TOS PROTOCOL AND PROCEDURE: DHP – MEASUREMENT OF LEAF AREA INDEX

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See configuration management system for approval history.

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Change Record

REVISION	DATE	ECO #	DESCRIPTION OF CHANGE
A	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.

REVISION	DATE	ECO #	DESCRIPTION OF CHANGE
			• 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.
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.
K	02/20/2018	ECO-05444	Major revisions: • Section 6.1, Equipment: Removed Maximo numbers and added Coupa vendors and vendor item numbers. • SOP F.1: Modified guidance for local storage of DHPs until successful publication of data on Data Portal. • Section 4.4, SOP C.1 and SOP D.1: Clarified guidance for data entry when images are collected from the same plot over multiple days: Update existing plot-level record with additional image records, do not create duplicate plot-level record. • Appendix C: Changed D14 SRER start date from 5/31 to 3/14 based on domain staff feedback.
L	11/06/2018	ECO-05875	Major revisions: • Standardized protocol name to 'Leaf Area Index' throughout document. • Section 2.4: Added 'Definitions' table. • Section 3: Clarified that Tower Plots selected for LAI measurement should be in dominant NLCD vegetation. • Section 3: Specified photo strategy when one or more Tower Plots are replaced with new plots mid-season. • SOP B, Table 8: Clarified instances in which upward-facing ground-level DHPs are collected. • SOP C: Added guidance for flooded plots. • SOP C/D: Clarified strategy for taking photos when avoiding foliage < 50 cm from the lens is impossible.

REVISION	DATE	ECO #	DESCRIPTION OF CHANGE
			• SOP C/D, Tables 10, 11, 12: Clarified camera setting adjustments and limits. • SOP D: Clarified instances when upward-facing image collection is not warranted (e.g., sparse trees). • SOP D: Replaced generic histogram image (Figure 4) with one that better shows how to interpret a photography histogram. • SOP F: Added guidance to delete images from the 'LAI_RAW_images' folder once successfully published to the Data Portal. • Appendix B, Reminders: Added data QA/QC content and reference to QA/QC checklist on SSL.
M	07/21/2021	ECO-06638	Major revisions: • Updated to new template (NEON.DOC.050006 Rev K) • Section 4.1: Added 5-year biogeochemistry protocol synchronization information. • Section 4.2: Clarified sampling initiation and sampling cessation guidance for Tower plots, for both bout and season. • SOP A.2: Added guidance to use Plot Prioritization list for Distributed plot sampling. • SOP A.2 and B.3: Configure camera with 2 s shutter-release delay to give time to steady camera before image is acquired. • Consolidated Image Acquisition Guidelines into new SOP B.3 • SOP B.3: Clarified that upward-facing images should still be acquired from flooded plots if possible. • SOP C.1 and D.1: Replaced 'boutNumber' with 'Week Bout Began'. • SOP C.1 and D.1: New 'biophysicalCriteria' field to document missing photos (e.g., due to localized flooding in a plot) and Distributed plot photos taken outside peak green. • SOP E.1: New guidance to document incomplete sampling after field work is complete. • SOP E.2: Added guidance to create an incident when images do not meet protocol requirements for ISO, f/stop, or shutter-speed or are out of focus. • SOP F.1: New content to describe high-priority data QC tasks.

