TOS PROTOCOL AND PROCEDURE: MEASUREMENT OF LEAF AREA INDEX

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Change Record

REVISION	DATE	ECO #	DESCRIPTION OF CHANGE
A_DRAFT	10/03/2011	ECO-00280	Initial Draft Release
B	01/13/2014	ECO-01140	Updates from 2013. Will be finalized in next rev
C	03/25/2014	ECO-01665	Production release, template change, and other changes as detailed in Appendix C (rev C only)
D	04/10/2014	ECO-01792	Added Appendix C with site-specific information
E	11/03/2014	ECO-02386	Migration to new protocol template, changes to histogram interpretation and optimizing exposure for upward-facing images.
F	04/14/2015	ECO-02559	Update of TOS protocol based on 2014 field experience and budget analysis.
G	9/16/2015	ECO-03118	Major revisions: • Updated downward-facing camera settings in Table 9 • Added standardized data entry and safety text • New histogram figures, and histogram interpretations in Table 12 • Added camera memory card configuration options to SOP A • Removed Appendix E, DSLR configuration, due to forthcoming DSLR Configuration SOP
H	03/20/2017	ECO-04391	Major revisions: • Clarified text in Section 4 about when to delete partial sets of images as a consequence of a delay. • New SOP C.2.1: Added instructions for using an Extended Monopole to take downward-facing photos when vegetation is too tall for shoulder height. • Added site-specific timing information for D03, D04, D17 and D20. • Removed CanEye image anlysis SOPs (previously SOPs F and G) – image analysis is no longer part of the Leaf Area Index data product • Updated Appendix C with current site list, and added sampling dates for year-round sites; changed dates from DOY to MM/DD format. Removed DOY conversion calendars. • Clarified use of 'hard stop' of Nov 1st for sampling in Section 4, and updated Appendix C to reflect per site implementation of 'hard stop' date.

REVISION	DATE	ECO #	DESCRIPTION OF CHANGE
J	11/15/2017	ECO-05151	Major revisions: • Section 6.4, Estimated Time: Added table that includes time estimates for all SOPs, rather than just field SOPs. • SOP E, Troubleshooting: Added guidance for upward-facing photos when snow covers foliage. • SOP F.1, DHP Handling: New workflow guidance for DHP Checker application, photo upload to cloud storage. • SOP G, Data Entry: Added reference to Fulcrum User Manual for DHP app, re-organized to incorporate guidance for digital workflow.

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1 OVERVIEW

1.1 Background

Leaf area index (LAI) is a useful proxy variable for numerous other variables of ecological interest including plant biomass, plant productivity, forage quality, carbon balance, ecosystem energy flux, plant density, and the heterogeneity of plant cover. LAI is also used widely as a key input variable to models that seek to predict ecological processes such as carbon cycling. Regional to continental scale estimates of LAI are typically derived from satellite data, but validation of satellite data with aircraft and ground-collected data is relatively uncommon. By leveraging NEON's aircraft and ground-collected estimates of LAI, it will be possible to develop ground-validated estimates of LAI at the continental scale.

There are numerous methods available for estimating LAI, and these fall into two general categories: direct and indirect. Direct methods are conceptually the most straightforward, and involve the destructive harvest and measurement of individual leaves from selected plants. Direct methods are also laborious relative to indirect methods, and as such, are not suitable for further consideration given the budgetary and logistical concerns that these methods pose at the continental scale of the Observatory. With indirect methods, on the other hand, it is possible to rapidly and non-destructively estimate LAI using a variety of optical instruments that measure the canopy gap-fraction, and then mathematically relate the gap-fraction to LAI.

NEON is using the Digital Hemispherical Photo (DHP) system (aka fisheye photos) to estimate LAI, since it is rapid and non-destructive. The image-derived gap-fraction (i.e., the proportion of visible sky, un-obscured by vegetation, calculated as a function of the direction of sky relative to image center) of a DHP is then used to calculate LAI. The benefits of using a DHP system include: 1) measurements of LAI in systems with tall woody stems are economical and efficient for field technicians to carry out; 2) measurement of low-stature vegetation – e.g. short-grass steppe – is possible without interfering with the vegetation itself during data collection; 3) because the data produced by the DHP method are in the form of an image file, it is straightforward to perform QA/QC both in the field and at NEON HQ; and 4) as data analysis algorithms evolve in the future, digital images are readily archived and can easily be re-analyzed for LAI by the user community as desired.

1.2 Scope

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

1.2.1 NEON Science Requirements and Data Products

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

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

1.3 Acknowledgments

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	EHSS Policy, Program and Management Plan
AD[02]	NEON.DOC.004316	Operations Field Safety and Security Plan
AD[03]	NEON.DOC.000724	Domain Chemical Hygiene Plan and Biosafety Manual
AD[05]	NEON.DOC.050005	Field Operations Job Instruction Training Plan
AD[06]	NEON.DOC.000914	TOS Science Design for Plant Biomass, Productivity, and Leaf Area Index
AD[07]	NEON.DOC.014051	Field Audit Plan

2.2 Reference Documents

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

RD[01]	NEON.DOC.000008	NEON Acronym List
RD[02]	NEON.DOC.000243	NEON Glossary of Terms
RD[03]	NEON.DOC.005003	NEON Scientific Data Products Catalog
RD[04]	NEON.DOC.001271	AOS/TOS Protocol and Procedure: Data Management
RD[05]	NEON.DOC.001575	Datasheets for TOS Protocol and Procedure: Measurement of Leaf Area Index
RD[06]	NEON.DOC.001398	NEON Raw Data Ingest Workbook for TOS Digital Hemispherical Photos
RD[07]	NEON.DOC.001236	NEON Algorithm Theoretical Basis Document: TOS Leaf Area Index - QA/QC of Digital Hemispherical Photos
RD[08]	NEON.DOC.001718	TOS SOP: DSLR Camera Use and Settings

2.3 Acronyms

Acronym	Definition
DHP	Digital Hemispherical Photo
DOY	Day of Year
DSLR	Digital Single Lens Reflex [camera]
LAI	Leaf Area Index
NDVI	Normalized Differential Vegetation Index (a proxy for vegetation greenness)

2.4 Definitions

N/A

3 METHOD

There are two high-level components to this LAI data collection protocol, which serve to capture LAI data across space and through time: 1) data are collected on the ground every 3 years from Distributed and Gradient plots, and these data are used in conjunction with AOP LAI data products to estimate LAI at the site scale; and 2) data are collected every two weeks from a subset of Tower plots (n=3) that will be used to construct a time-series dataset that will complement the spatially-extensive snapshot of LAI generated from AOP data.

The plotIDs for the Distributed and Gradient plots that will be used for LAI sampling will be provided by Science Operations. In order to speed data collection from Tower Plots, those plots selected for LAI time series measurements should be the three plots that are closest to, or most readily accessed from, roads near the TIS Tower, as determined by Field Operations. For more details of the LAI spatial and temporal sampling strategy, see the Plant Biomass and Productivity Science Design (AD[06]).

Digital hemispherical photos are taken at 12 points within each of the specified plots, and these photo points radiate outward from the plot center in the cardinal directions (Figure 1). Collection of quality LAI data with a DHP system at each point-location is highly dependent on taking the hemispherical photos in appropriate light conditions, and on properly exposing the images. If vegetation is on average shorter than waist height (roughly 1 m), downward-facing images will suffice for a given plot (Table 8); the goal is to maintain a minimum distance of approximately 50 cm between the lens and the vegetation for the 'average' technician height. Otherwise, extended monopole and/or upward-facing images are employed to properly capture LAI for the plot. In the laboratory, image files are organized according to a series of nested subfolders, checked for matching metadata collected in the field, and moved to a network location for automatic syncing with a NEON cloud-storage location. Sets of images are then available for plot- and point-level LAI analysis by NEON's data end-users.

