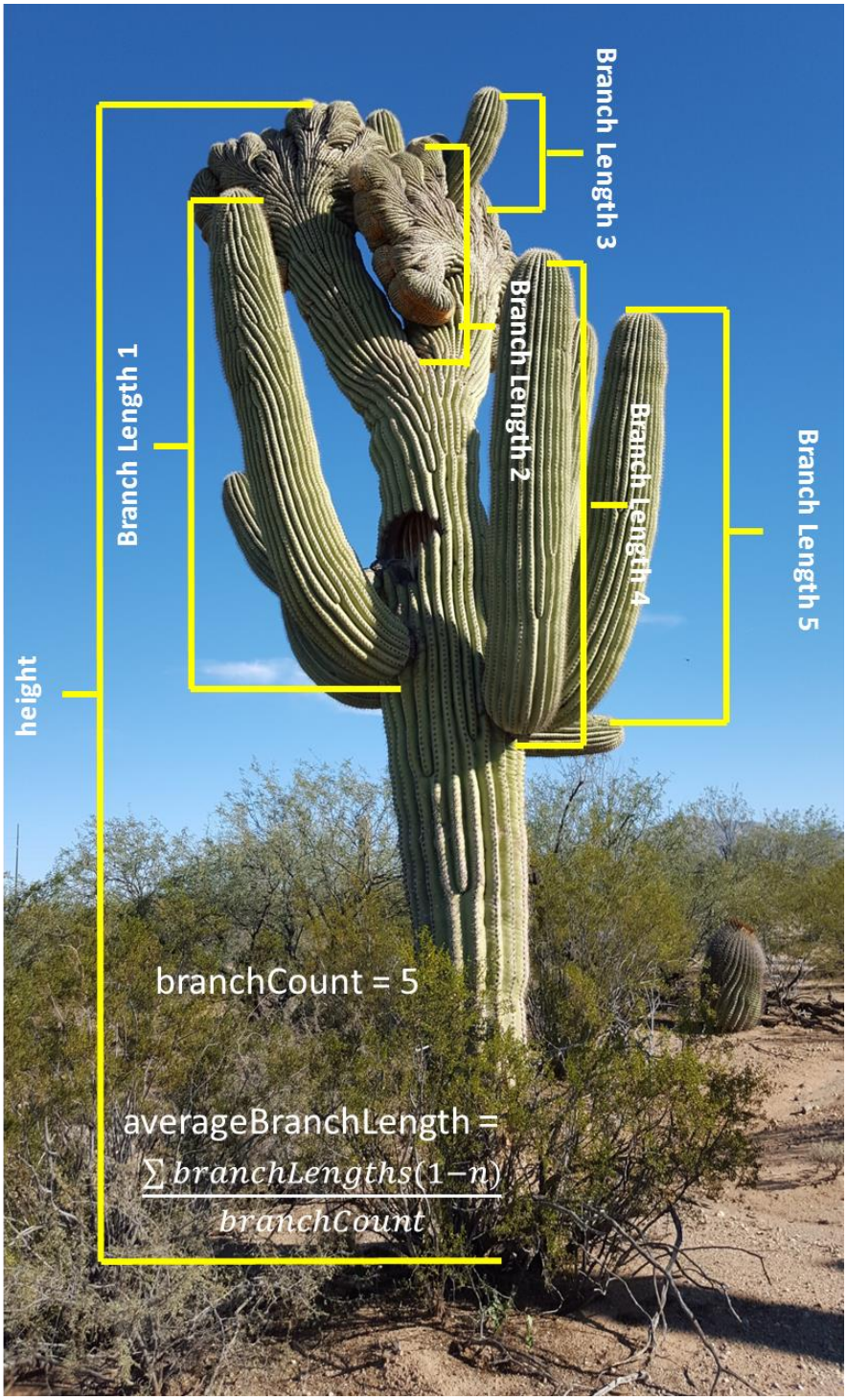


Figure 5. Branch length measurement (measure along the stem) in *Carnegiea gigantea*. Measure each branch then average the length of all branches. Enter that value in the averageBranchLength data field. For cacti that have become cristate like in this picture, note "crested" in the **remarks** field. Photo by Sienna Hiebert.

7 REFERENCES

Dimmitt, M. A. 2000. Cactaceae (cactus family). Page 628 *in* S. J. Phillips and Comus, editors. A Natural History of the Sonoran Desert. Arizona-Sonora Desert Museum. Arizona-Sonora Desert Museum Press, Tucson, Arizona, and University of California Press, Berkeley, California.

Engelmann, G., and J. M. Bigelow. 1856. The Botany of the Expedition: Description of the Cactaceae. Pages 1–58. Explorations and surveys for a railroad route from the Mississippi River to the Pacific Ocean. Route near the twenty-fifth parallel, Explored by Lieutenant A. W. Whipple, Topographical Engineers, in 1853 and 1854., War Department, Washington, D. C.

Molina-Freaner, F., C. Tinoco-Ojanguren, and K. Niklas. 1998. Stem biomechanics of three columnar cacti from the Sonoran Desert. American Journal of Botany 85:1082–1082.

Niklas, K. J. 2002. On the allometry of biomass partitioning and light harvesting for plants with leafless stems. Journal of theoretical biology 217:47–52.

Steenbergh, W. F. 1972. Lightning-caused destruction in a desert plant community. The Southwestern Naturalist:419–429.

APPENDIX A QUICK REFERENCES

Quick Reference: Making Quality Measurements of Cactaceae

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 on datasheet.

Step 6 – Tag qualifying species.

Step 7 – Take and record biomass measurements.

Step 8 – Remove temporary flagging.

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

APPENDIX B REMINDERS

Making quality measurements of vegetation structure

Measurement Area: Make sure 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 on datasheet.

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 ESTIMATED DATES FOR ONSET AND CESSATION OF SAMPLING

The dates in **Table 8** below are based on historic records and estimated from MODIS-EVI phenology data averaged from 2001-2009, 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. All dates are provided in day-of year format. The sites included in **Table 8** are only sites where cacti are expected to be. If cacti exist at a site that is not included on **Table 8**, 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 8. 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	Additional Sampling Information
03	DSNY	190	60	
	JERC	220	90	
	OSBS	190	70	
04	GUAN	Any	60d after start	Start Date should be consistent from year to year (± 2 weeks). Target taxa present.
10	CPER	210	90	Target taxa present.
	RMNP	210	120	
11	CLBJ	180	60	
	KLEM	NA	NA	
13	MOAB	225	85	
14	JORN	245	80	Target taxa present.
	SRER	240	150	Target taxa present.
15	ONAQ	170	75	