REVISION	DATE	ECO #	DESCRIPTION OF CHANGE
N	02/11/2025	ECO-07123	Major revisions: • Migrated to protocol template rev M. • Section 2.4: Added definitions for 'average overstory' and 'average understory'. • Section 3: Updated Figure 1 with pointIDs and new subplotID naming convention. • Section 4.1 and Section 4.4: Updated sampling bout frequency at Tower plots; now a 4-week sampling interval is implemented at certain sites during the peak green lull. • Section 4.1.1: Clarified that downward-facing photos should be collected at times of day with low contrast – i.e., avoid bright foliage and deep shadows. • SOP C.1: Added guidance for assessing histogram and adjusting exposure for downward-facing photos. • SOP C.1: New Figure 5 showing a histogram of an underexposed downward-facing. • SOP C.1 and SOP D.1: Added details describing how to document when no photo is taken due to biophysical criteria not being met. • SOP D: Added clarification to when upward-facing photos should be taken. • SOP D.1: Replaced Figure 11 with new, more typical histogram from a properly exposed upward-facing image. • SOP F.2: New guidance to back up the most recent two years of images from each site to an external drive. New file upload workflow and Incident submission if an upload quality flag is generated. • Appendix C: Extended sampling end dates for CLBJ and OAES to capture the end of second greenness peak. • Appendix C: Updated sampling windows using the latest MODIS-EVI data and added a 4-week sampling interval during peak green for Tower plots at some sites. • Appendix D: Revised guidance for when to collect downward-facing images at sites in Alaska.

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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 employs a Digital Hemispherical Photo (DHP) system (aka fisheye photos) to estimate LAI, because this method 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 by researchers 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

Dr. Richard Fernandes from the Canadian Centre for Remote Sensing provided valuable insight regarding plot design and optimal acquisition of Digital Hemispherical Photos in the field.

2 RELATED DOCUMENTS AND ACRONYMS

2.1 Applicable Documents

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

AD[01]	NEON.DOC.004300	EHS Safety Policy and Program Manual
AD[02]	NEON.DOC.004316	Operations Field Safety and Security Plan
AD[03]	NEON.DOC.000724	Domain Chemical Hygiene Plan and Biosafety Manual
AD[04]	NEON.DOC.050005	Field Operations Job Instruction Training Plan
AD[05]	NEON.DOC.004104	NEON Science Data Quality Plan
AD[06]	NEON.DOC.000914	NEON Science Design for Plant Biomass and Productivity

2.2 Reference Documents

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

RD[01]	NEON.DOC.000008	NEON Acronym List
RD[02]	NEON.DOC.000243	NEON Glossary of Terms
RD[03]	NEON.DOC.002652	NEON Data Products Catalog
RD[04]	NEON.DOC.001271	AOS/TOS Protocol and Procedure: DMP – 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.003282	NEON Protocol and Procedure: SIM – Site Management and Disturbance Data Collection
RD[08]	NEON.DOC.005247	AOS/TOS Standard Operating Procedure: NEON Aquatic and Terrestrial Site Navigation
RD[09]	NEON.DOC.004891	TOS Commissioning Test Report: Digital Hemispherical Photos Process Quality
RD[10]	NEON.DOC.001718	TOS Standard Operating Procedure (SOP): DSLR Configuration
RD[11]	NEON.DOC.002984	Standard Operating Procedure (SOP): Minimizing Site Disturbance During Aquatic and Terrestrial Observation System Sampling

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

Average understory: The average height of plants < 3 m tall within a plot.

Average overstory: The average canopy height at the plot level.

Digital Hemispherical Photo (DHP): A digital photo generated with a fisheye lens that is used to estimate leaf area index.

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

Leaf Area Index (LAI): One-sided leaf area per unit ground area.

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

Trees (single or multi-bole): Self-supporting woody stems with DBH ≥ 10 cm.

3 METHOD

There are two high-level components to this LAI data collection protocol, and these components serve to capture LAI data across space and through time:

1. **Distributed Plots**: Data are collected on the ground every 5 years from Distributed Plots. These data are used in conjunction with AOP LAI data products to estimate LAI at the site scale.
    - The plotIDs for the Distributed Plots used for LAI sampling are provided by Science via a Plot Prioritization list.
2. **Tower Plots**: Data are collected every two weeks from leaf-out to senescence from a subset of Tower Plots (n=3). These data are used to construct a time-series dataset that will complement the spatially-extensive snapshot of LAI generated from Distributed Plots and AOP data.
    - Tower Plots selected for the LAI time-series are chosen by Field Science. Plots should be close to each other and readily accessed from roads near the TIS Tower to enable image collection from all plots in a single morning/evening (ideally).
    - To avoid trampling DIV sampling locations, Tower plots selected for LAI are ideally not the same Tower plots sampled for DIV.
    - It is assumed that all Tower Plots are within the same NLCD vegetation type, and it therefore does not matter which 3 Tower Plots are selected. If Tower Plots are established in > 1 NLCD vegetation type, select plots for LAI from the dominant NLCD vegetation type.
    - If Tower Plots selected for measurement change mid-season, a minimum of one bout should include LAI measurements from the complete set of 'old' plots AND the complete set of 'new' plots.