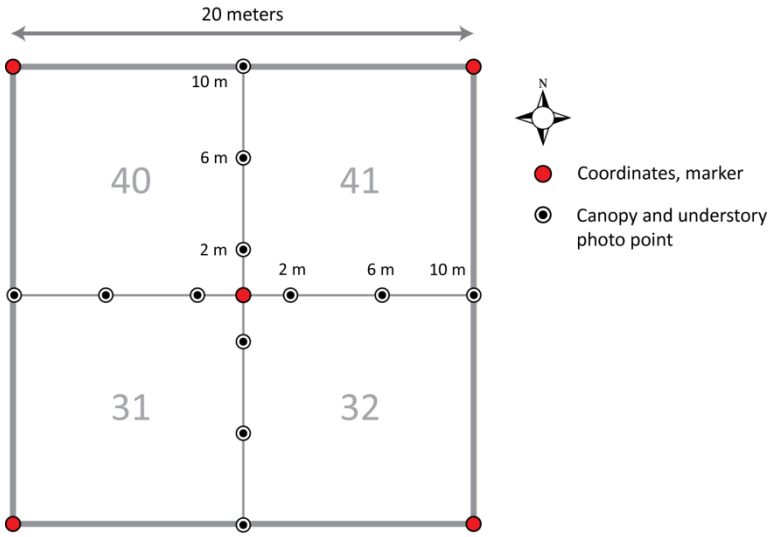

Figure 1. Distributed base plot (or 20 m x 20 m Tower plot) showing the location and spacing of DHP photo points relative to plot center; grey numbers represent subplotIDs. Spacing between points and number of points is the same for both 20 m x 20 m and 40 m x 40 m Tower plots, and photo points are always centered on the plot centroid.

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

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

The procedures described in this protocol will be audited according to the Field Audit Plan (AD[07]). Additional quality assurance will be performed on data collected via these procedures according to the NEON Algorithm Theoretical Basis Document: TOS Leaf Area Index - QA/QC of Digital Hemispherical Photos (RD[07]).

4 SAMPLING SCHEDULE

4.1 Sampling Frequency and Timing

The frequency and timing of DHP image collection depends on whether Distributed/Gradient plots will be sampled, or whether Tower plots will be sampled (Table 1).

Table 1. Number of plots and sampling frequency guidelines for DHP collection in Distributed/Gradient and Tower plots.

Plot type	Plot Number	Sampling Events	Yearly Interval
Distributed plot	n ≤ 20	1X per sampling year	Every 3 y.
Gradient plot	n ≤ 5	1X per sampling year	Every 3 y; sampled concomitantly with Distributed plots at a given site.
Tower plot	n = 3	* Every 2 weeks	Annual

* Should sampling events for Distributed/Gradient plots and Tower plots overlap, simultaneous sampling may not be possible if sufficient camera bodies and fisheye lenses are not available. Should this event arise, prioritize sampling Distributed/Gradient plots over Tower plots.

4.2 Criteria for Determining Onset and Cessation of Sampling

Onset and cessation of DHP image collection depends on whether Distributed/Gradient plots will be sampled, or whether Tower plots will be sampled (Table 2).

Table 2. Number of plots and sampling start/stop guidelines for DHP collection in Distributed/Gradient and Tower plots.

Plot type	Plot Number	Sampling Start	Sampling Stop
Distributed plot	n ≤ 20	Start date must be chosen such that sampling is completed within a 1 month window that includes the AOP flight date (or beginning of flight date range)[1, 2]	1 month after sampling Start Date.
Gradient plot	n ≤ 5	Same as Distributed plots	Same as Distributed plots
Tower plot	n = 3	Start of growing season, as new leaves and needles become visible and begin to expand[2]	Site-specific sampling stop dates are provided in Appendix C. Except at sites with year-round sampling, dates correspond to whichever comes first: 1. DOY > 305 (1st November) 2. Site-specific NDVI returns to pre-growing-season level[3]

[1] Provided the flight date (or range of possible dates) is confirmed and not subject to change more than ± 1 week. If no AOP flight is scheduled in a given year, postpone ground LAI sampling at Distributed and Gradient plots to the next year in which an AOP flight is scheduled. The annual schedule for AOP flights is provided by Science Operations, and Domain Managers should communicate with AOP managers to keep abreast of current flight plans.

[2] D04 exception: Distributed Plots in Puerto Rico are scheduled without reference to AOP.

[2] Based on multi-year averages; dates provided by Field Operations. Field Operations may also rely on phenology observations made on the indicator individuals to inform start of LAI sampling.
[3] Determined by Science Operations (Appendix C).

It is the responsibility of Field Operations to determine the exact timing of sampling within a given day.

4.3 Timing for DHP Image Transfer

Once DHPs have been collected for a given sampling bout, they must first be organized into directories according to SOP F.1, then copied to an approved network location in the Domain Support Facility (DSF) for electronic transfer and ingest into NEON's centralized cloud storage system. Image copying and organization should take place as soon as possible after completion of sampling in the field.

Because image file sizes are relatively large, and syncing to NEON cloud storage can be slow, be sure to copy, organize, and transfer bouts of DHPs as they are collected, rather than waiting for multiple bouts of DHPs to accrue.

4.4 Sampling Timing Contingencies

When unexpected field conditions require deviations from this protocol, the guidance provided here must be followed to ensure that basic data quality standards are met (Table 3). For delays ≤ 7 days , it is acceptable to take a complete set of upward-facing photos, delete a partial image set of downward-facing photos caused by the delay (i.e., delete the downward-facing image set with < 12 images), then return after a delay and take a complete set of downward-facing photos (or vice versa).

Table 3. Contingency decisions relevant to collection of DHPs in the field.

Delay/Situation	Action	Outcome for Data Products
Hours	If 1) Delay interrupts data collection mid-plot: a) stop data collection for the plot, and **delete** partial image sets – i.e., delete images if the delay prevented a full set of 12 upward- or downward-facing photos from being collected; b) upon resuming, ensure light conditions are favorable; and c) repeat data collection for interrupted image set(s) on the same day if possible.	A delay of hours can lead to poor light conditions for collection of LAI data. This can lead to overestimation or imprecise estimation of LAI.
	If 2) Delay occurs between plots: a) Ensure light conditions are favorable for data collection; and b) resume data collection for next plot.	A delay of hours can lead to poor light conditions for collection of LAI data. This can lead to overestimation or imprecise estimation of LAI.
1-7 days	If 1) Delay interrupts data collection mid-plot:	None

Delay/Situation	Action	Outcome for Data Products
	a) stop data collection for the plot, and **delete** partial image sets – i.e., delete images if the delay prevented a full set of 12 upward- or downward-facing photos from being collected; b) on the next possible sampling day within 7 days of the delay, ensure light conditions are favorable; and c) repeat data collection for interrupted image set(s).	
	If 2) Delay occurs between plots: a) Return to the field ASAP; b) ensure light conditions are favorable for data collection from an entire plot; and c) resume data collection for the next plot.	None
8+ days	If 1) Delay interrupts data collection mid-plot: a) stop data collection for the plot, and **delete** partial image sets – i.e., delete images if the delay prevented a full set of 12 upward- or downward-facing photos from being collected; b) for Tower Plots, skip sampling for current boutID and continue sampling as part of the next boutID. c) For Distributed Plots, return to sampling as soon as possible.	Decreased sample size resulting in imprecise estimation of LAI.
	If 2) Delay occurs between plots: a) For Tower Plots, skip sampling for current boutID and continue sampling as part of the next boutID; and b) For Distributed Plots, return to sampling as soon as possible.	Decreased sample size

5 SAFETY

This document identifies procedure-specific safety hazards and associated safety requirements. It does not describe general safety practices or site-specific safety practices.