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 approximately 2 m, downward-facing images will suffice for a given plot (a monopod is employed if vegetation is taller than 1 m but on average less than 2 m height; **Table 10**). The goal is to maintain a minimum distance of approximately 50 cm between the lens and the vegetation for the 'average' technician height. Upward-facing images are employed to capture LAI for vegetation taller than 2 m. 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 (e.g., Brown *et al.* 2020).

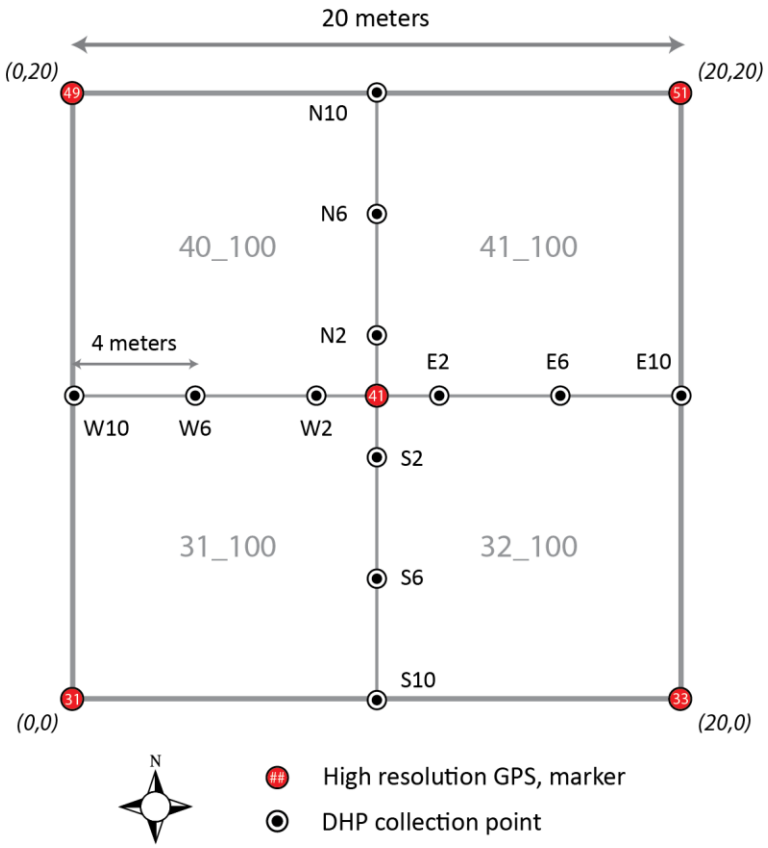

Figure 1. Distributed base plot (or 20 m x 20 m Tower plot) showing the location and spacing of LAI photo points relative to plot center; grey numbers represent subplotIDs (##_100). Spacing between points and number of points is the same for both 20 m x 20 m and 40 m x 40 m Tower plots, and photo points are always centered on the plot centroid (marker '41').

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. If local conditions create uncertainty about carrying out these steps, it is critical that technicians document the problem and enter it in NEON's problem tracking system.

Quality assurance is performed on data collected via these procedures according to the NEON Science Data Quality Plan (AD[05]).

4 SAMPLING SCHEDULE

4.1 Sampling Frequency and Timing

The frequency and timing of digital hemispherical image collection depends on plot type (**Table 1**).

Table 1. Sampling frequency for Measurement of Leaf Area Index procedures on a per SOP per plot type basis.