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

Because DHP images are often collected in the field at dawn or dusk, it is advisable to bring a headlamp to aid navigation between plots.

Make sure headlamp is turned off during data collection!

6 PERSONNEL AND EQUIPMENT

6.1 Equipment

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

Table 4. Equipment list – A team of two people collecting DHPs from a plot

Item No.	R/S	Description	Purpose	Quantity*	Special Handling
Durable Items					
MX100320	R	Compass with mirror and declination adjustment	Orient to image locations	1	N
MX104649	R	DSLR camera body	Capture DHP images	1	N
MX104654	R	DSLR memory card (16 Gb minimum)	Store and backup DHP images on camera	2	N
MX104651	R	Fisheye lens	Capture DHP images	1	N
MX100703	S	GPS receiver, recreational accuracy	Navigate to sampling location	1	N
MX101632	S	Headlamp	Hands-free lighting at dusk and dawn	2	N
MX100322	S	Laser rangefinder	Measure overstory height	1	N

Item No.	R/S	Description	Purpose	Quantity*	Special Handling
	S	Microfiber or paper lens cleaning cloth	Clean camera lens	1	N
MX109639	S	Wireless remote shutter release (Vello FreeWave Plus for Nikon or similar)	Remotely focus camera and trip shutter release on Nikon D800/D810 camera models	1	N
MX111179	S	Nikon wireless shutter release	Remotely focus camera and trip shutter release (D750 only)	1	N
	S	U-bolt with rubber feet	Affix to monopod to enable camera to be held above the ground surface when shooting upward-facing photos from ground level	1	N
MX111181	R	Ball-head tripod mount	Attach to monopod for downward-facing 'extended monopod' photos of mid-stature vegetation	1	N
Consumable items					
	S	AA battery	Spare battery for GPS receiver		
MX104653	R	EN-EL15 lithium ion battery	Spare battery for DSLR camera	2	N
MX104659	R	Camera bag	Protect DSLR camera body and lenses	1	N
MX104736	R	Camera monopod	Hold camera steady away from body	1	N

Item No.	R/S	Description	Purpose	Quantity*	Special Handling
Resources					
RD[05]	R	LAI field data sheet	Record sampling event metadata in the event of tablet failure	Varies	N

R/S=Required/Suggested

Table 5. Equipment list –Transferring DHPs from the camera to the server, and handling field-collected sampling metadata

Item No.	R/S	Description	Purpose	Quantity	Special Handling
Durable items					
MX104654	R	DSLR memory card	Contains field-collected DHPs	2	N
MX104657	R	DSLR memory card reader	Transfer images from memory card to Domain Support Facility temporary storage following sampling event	1	N
Resources					
RD[05]	R	Completed LAI field datasheets	Contains field-collected DHP metadata	Varies	N
	R	Disk storage	Available disk space to temporarily store and backup images before they are transferred to NEON cloud storage, laptop hard drive, external drive, USB drive, or equivalent.	1	N

R/S=Required/Suggested

6.2 Training Requirements

All technicians must:

- Complete required safety training and protocol-specific training for safety and implementation of this protocol as required in Field Operations Job Instruction Training Plan (AD[05]).
- Be trained to configure, use, and care for the DSLR system when acquiring high-quality hemispherical photos.
- Be trained to properly use a mirror-site compass, including looking up and setting the appropriate declination.
    - Declination changes with time at each site, and should be looked up annually at http://www.ngdc.noaa.gov/geomag-web/.
- Be trained to calibrate pacing, to repeatably pace off accurate distances in the field.

6.3 Specialized Skills

For image acquisition in the field, it is required that one technician have a proficient, working knowledge of manual image exposure, and evaluation of image exposure with the specified camera hardware. Technicians must become familiar with camera hardware and techniques to obtain proper image exposure prior to data collection in the field.

6.4 Estimated Time

The time required to implement a protocol will vary depending on a number of factors, such as skill level, system diversity, environmental conditions, and distance between sample plots. The timeframes provided below are estimates based on completion of a task by skilled technicians (i.e., not the time it takes at the beginning of the field season). Use this estimate as framework for assessing progress. If a task is taking significantly longer than the estimated time, a problem ticket should be submitted.

Table 6. Estimated staff and labor hours required for implementation of Measurement of Leaf Area Index SOPs.

SOP	Estimated time	Suggested staff	Total person hours
SOP A: Preparing for Sampling (DSF)	0.5 h	1	0.5 h
SOP B: Field Sampling Prep	0.25 h	2	0.5 h
SOP C: Field Sampling, downward-facing DHPs	0.25 h per plot	2	0.5 h per plot
SOP D: Field Sampling, upward-facing DHPs	0.25 h per plot	2	0.5 h per plot
SOP E: Post-Sampling Tasks	0.75 h	1	0.75 h

7 STANDARD OPERATING PROCEDURES

SOP A Preparing for Sampling

1. Prepare equipment and materials as specified in **Table 4**.
2. Configure the DSLR for DHP image acquisition according to settings below (**Table 7**). More detailed instructions are included in the TOS SOP: DSLR Camera Use and Settings (RD[08]).

Table 7. Desired Nikon DSLR settings for collecting DHPs in the field. Details in the 'How to Change' field are specific to the Nikon D800/D810; for additional camera models see RD[08].

Camera Parameter	Desired Setting	How to Change
Image quality	RAW, compressed Bit-depth = 12	"QUAL" button, primary wheel
White balance	Auto (A)	"WB" button, primary wheel
Shutter Mode	Single shot (S)	Left knob, outer ring
Metering Mode	Matrix	Back knob, upper-right
Focus Mode	Auto-area Auto Focus (AF-S auto)	Focus switch/button, primary and secondary wheels
Playback display options	Overview	Playback Menu
File naming	DXX (where XX is NEON Domain number)	Shooting Menu
Color space	sRGB	Shooting Menu
Active D-lighting	Auto	Shooting Menu
High ISO NR	Normal	Shooting Menu
ISO sensitivity settings	Auto-ISO sensitivity control = ON Maximum sensitivity = 12,800 Minimum shutter speed = 1/30	Shooting Menu
Time Zone and Date	Time Zone = Domain specific Date and Time = Current local (24h format) Date Format = Y/M/D Daylight Savings = current local	Setup Menu
Card options	Save images to both cards simultaneously	Shooting Menu

A.1 Scheduling the field day

The following timing considerations arise with respect to collecting high-quality LAI data on a given day:

- DHP images should not be collected when water droplets will form on the lens (i.e. it is raining, misting, there is heavy condensation, etc.). Check the local weather forecast prior to initiating field work to ensure that data collection will be possible.
- **Upward-facing DHPs must only be collected when direct sunlight is NOT visible on the foliage.** That is, upward facing images may be acquired during an approximately 45 min period at dawn or dusk, or any time during the day when it is sufficiently overcast such that a person does not cast a visible shadow. Sites at extreme latitude may not experience traditional sunrise/sunset during summer months, see guidelines in Appendix E.
- Downward-facing DHPs may be collected either with or without sunlight on the foliage. However, target times of day to avoid situations that generate deep shadows. If possible, select overcast or mid-day conditions when shadows are minimal. **DO NOT take downward-facing images either before the sun has come up or after the sun has set.** Shadows and low-light make it difficult to distinguish green from brown colors during image analysis.
- On a given measurement day, plan on arriving at the location of the first plot to be measured at least 20 minutes before light conditions are appropriate.