Plot Type	Plot Number	Bout Duration	Bouts Per Year	Bout Interval	Yearly Interval	Remarks
Distributed plot	n ≤ 20	1 month	1X per sampling year	NA	Every 5y	Sampling is synchronized with AOP flyover.
Tower plot	n = 3	1-2 days	Site specific	* Every 2 or 4 weeks	Annual	Bout duration based on sampling conditions; see Appendix C for site-specific bout interval during peak green window.

* Should sampling events for Distributed and Tower Plots overlap, simultaneous sampling may not be possible if sufficient camera bodies and fisheye lenses are not available. Always prioritize sampling Distributed Plots.

Scheduling Considerations

Implementation of this protocol in Distributed plots is scheduled on an inter-annual basis at a given site as part of a suite of synchronized TOS measurements aimed at characterizing biogeochemistry (**Table 2**).

Table 2. Coordination of Leaf Area Index sampling with other TOS plant and soil protocols through time. Years 1 through 7 are shown to illustrate the temporal grouping of protocols, and the pattern repeats beyond year 7. Light grey cells indicate synchronized 'chemistry' and 'productivity' protocol groups; medium grey cells show protocols implemented annually in Tower Plots; dark grey cells are protocols implemented every 5 y in Tower Plots.

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

Protocol*	Interval (y)	Plot Type	Number of Plots	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
CDW	5	tower	20 or 30†				X			
VST	5	tower	20 or 30†					X		

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

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

Distributed plot LAI scheduling tips for 5-year protocol synchronization:

- Employ two teams of two.
- LAI and Canopy Foliar Sampling may be combined.
- Have a backup team and camera setup available to capitalize on overcast days.

For Tower plot bouts scheduled on either a 2-week or 4-week interval:

- Sampling may begin up to 7 days *before* the scheduled start date if weather forecasts indicate site conditions will meet protocol sampling requirements for LAI (e.g., cloudy conditions, no rain, etc.)

4.1.1 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 D**.
- Downward-facing DHPs may be collected either with or without sunlight on the foliage. **DO NOT take downward-facing images either before the sun has come up or after the sun has set.**
    - Target times of day to avoid situations that generate high contrast – i.e., very bright foliage and deep shadows. Aim to collect photos when light is indirect and shadows are minimal. For example, if collecting upward-facing images before sunrise, finish collecting upward-facing DHPs from all plots first, then return to each plot and collect downward-facing DHPs.

- Shadows and very low-light (i.e., well before sunrise or well after sunset) make it difficult to distinguish green from brown colors during image analysis.

- On a given sampling day, plan on arriving at the location of the first plot to be sampled at least 20 minutes before light conditions are appropriate.

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

4.2 Criteria for Determining Onset and Cessation of Sampling

Onset and cessation of LAI sampling depends on plot type (Distributed vs. Tower Plots; **Table 3**). Site-specific dates in **Appendix C** are derived from a 10-year average of MODIS-EVI phenology data (Didan 2023), and are provided as a guide for scheduling purposes only. To determine actual start dates in a given year:

- **For Distributed plots**: LAI sampling schedules for a site should be constructed with input from the NEON AOP flight schedule to ensure a flight is scheduled and will overlap ground sampling as described in **Table 3**.
    - At Ag sites, the Distributed plot sampling event may not capture all plots in peak green due to planting cycles.
- **For Tower plots**: When leaf, needle, or blossom expansion begins. Phenology observations made on indicator individuals of dominant species are a good data source for when LAI Tower plot sampling should begin.

Table 3. Number of plots and sampling start/stop guidelines for LAI sampling in Distributed and Tower Plots.

Plot type	Plot Number	Sampling Start	Sampling Stop
Distributed	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]	***For a bout***: 1 month after sampling Start Date.
Tower	n = 3	Start of growing season, as new leaves, needles, or blossoms become visible and begin to expand.	***For a bout***: 1 week (7 d) after bout Start Date. ***For the season***: Site-specific sampling stop dates are provided in **Appendix C**. Except at sites with year-round sampling, dates correspond to whichever comes first:

Plot type	Plot Number	Sampling Start	Sampling Stop
			1. DOY ≥ 305 (1st November); that is, October is the latest month in which sampling is scheduled. 2. Site-specific NDVI returns to pre-growing-season level.

4.3 Timing for Laboratory Processing and Analysis - DHP Image Transfer

Once DHPs have been collected for a given sampling bout, they must first be organized into directories according to SOP E and validated against their corresponding Fulcrum records using a QC verification tool ('Warbler' DHP QAQC Shiny application, see RD[04]), then uploaded to an ingest bucket for publication via NEON's data portal. ***Failure to do so in a timely manner*** will result in parser error messages (**Table 4**).

Table 4. Timing requirement for DHP image transfer.

Sample type	Activity	Holding Time
DHP Images	QC and upload to cloud storage	Within 30 days of field collection

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 5**).

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).
- When DHPs are collected on multiple days from the same **plotID**, see data entry guidance in SOP B and SOP C, and consult the DHP Fulcrum User Manual in the Sharepoint SSL for detailed instructions.

Table 5. Contingency decisions relevant to collection of DHPs in the field.

Delay/Situation	Action	Outcome for Data Products
Hours	*If delay interrupts data collection mid-plot:* 1. 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; 2. upon resuming, ensure light conditions are favorable; and 3. 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 delay occurs between plots: 1. Ensure light conditions are favorable for data collection; and 2. 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 delay interrupts data collection mid-plot:* 1. 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; 2. on the next possible sampling day within 7 days of the delay, ensure light conditions are favorable; and 3. repeat data collection for interrupted image set(s).	None
	If delay occurs between plots: 1. Return to the field ASAP; 2. ensure light conditions are favorable for data collection from an entire plot; and 3. resume data collection for the next plot.	None
8+ days	*If delay interrupts data collection mid-plot:* 1. 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;	Decreased sample size resulting in imprecise estimation of LAI.

Delay/Situation	Action	Outcome for Data Products
	2. For Tower Plots scheduled on a 2-week interval, skip sampling for current eventID and continue sampling as part of the next eventID. 3. For Distributed Plots, return to sampling as soon as possible.	
	If delay occurs between plots: 1. For Tower Plots scheduled on a 2-week interval, skip sampling for current eventID and continue sampling as part of the next eventID. 2. For Distributed Plots, return to sampling as soon as possible.	Decreased sample size
15+ days (**Tower bout on 4-week interval only**	*If delay interrupts data collection mid-plot:* 1. 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; 2. Skip sampling for current eventID and continue sampling as part of the next eventID.	Decreased sample size resulting in imprecise estimation of LAI.
	If delay occurs between plots: Skip sampling for current eventID and continue sampling as part of the next eventID	

4.5 Missed or Incomplete Sampling

Sampling according to the schedule is not always possible, and multiple factors may impede work in the field at one or more plots or sampling locations in a given bout. For example:

- Logistics – e.g., insufficient staff or equipment
- Environment – e.g., deep snow, flooding, inclement weather, or
- Management activities – e.g., controlled burns, pesticide application

Instances such as those listed above must be documented for scheduling, tracking long-term plot suitability, and informing end users of NEON data availability. Some types of missed sampling are due to events that should be recorded in the Site Management App; refer to the Site Management and Event Reporting Protocol for more detail (RD[07]).

Missed or Incomplete Sampling Terms

Terms that inform Missed or Incomplete Sampling include:

- **Protocol Sampling Dates**: Bout-specific sampling dates (**Appendix C**).
- **Scheduled Sampling Dates**: Bout-specific sampling dates scheduled by Field Science and approved by Science. These dates coincide with or are a subset of the Protocol Sampling Dates.
- **Missed Sampling**: Incidence of *scheduled sampling* that did not occur. Missed Sampling is recorded at the same resolution as data that are ordinarily recorded.
- **Sampling Impractical**: The field name associated with a controlled list of values that is included in the data product to explain a Missed Sampling event – i.e., why sampling did not occur.
- **Rescheduled**: Missed Sampling is rescheduled for another time according to one of the scenarios documented in **Figure 2**, resulting in no change to the total number of sampling events per year.