A.2 Prepare equipment

The following preparatory actions may need to be taken:

- **Mobile device**: Synchronize with cloud
- **Micro-fiber lens cleaning cloth**: Clean soiled cloth if necessary.
- **DSLR fisheye lens**: Clean with lens cloth if necessary.
- **DSLR batteries**: Charge.
- **DSLR memory card**: Check that any images on memory card are backed up, and empty memory cards of pre-existing images.
- **GPS unit**: Charge and load target plot locations.
- **Headlamp**: Check batteries.
- **Compass**: Check/set correct declination.
    - Declination changes with time and should be looked up annually per site: http://www.ngdc.noaa.gov/geomag-web/
- **Meter tape**: Calibrate technician pacing: determine # paces equivalent to 4 m (distance between photo points).
    - Being able to repeatedly pace off accurate distances in the field will speed collection of LAI data, compared to laying out a meter tape in two directions for guidance at each plot.
- **LAI field datasheets** (RD[05]): Print.
    - The LAI field datasheet is provided as a companion document, and is intended as backup for standard data collection via mobile device.

SOP B Field Sampling: Preparing to Collect DHPs from a Plot

- Keep an eye on lighting conditions. They may change while images are being acquired.
- Place backpacks and other gear outside the plot and out of the potential field of view of the camera.
- Record plot-level sampling metadata data:
    - **boutNumber** = a two digit number assigned by Field Operations.
    - For Tower Plots, boutNumber starts over with boutNumber = 01 at the beginning of each calendar year, and increments sequentially throughout the season for each scheduled Tower Plot sampling bout.
    - For Distributed/Gradient plots, always assign boutNumber = 00.

RECORDING A MISSED TOWER PLOT BOUT

- If a Tower Plot bout is missed, skip the missed boutNumber, and assign the next boutNumber in the sequence when the next bout occurs.
    - *Example:* If boutNumber = 02 is skipped at WREF, the sequence would be: 01, 03, 04, etc.
- This will ensure it is clear to end-users that a bout was missed.

B.1 Determining camera orientation and height

- To decide which combination of camera orientation and camera position are required for a given plot, visually survey the vegetation structure in the entire plot and refer to Table 8.
- The camera position may change throughout the year for a given plot if fast-growing herbaceous plants are present – e.g. in tall-stature grasslands or croplands it will make sense to shift from shoulder-height downward-facing photos to extended-monopod downward-facing photos as plants grow.
- Record the following in the LAI Field ingest table (RD[05]).
    - **understoryHeight** = visually estimated average understory height for the entire plot, recorded to the nearest 0.1 m
    - **overstoryHeight** = visually estimated average overstory height for the entire plot, recorded to the nearest 1 m (Note: A rangefinder may be used for this purpose, but is optional, as the accuracy is not required for this measurement).

Table 8. Guidelines for determining proper camera positioning when taking DHPs.

Understory Vegetation[1]	Overstory Vegetation	Required Camera Orientations	Camera Position(s)[2]	Protocol Reference

Understory Vegetation[1]	Overstory Vegetation	Required Camera Orientations	Camera Position(s)[2]	Protocol Reference
Majority < 0.75–1 m height	None	Single downward-facing photo per point	Shoulder height	SOP C
Majority < 0.75 – 1 m height	Majority < 2 m height	Single downward-facing photo per point	Extended monopod	SOP C
Majority > 0.75 – 1 m height	None	Single downward-facing photo per point	Extended monopod	SOP C
Majority > 0.75–1m height	Majority < 3 m height	Upward and downward-facing photos per point	Shoulder height (upward) and extended monopod (downward)	SOP C & SOP D
Majority < 0.75–1m height	Majority > 3 m height	Upward and downward-facing photos per point	Shoulder height	SOP C & SOP D
Majority > 0.75–1m height	Majority > 3 m height	Upward and downward-facing photos per point	Shoulder height (upward) and extended monopod (downward)	SOP C & SOP D

[1] >50% of vegetation is characterized by the specified height criteria. For shoulder height camera position, height criteria is based on desired 50 cm minimum distance of vegetation from the camera lens.

[2] See Figure 7 for an example of a researcher holding a camera at shoulder height

SOP C Field Sampling: Downward-Facing DHPs

C.1 Image acquisition guidelines

Configure the camera for acquiring downward-facing DHPs according to the settings specified in Table 9. Consult RD[08] for detailed instructions on how to configure the DSLR.

Table 9. Camera settings for shoulder height and extended monopod downward-facing DHPs.

Camera Position	Exposure Mode	Focus	ISO	Shutter*	Aperture
Shoulder height	Aperture priority (A)	Auto-area Auto Focus	ISO-auto = ON Initial = 100	Open no longer than 1/30 s	≥ f/8 best, no lower than f/4
Extended monopod	Aperture priority (A)	Auto-area Auto Focus	ISO-auto = ON Initial = 100	Open no longer than 1/250 s (1/400 s if windy)	Best: f/8 – f/11; No lower than f/8

* When in aperture priority mode, minimum shutter speeds are set via the ISO Sensitivity settings sub-menu within the Shooting Menu. See RD[08] for explicit instructions.

- Take DHPs along the cardinal axes that bisect the plot in the following sequence (Figure 1):
  - 1st : North axis
  - 2nd: East axis
  - 3rd: South axis
  - 4th: West axis
- Along each cardinal plot axis, always take DHPs at photo-points in the following sequence Figure **1**):
  - 1st: 2m photo-point
  - 2nd: 6m photo-point
  - 3rd: 10m photo-point
- **Keep the camera lens pointed perpendicular to the ground at all times.** If the terrain at an individual photo-point is sloped, tilt the camera so that the photo is taken as close to perpendicular to the slope as possible.

C.2 Taking downward-facing DHPs

Steps below describe how to take downward-facing DHPs when the camera is held at shoulder height. For instructions using the 'Extended Monopole' technique, see SOP C.2.1

1. Use a declination-corrected mirror-sight compass and calibrated pacing to locate the target photo point.
   - **Make sure that no ferrous metal objects are within at least 50 cm of the compass at all times.**
2. Orient the camera lens perpendicular to the cardinal axis at shoulder height, and visually assess the distance between the lens and the vegetation. Foliage should be ≥ 50cm from the lens; if foliage is < 50cm from the lens:
   a. Select an alternate spot as close as possible to the designated photo-point
      - Alternate point should be ≤ 1 meter from the designated photo-point

   b. If (a) is not possible at ≥ 50% of points, and you are holding the camera at shoulder height, consider taking extended monopod photos.

If foliage is < 50 cm from the camera lens, select an alternative location as close to the photo point as possible.

3. Adjust the camera for proper image exposure:
   a. Look through the viewfinder while aiming the lens at the ground. Looking through the viewfinder ensures the camera is metering the scene you want to record, and allows you to observe how changes in f/stop affect shutter speed.
   b. Push the shutter-release button half-way until a "beep" is heard, indicating the camera has achieved focus lock and has determined the correct shutter speed.
   c. To maintain the greatest depth of field without sacrificing image quality, adjust the f/stop value so it is as high as possible, while not allowing the shutter to be open longer than 1/30 second. ISO values should not exceed 12,800.
4. Place the monopod at shoulder height, with the lens facing down.
5. Stand on the cardinal axis at the selected photo location. To minimize inclusion of trampled vegetation in the photo, point the camera/monopod perpendicular to the cardinal axis (either direction).
   - Choose a direction so that the photographer's shadow is minimized in the image.