The documentation that must accompany missed sampling depends on the timing, subsequent action, and the audience appropriate for numerous scenarios (**Figure 2**).

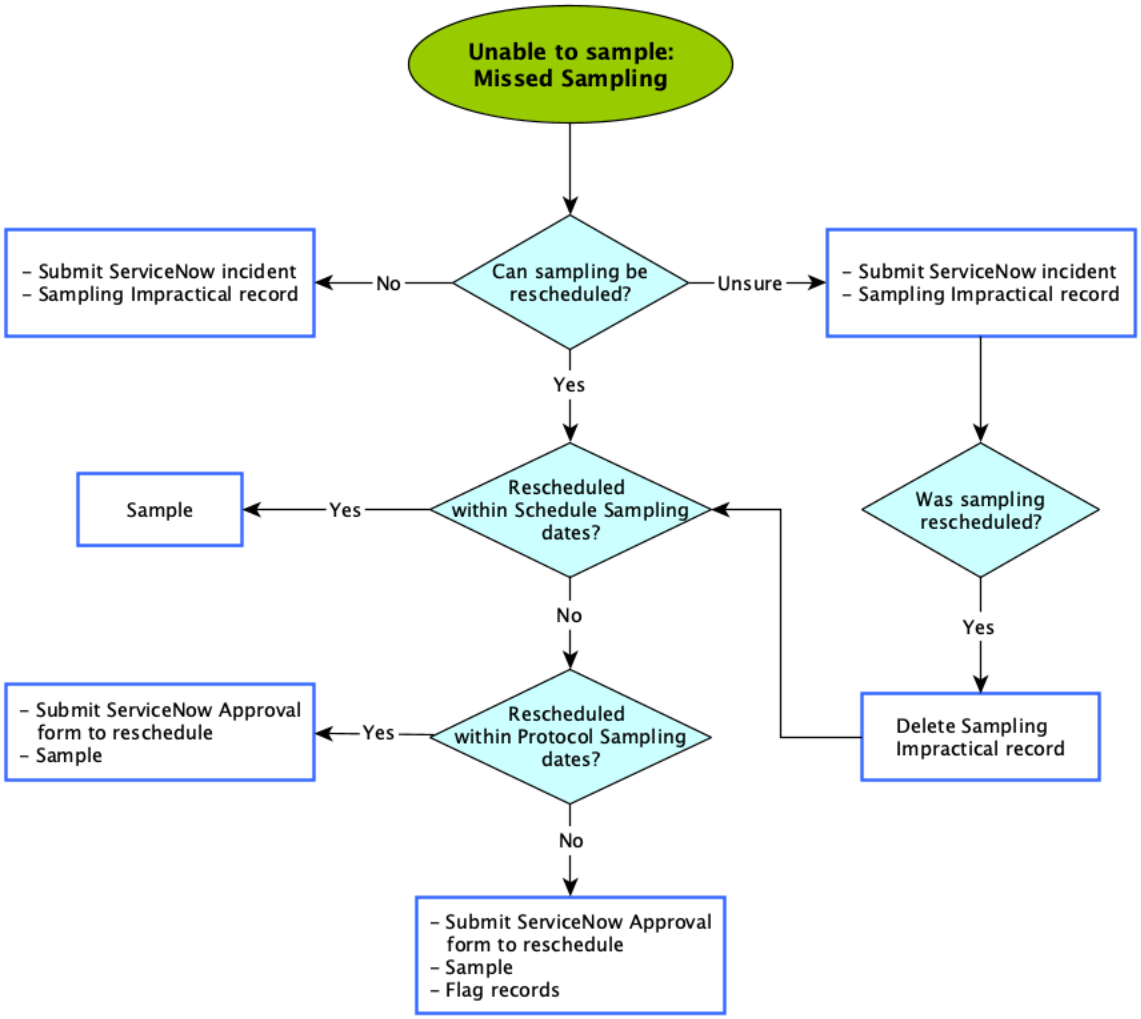

Figure 2. The documentation to account for a Missed Sampling event depends on the situation for each sampling unit not sampled per bout that is not sampled. Diamonds represent decision points and boxes describe the required action. Required actions may include: a) Submitting a ServiceNow incident, b) creating a Sampling Impractical record, c) creating a data Flag, d) creating a Site Management record, or e) some combination of (a) – (d).