6. Keep the camera so that the lens is as close to perpendicular to the ground as possible.
7. Focus the lens every time you change camera position. Press the shutter release button half way. You should hear a "beep" indicating the camera has achieved focus lock.
8. Carefully press the shutter release button the rest of the way to take the photo.
9. Check the photo for quality:

- Make sure the image is not blurry.
- Check that appropriate shutter speed and f/stop values were obtained.
- Make sure the exposure is such that vegetation is clearly distinguishable from soil or litter.
- If necessary, delete and re-shoot until a satisfactory image is taken (see Figure 2).
- **If it is not possible to obtain an image that meets the f/stop, ISO, and shutter speed guidelines in Table 9, collect DHPs when more light is available**. Unlike upward-facing DHPs, downward-facing DHPs may be taken with direct sunlight on the foliage.

10. **Collect required LAI field data as images are acquired** so that sampling metadata and image file data may be linked to specific pointIDs and plotIDs.

    - **pointID** = A value derived from the cardinal direction of the plot axis (i.e. N, S, E, W) plus the distance from the plot-center to the photo-point in meters. Examples: N2, E10, etc.
    - **cameraOrientation** = A categorical indicator; for downward-facing images, assign 'D'
    - **cameraPosition** = A categorical indicator;
        - For images taken at shoulder height, assign 'S'
        - For images taken with the extended monopole, assign 'EM' (see SOP C.2.1).
    - **imageType** = A categorical indicator classifying the photo subject matter; assign 'U' for understory.
        - Record 'U' for all downward-facing images, even if there is no overstory vegetation (e.g. grassland, cropland), and
        - Record 'U' if you are using the extended monopole to photograph a mixture of understory and mid-stature overstory.
    - **imageFileNumber** = the numeric portion of the file name automatically generated by the camera.
        - Example: Record '0492' for an image named 'D05_0492.NEF' by the camera.

11. Proceed to the next photo-point, and return to step 1.

Figure 2. Example of a properly exposed downward-facing DHP at the D01 Harvard Forest site (photo by B. Chemel). Note that green leaves are clearly distinguishable from soil and litter. It is normal for a technician's feet and a portion of the legs to be included in the photo. These will be masked out by the end-user during image analysis.

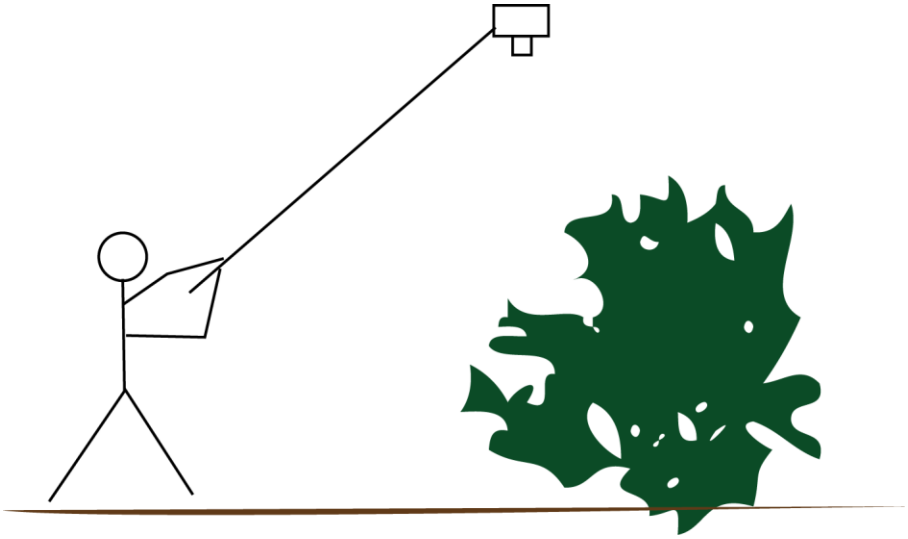

Figure 3. Illustration of using the extended monopole technique to acquire DHPs from mid-stature vegetation.

SOP C.2.1 Taking DHPs with the Extended Monopole Technique

The Extended Monopole technique is easiest when two technicians work together. One person holds and positions the camera, and the other person records data and operates the remote shutter release.

1. Adjust the camera for proper image exposure (**Table 9**). In addition:
    - Set the camera so there is a 2 s delay for the shutter-release.
2. Adjust the camera for proper image exposure as in step (3) above.
3. Standing on the cardinal axis at the selected photo location, one person extends the monopod outward above the head with the lens facing down (as in **Figure 3**).
    - Choose a direction so that the photographer's shadow is minimized in the image.
    - If necessary, adjust the ball-mount so the camera remains perpendicular to the ground.
4. The second person assumes a position next to the person holding the monopod, and positions the remote shutter release within range of the receiver.
5. The second person trips the shutter-release with the remote, and during the 2 s delay, moves directly behind the first person to ensure they do not appear in the photograph.
6. Check the photo for quality as described above, and repeat if necessary.
7. Record required field data as above.
    - **cameraPosition** = 'EM'
8. Proceed to the next photo point.

SOP D Field Sampling: Upward-Facing DHPs

D.1 Image acquisition guidelines

Configure the camera for acquiring upward-facing DHPs according to the settings specified in Table 10. Consult RD[08] for detailed instructions on how to configure the DSLR. These settings allow as much light as possible to be recorded by the camera while still enabling capture of a "good" quality image. Guidelines for modifying these settings are provided in the SOP below.

Table 10. Initial camera settings for upward-facing DHPs. Settings may be adjusted after a test image is acquired

Camera Placement	Exposure Mode	Focus	ISO	Shutter	Aperture
Shoulder height	Manual (M)	Manual, set to "∞"	ISO-auto = OFF Initial = 400	1/30 s	f/8
Ground level	Manual (M)	Auto-area Auto Focus	ISO-auto = OFF Initial = 400	1/30 s	f/8

- Take DHPs along the cardinal axes that bisect the plot in the following sequence (Figure 1):
  - 1st : North axis
  - 2nd: East axis
  - 3rd: South axis
  - 4th: West axis
- Along each cardinal plot axis, always take DHPs at photo-points in the following sequence (Figure 1):
  - 1st: 2m photo-point
  - 2nd: 6m photo-point
  - 3rd: 10m photo-point
- **Keep the camera perpendicular to the ground at all times**. If the terrain at an individual photo-point is sloped, tilt the camera so that the photo is taken as close to perpendicular to the slope as possible.
- When upward-facing photos are taken with the camera at ground level, minimize disturbance to the vegetation as the camera is placed into position.

D.2 Taking Upward-Facing DHPs

1. Use a declination-corrected mirror-sight compass and calibrated pacing to locate the target photo point. **Make sure that no ferrous metal objects are within at least 50 cm of the compass at all times.**
2. Find a position at or as close to the photo-point possible with distinct sky and foliage elements overhead and acquire a test image. The goal is to avoid saturating bright sky, and to maintain foliar elements as dark as possible – i.e., the image should show high contrast between leaves and sky, but without overly bright sky "bleeding through" and washing out small leaves and needles.
   a. Looking through the camera viewfinder, point the lens straight up toward the canopy, and press the shutter-release button half way to activate the viewfinder light meter.
   b. With the lens still pointing up, adjust the f/stop, shutter speed, and ISO according to Table **11** until the built-in light meter (also know as the 'exposure indicator' in some camera models) indicates proper exposure).
   c. Press the shutter-release button all the way down to take the test image.

Table 11. Strategy for optimizing image exposure while taking upward-facing DHPs in manual exposure mode.

Exposure Problem	Histogram Characteristics	Optimization Steps (in order of preference)
Too much light	Pixels "pile up" against right edge	Increase f/stop up to f/16
		Decrease ISO to lowest numeric value (e.g., 100)
		Decrease time shutter is open.
Too little light	Large gap between brightest pixels and right edge	Increase ISO up to 12,800
		Decrease f/stop to f/4
		If still unacceptable, light conditions are too poor.

3. Check the test image exposure results.
   a. Press the "Play" button on the back of the camera to review the test image in the large LCD screen.
   b. Select the "histogram" view using the up/down arrow buttons.
      - Always press "Play" to bring up the image and histogram, rather than viewing the histogram immediately after acquiring the image. The initial histogram generated WITHOUT first pressing "Play" is only an on-the-fly approximation of the true histogram; it is different than the histogram available in review mode and is not reproducible.

c. Check the white saturation levels in the test image. Whites become saturated when the histogram is pushed too far to the right, and the bright parts of the image overflow the available luminance range.
   - Error! Reference source not found. and **Figure 5** show histograms from a properly exposed image; although the brightest pixels reach the right-most edge of the histogram, there is no significant peak of pixels, or "pile-up" at the right edge. It is also acceptable for a gap to exist between the brightest pixels and the right-most edge.
   - Figure 6 shows a histogram from an overexposed image. If the exposure is too bright, the white peak will reach the right-most extent of the histogram, and pixels will "pile-up," creating a peak at the right edge.

4. If necessary, adjust the exposure according to Table 11 and take another test image until a correctly exposed image is produced (**Error! Reference source not found.** and **Figure 5**). Tips for adjusting exposure:
   - Higher f/stops →reduced light to the sensor, greater depth of field, more of the subject in focus.
   - Shutter open for less time → reduced light to sensor, better ability to "freeze" motion and avoid blurriness associated with subject motion or camera shake.
   - Lower ISO→ sensor is less sensitive to light but image grain is less prominent; below ISO 12,800, images will have fewer "noise" artifacts.

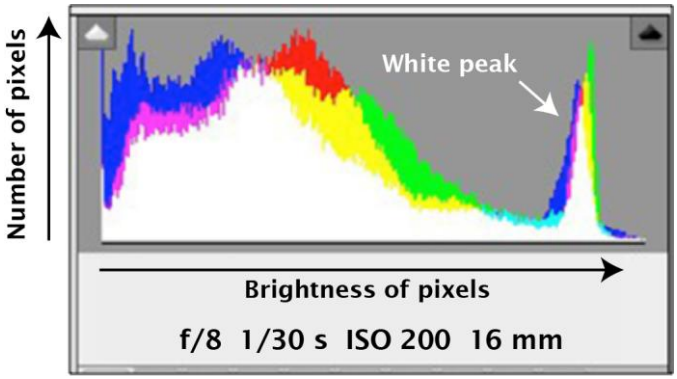

Figure 4. An example histogram from a properly exposed image. The red, green, and blue histograms are shown in their respective colors, and a combined luminance histogram is shown in white (the latter is shown on the Nikon DSLR).

5. At the designated photo-point, briefly, orient the camera lens perpendicular to the ground, pointed upward, and visually assess the distance between the lens and the vegetation. Foliage should be ≥ 50cm from the lens. If foliage is < 50cm from the lens:
   a. Select an alternate spot within 1 m of the designated photo-point.
   b. If (a) is not possible, consult the "Troubleshooting" section of this SOP.

6. Stand at the selected photo location.
7. For upward-facing photos taken at ground level, minimize inclusion of areas with trampled vegetation near the cardinal axis by pointing the camera/monopod into undisturbed vegetation perpendicular to the cardinal axis (either direction).
8. Place the monopod either at shoulder height or on the ground (Figure 7).
9. Orient the camera so that the lens is as close to perpendicular to the ground as possible.
10. Press the shutter-release button carefully, to avoid moving the camera too much. The camera does not beep when the shutter-release button is pushed in manual focus mode.
11. Check the photo for quality:
    - Make sure histogram white saturation values are appropriate.
    - Make sure the image is not blurry.
    - Check that appropriate shutter speed and f/stop values were obtained.
    - Check that there is clear distinction between foliage and sky.
    - If necessary, delete and re-shoot until a satisfactory image is taken (see Figure 5).
    - If it is not possible to obtain an image with f/stop ≥ 4 and with the shutter open for less than 1/30 s, collect DHPs when more light is available.
12. **Fill out the LAI Field ingest as images are acquired** so that camera placement metadata and image file names may be linked to specific pointIDs and plotIDs.
    - **pointID** = A value derived from the cardinal direction of the plot axis (i.e. N, S, E, W) plus the distance from the plot-center to the photo-point in meters. Examples: N2, E10, etc.
    - **cameraPosition** = A categorical indicator; values = 'S', 'G', 'EM' or 'O'; where:
        - S = shoulder height
        - G = ground level
        - EM = Extended monopole, and
        - O = other.
    - **cameraOrientation** = A categorical indicator for which direction the camera was facing when the shutter was tripped; where:
        - D = downward-facing
        - U = upward-facing
    - **imageType** = A categorical indicator classifying the photo subject matter; where:
        - U = understory, including upward-facing images taken at ground level
        - O = overstory, for upward-facing images taken at shoulder height.
    - **imageFileNumber** = the numeric portion of the file name automatically generated by the camera.
        - *Example*: Record '0492' for an image named 'D05_0492.NEF' by the camera
    - **remarks** = for example, "no N2 image; impenetrable thicket"

13. Proceed to the next photo-point and return to step 1.

Figure 5. An example of a properly exposed upward-facing DHP, and its associated histogram. Note that the brightest pixels reach the right edge of the histogram, but there is no significant peak at the right.

Figure 6. An example image and histogram of an overexposed upward-facing DHP. Note that the brightest pixels "pile-up" into a peak at the right-most edge of the histogram.

Figure 7. A field researcher acquiring an upward-facing DHP with the monopod/camera ensemble held at shoulder height

SOP E Troubleshooting

Table 12. Common issues encountered during acquisition of upward-facing DHPs, and available solutions.

Issue Encountered	Camera Placement	Solution(s)
1) f/stop < 4 and 2) Shutter open longer than 1/30 s	Shoulder height or Ground level	Collect DHPs when more light is available, and ensure direct sunlight is NOT on the foliage.
Vegetation is < 50 cm from the lens at the photo point, and there is no location within 1 m of the photo point where vegetation is ≥ 50 cm from the lens.	Shoulder height, upward-facing	*Preferred:* Lower the camera height until foliage is ≥ 50 cm from the lens. Record alternate photo height in "remarks" column of field datasheet.
		Second choice: Maximize the distance between the foliage and lens. Record alternate photo height and distance to foliage in "remarks".
	Shoulder height, downward-facing	Consider collecting photos of the understory with an extended monopole.
Vegetation is < 50 cm from the lens at the photo point.	Ground level	None. This issue cannot be avoided with DHPs acquired under these conditions.
Snow on vegetation	All	Acquire upward- and downward-facing photos as scheduled, unless site access is unsafe.