To Report Missed or Incomplete Sampling:

1. Missed or Incomplete Sampling that cannot be rescheduled within the Schedule sampling dates must be communicated to Science by a ServiceNow Incident.
    a. For Missed Sampling that is Rescheduled, there are some cases that require approval by Science and Operations (**Figure 2**).
    b. Consult **Figure 2** above to determine required actions if scheduled activities are delayed or canceled. This protocol is the ultimate source of information should any discrepancy exist

between this document and other summary materials – e.g., the 'Scheduled Field Activities – Delays and Cancellations' spreadsheet linked via the front page of the Field Science SSL.

2. Create a Fulcrum record for each Missed Sampling event in the field that cannot be rescheduled. That is, if data are recorded in the field at the plot level, a record must be made for each plot missed.
    a. Create a record in the *DHP: Leaf Area Index [PROD]* app for each **plotID** that could not be sampled in the field and that cannot be rescheduled.
    b. Record the **Start Date** as the scheduled date, and record the **Start Time** as 12:00 noon.
3. For each Missed Sampling record, the **Sampling Impractical** field must be populated in the mobile collection device (**Table 6**).
    a. Select a value for the **Sampling Impractical** field that best fits the reason sampling did not occur.
    b. The **Sample Fate** field should populate to 'not a physical sample' and remain locked.
    c. It is not necessary to create child records.
4. For Rescheduled sampling events that occur outside of the defined Protocol Sampling Dates, a protocol-specific Flag must also be recorded (**Figure 2**).
    a. In Distributed plots that occur outside of the defined Protocol Sampling Dates, select **Biophysical Criteria** = 'date outside peak green' for each child record.

Table 6. Protocol-specific Sampling Impractical reasons entered in the Fulcrum application. In the event that more than one is applicable, choose the dominant reason sampling was missed.

Sampling Impractical reason	Description
Extreme weather	Events (e.g., thunderstorms, hurricanes) that compromise safety and access
Location flooded	Standing or flowing water too deep to complete sampling safely
Logistical	Site or plot access compromised, staffing issues, errors (e.g., equipment not available in the field)
Management	Management activities such as controlled burn, pesticide applications, etc.
Other	Sampling location inaccessible due to other ecological reason. Describe briefly in required **remarks**.
Too windy	Windspeed causes foliage movement and blurry photos, and camera cannot be configured within requirements to compensate.

4.6 Estimated Time

The time required to implement a protocol will vary depending on a number of factors, such as skill level, system diversity, environmental conditions, and distance between sample plots. The timeframe provided below is an estimate based on completion of a task by a skilled two-person team (i.e., not the time it takes at the beginning of the field season). 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. Please note that if sampling at particular locations requires significantly more time than expected, Science may propose to move these sampling locations.

Table 7. Estimated staff and labor hours required for implementation of the Measurement of Leaf Area Index protocol.

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

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 EHS Safety Policy and Program Manual (AD[01]) and Operations Field Safety and Security Plan (AD[02]). Additional safety issues associated with this field procedure are outlined below. If an employee witnesses any unsafe conditions or uncontrolled hazards that present an imminent danger, they should immediately take action to stop work and report such conditions to their manager. Employees must also report all workplace injuries, illnesses, incidents, or releases to the environment as soon as possible, regardless of the severity.

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

6.1 Training Requirements

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

Also, all technicians must:

- 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.

6.2 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.