SOP F Post-Field- Sampling Tasks

F.1 DHP handling

1. As soon as possible following field sampling, copy images from the camera memory card(s) to a temporary local storage location, preferably external media (e.g., USB drive or equivalent).
2. Use the field collected metadata, and organize DHPs into the following directory structure:

   \\...\YYYY\boutID\plotID\imageType\[12 DHP .NEF files]

   where:

   - **YYYY** = the year the bout began (typically the current year)
   - **boutID** = XXXXZZ, where XXXX is the unique 4-letter NEON site code, and ZZ = the most recent bout # from the Digital Hemispherical Photos mobile ingest application.
     - boutNumber = 00 for Distributed or Gradient plots.
     - boutNumber = 01, 02, 03, etc. for Tower Plots; Field Operations is responsible for incrementing the correct bout # for Tower Plots.
       - If a Tower bout is canceled, skip that boutNumber, and create a non-sequential boutID folder.
       - *Example*: If boutNumber = 02 is skipped at WREF, the sequence of boutID folders would be WREF01, WREF03, WREF04, etc.
   - **plotID** = a separate sub-folder for images from each plot
   - **imageType** = a subfolder named either “understory” or “overstory”, case-sensitive

for example:

\\...\2017\ABBY01\ABBY_067\overstory\[12 DHP .NEF files]

3. Use Table 13 to determine the correct directory for each image type.

Table 13. Criteria for determining placement of DHP images within required file path and folder structure.

Camera Orientation	Camera Position	File Path
Downward	Shoulder	…\boutID\plotID\understory
Downward	Extended Monopole	…\boutID\plotID\understory
Upward	Ground	…\boutID\plotID\understory
Upward	Shoulder	…\boutID\plotID\overstory

4. Use the DHP Checker app (Warbler) to validate that each DHP can be matched with a data record from the field, and that each record created in the field can be matched with a DHP.
   - Rectify any DHP organizational errors or data entry errors that are identified.
   - See the Data Management Protocol for how to use the DHP Checker app (RD[04]).
5. Once all DHPs and field data records pass checks, copy the **boutID** folder containing validated images to the NEON network **LAI_RAW_validated** directory for syncing to NEON cloud storage.
   a. You may need to create the necessary **YYYY** folder within **LAI_RAW_validated** if it does not yet exist.
   b. The final validated directory structure must look *exactly* like this example:

      \\...\neon\DSF\CI Dropbox\Domain 16\TOS\LAI_RAW_validated\D16\2018\ ABBY01\ABBY_067\overstory\[12 DHP .NEF files]
6. Place a copy of the **dhpBreadcrumb.txt** file (downloaded with the DHP Checker app) into the validated **boutID** folder on the NEON network drive (e.g., into the **ABBY01** folder in the example immediately above). *Only place the breadcrumb file into the **boutID** folder if you are also placing the accompanying DHPs into the **plotID** folders*. The reasons for this are:
   a. A script automatically moves validated DHPs to the NEON cloud storage location every hour, and subsequently deletes the image files from the folder.
   b. The script does NOT move .txt files, so the **dhpBreadcrumb.txt** file will be left in the folder. Thus, it is possible to verify that the process is working as expected by noting folders with ONLY the breadcrumb, and with no DHPs in the **plotID** folders.
7. After DHPs from a given bout are successfully copied to NEON cloud storage, image files on the camera memory card(s) may be deleted. That is, if only the **dhpBreadcrumb.txt** file exists in the **boutID** folder, and the **plotID** folders contain no DHPs, images on the camera card(s) may be deleted.

F.2 Refreshing the Sampling Kit

- Check battery levels on the DSLR; recharge if necessary.
- Recharge batteries on the GPS unit.
- Clean the micro-fiber cloth, if necessary.

F.3 Equipment Maintenance, Cleaning and Storage

- Clean the hemispherical lens with a clean micro-fiber cloth or paper lens cleaning tissue, if necessary.

SOP G Data Entry

G.1 Field collected data

The importance of thorough, accurate data entry cannot be overstated; the value of field efforts are only manifested once the data are properly entered for delivery to NEON's end users.

Mobile applications are the preferred mechanism for data entry. Data should be entered into the protocol-specific application as they are being collected, whenever possible, to minimize data transcription and improve data quality. For detailed instructions on protocol-specific data entry into mobile devices, see the internal NEON Sampling Support Library (SSL). Mobile devices should be synced at the end of each field day, where possible; alternatively, devices should be synced immediately upon return to the Domain Support Facility.

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

Be sure to enter data for all plots sampled within a bout. If an entire bout is missed, no data need to be entered, and the missed boutNumber is skipped when data are entered so that it is clear to end-users that an intended bout was missed.

DIGITAL DATA ENTRY

- Plot-level data collection: The **yearBoutBegan, boutNumber,** and **plotID** fields are used to construct the sampleID for the plot and the subsampleID for each image.
    - *Make SURE these are entered correctly before creating child records for each photo*.
- If corrections to any of the above fields need to be made and child records for photos have already been created, you will need to open each child record for editing in order to update the subsampleID.
- For detailed digital data entry instructions, see the Fulcrum DHP User Guide on the Sampling Support Library (SSL).

8 REFERENCES

N/A

APPENDIX A QUICK REFERENCES

A.1 Taking Hemispherical Images

1. Determine number and type(s) of images needed for sample plot.
2. Assess if lighting conditions are favorable.
3. Dawn/Dusk sampling
   a. Dawn sampling: Start with upward-facing images
   b. Dusk sampling: Start with downward-facing images
4. Take test image to assess lighting conditions. Adjust camera settings as needed.
5. Begin on north axis, taking downward-facing photos at 2 m, 6 m, and 10 m.
6. Check each image for exposure. Delete and reshoot as needed.
7. Record pointID and other required information on datasheet.
8. Continue taking downward-facing images, moving sequentially to east, south, and then west axes, always starting at the photo point closest to the plot origin.
9. Take images of other required cameraOrientation (if needed) and test image.
10. Begin on north axis, take pictures sequentially at 2 m, 6m, and 10 m and continue sequentially to east, south, and then west axes.
11. Check white saturation, exposure, and focus of each image. Delete and reshoot as needed.
12. Record pointID and other required information on datasheet.
13. Transcribe datasheet and download camera images to NEON computer.

APPENDIX B REMINDERS

B.1 Getting Ready for Image Collection

At least two days before field effort: Make sure…

- ☑ Fisheye lens is clean and not scratched.
- ☑ Primary and backup batteries for camera are charged.
- ☑ Default camera settings are correct. See table below.
- ☑ Mirror-site compass is set to correct declination.
- ☑ Sample locations are uploaded to GPS.
- ☑ You can accurately pace 4 m.
- ☑ LAI Field QC datasheets are printed.
- ☑ All equipment is gathered and in working order.

B.2 Taking Quality Hemispherical Images

When you arrive at site: Make Sure…

- ☑ Direct sunlight is NOT visible on foliage in upward facing images.
- ☑ It is not raining.
- ☑ Backpacks and other gear are placed outside the plot and out of view of the camera.
- ☑ There are no ferrous metal objects with 50 cm of the site-mirror compass.
- ☑ You've determined number and type of photographs needed.

B.3 When taking images: Check that…

- ☑ Camera settings are correct.
- ☑ Downward-facing image: Aperture-priority mode, focus automatic
- ☑ Upward-facing shoulder height image: Manual exposure mode, focus manually set to infinity (∞).
- ☑ Proper lighting conditions are present.
- ☑ Photos are taken in the correct order for the time of day
- ☑ Test photo indicates proper exposure.
- ☑ Images are taken sequentially at 2 m, 6 m, and 10 m from plot origin, beginning on the north axis before proceeding to the photo-point locations on east, south, and west axes.
- ☑ Foliage is not within 50 cm of camera lens.
- ☑ Camera is held as close to perpendicular to ground surface as possible.
- ☑ Quality of every image is assessed immediately after taking it.
- ☑ Point ID and other required information are recorded on LAI field datasheet.
- ☑ Any deviations from protocol are described in notes section of datasheet.

APPENDIX C ESTIMATED DATES FOR ONSET AND CESSATION OF SAMPLING

Temporally-intensive LAI sampling begins in Tower plots at the start of the growing season, as new leaves and needles become visible and begin to expand. Table 14 below, provides estimated Start and End Dates for LAI sampling in Tower plots based on MODIS-EVI phenology data, averaged for 2001-2009. The Peak Greenness field represents the date range during which AOP is expected to fly each site, and during which spatially-intensive LAI sampling in Distributed plots is expected to occur. An additional contingency for Distributed plot LAI sampling is that all plots should be measured within a 1 month window that includes the actual AOP flight date.

Table 14. Site-specific sampling start and end dates for LAI timecourse sampling in Tower plots, and peak greenness sampling date ranges for spatially-intensive Distributed plot LAI sampling.

Domain Number	Site ID	Start Date	End Date	Peak Greenness	Additional Sampling Information
01	BART	04/30	10/27	06/19-08/08	
	HARV	04/20	10/27	06/09-08/08	
02	BLAN	03/16	11/01	05/31-07/29	Variable peak greenness window; may end by 06/30.
	SCBI	03/26	11/01	05/31-08/08	
	SERC	03/21	11/01	06/04-08/08	
03	DSNY	03/01	11/01	05/20-07/09	• Distributed Plots: Variable peak greenness window; may begin by 04/30, end by 06/04. • Tower Plots: Year-round sampling, shifting to every 4 weeks between 11/15 – 3/1 (instead of every 2 weeks).
	JERC	03/31	11/01	06/24-08/08	• Distributed Plots: Variable peak greenness window; may end by 07/14. • Tower Plots: Year-round sampling, shifting to every 4 weeks between 11/5 – 3/31 (instead of every 2 weeks).

Domain Number	Site ID	Start Date	End Date	Peak Greenness	Additional Sampling Information
	OSBS	03/11	11/01	05/31-07/09	• Distributed Plots: Variable peak greenness window; may begin by 04/30, end by 05/25. • Tower Plots: Year-round sampling, shifting to every 4 weeks between 11/10 – 3/10 (instead of every 2 weeks).
04	GUAN	01/01	12/31	NA	• Distributed Plots: No peak greenness according to MODIS, schedule during height of rainy season, approximately mid-September. • Tower Plots: Year-round sampling
	LAJA	01/01	12/31	NA	• Distributed Plots: No peak greenness according to MODIS, schedule during height of rainy season, approximately mid-September. • Tower Plots: Year-round sampling.
05	STEI	04/30	10/17	06/14-08/03	
	TREE	04/30	10/17	06/14-08/03	
	UNDE	05/05	10/12	06/19-08/03	
06	KONA	03/31	10/27	06/09-07/31	Variable peak greenness window; may end by 07/09.
	KONZ	03/31	10/27	06/09-07/31	Variable peak greenness window; may end by 07/09.
	UKFS	03/16	11/01	06/09-07/31	Variable peak greenness window; may end by 07/04.
07	GRSM	03/31	11/01	06/04-08/03	
	MLBS	04/20	11/01	06/09-08/08	
	ORNL	03/31	11/01	05/20-07/29	
08	DELA	03/01	11/01	05/15-07/24	

Domain Number	Site ID	Start Date	End Date	Peak Greenness	Additional Sampling Information
	LENO	03/11	11/01	05/25-07/19	
	TALL	03/16	11/01	05/15-07/14	
09	DCFS	04/30	10/17	06/30-07/24	
	NOGP	04/25	10/17	06/19-07/19	
	WOOD	04/30	10/17	06/30-07/31	
10	CPER	03/31	11/01	06/14-07/31	Variable peak greenness window; may begin by 06/14, or end by 06/14.
	RMNP	04/30	10/12	06/30-07/31	
	STER	03/31	09/30	05/31-07/09	Variable peak greenness window; may end by 06/04 (early crop harvest?)
11	CLBJ	03/01	11/01	05/15-06/30	Variable peak greenness window; may end by 06/09.
	OAES	03/16	11/01	05/10-06/14	
12	YELL	06/01	10/07	06/14-07/09	Late Start Date reflects access restrictions due to Bear Management Area closure around Tower Plots.
13	MOAB	03/26	10/27	06/14-08/13	
	NIWO	05/20	09/27	07/09-08/08	
14	JORN	03/21	11/01	07/04-09/02	Variable peak greenness window; may begin by 05/20, end by 07/31.
	SRER	05/31	11/01	07/09-08/28	Variable start and end dates, pay attention to within-year phenology. Variable peak greenness window; may begin by 03/31, end by 04/30.
15	ONAQ	03/16	10/07	05/10-06/19	Variable peak greenness window; may begin by 04/10, end by 05/15.
16	ABBY	04/20	10/27	06/14-07/24	

Domain Number	Site ID	Start Date	End Date	Peak Greenness	Additional Sampling Information
	WREF	04/25	10/17	06/14-07/31	
17	SJER	09/30	06/04	03/06-04/05	• End Date and Peak Greenness dates are in same growing season as Start Date, but next calendar year. • Start and End dates are variable, pay attention to within year phenology. • Tower Plots: Year-round sampling, shifting to every 4 weeks between 6/5 – 9/30 (instead of every 2 weeks).
	SOAP	03/31	10/17	06/04-07/04	
	TEAK	04/30	10/27	06/30-07/24	
18	BARR	06/24	08/08	07/14-07/31	
	TOOL	06/09	08/28	07/04-07/24	
19	DEJU	05/10	09/07	06/19-07/31	
	HEAL	05/15	09/01	06/30-07/31	
	BONA	05/15	09/07	06/14-07/19	
20	PUUM	01/01	12/31	NA	• Distributed Plots: No peak greenness, time to coincide with AOP. • Tower Plots: Year-round sampling

APPENDIX D DATASHEETS

The following datasheets are associated with this protocol:

Table 15. Datasheets associated with this protocol

NEON Doc. #	Title
NEON.DOC.001575	Datasheets for TOS Protocol and Procedure: Measurement of Leaf Area Index
NEON.DOC.001398	NEON Raw Data Ingest Workbook for TOS Digital Hemispherical Photos

These datasheets can be found in Agile or the NEON Document Warehouse.

APPENDIX E SITE-SPECIFIC INFORMATION

Domain Number	Site ID	Specific Issues	Solutions
01	BART		
	HARV		
02	BLAN		
	SCBI		
	SERC		
03	DSNY		
	JERC		
	OSBS		
04	GUAN		
	LAJA		
05	STEI		
	TREE		
	UNDE		
06	KONA		
	KONZ		
	UKFS		
07	GRSM		
	MLBS		
	ORNL		
08	DELA		
	LENO		
	TALL		
09	DCFS		
	NOGP		
	WOOD		
10	CPER		
	RMNP		
	STER	Herbicide application kills plants	Do not alter photo strategy due to herbicide application. Important for dataset to contain zero LAI points.
11	CLBJ		
	OAES		
12	YELL		

Domain Number	Site ID	Specific Issues	Solutions
13	MOAB		
	NIWO		
14	JORN		
	SRER		
15	ONAQ		
16	ABBY		
	WREF		
17	SJER		
	SOAP		
	TEAK		
18	BARR	Sun may not set during summer months.	Upward-facing photos: Light is as indirect as possible.Take photos as late or early in the day as is feasible, avoid photos with the sun directly behind foliage. Downward-facing photos: Light must be strong enough to differentiate greens from browns; avoid strong shadows if possible.
	TOOL		
19	DEJU	Sun may not set during summer months.	Same as D18 guidance above.
	HEAL		
	BONA		
20	PUUM		