7 STANDARD OPERATING PROCEDURES

SOP Overview

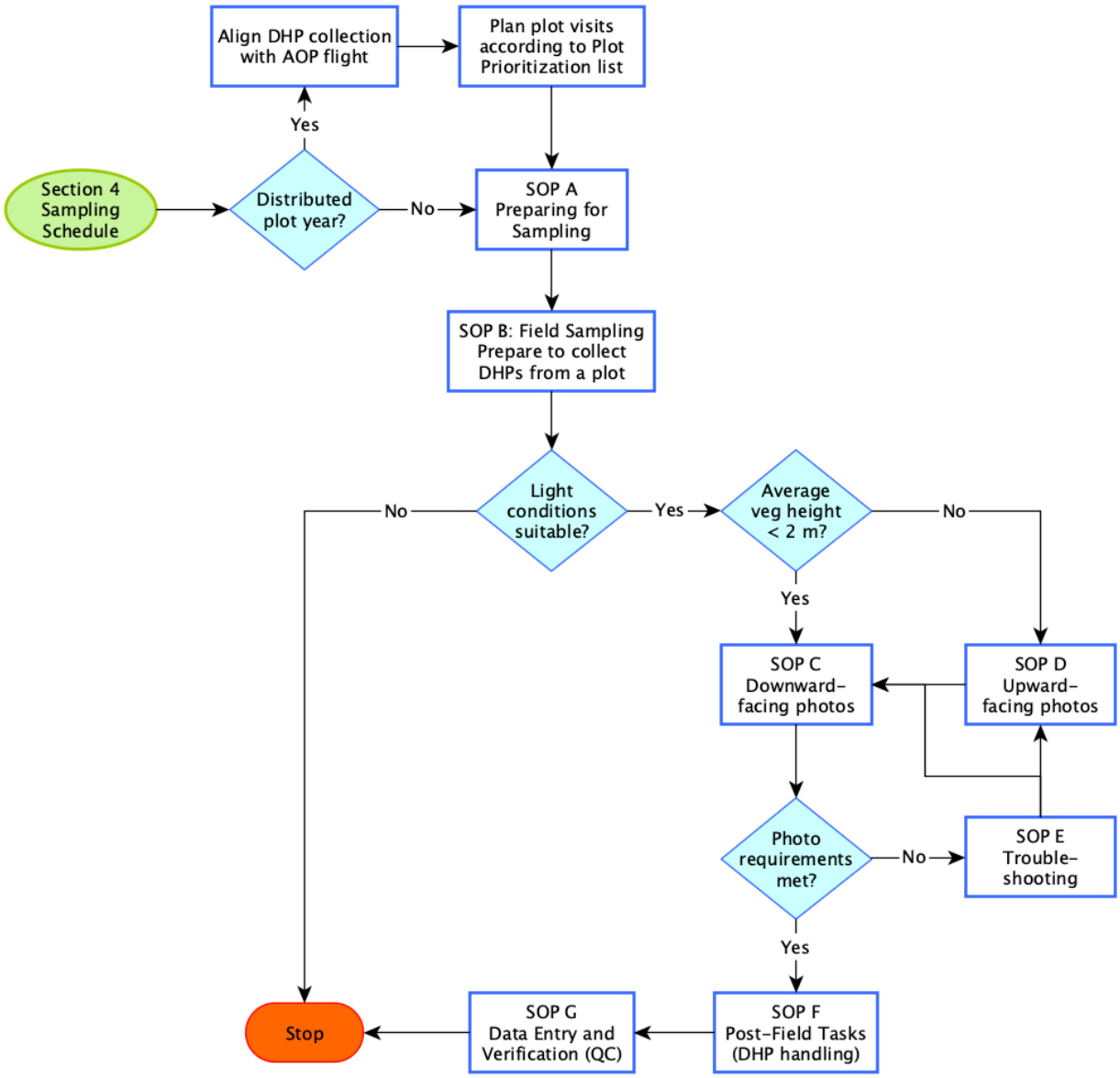

Figure 3. High-level workflow diagram illustrating major components and decision points within the Leaf Area Index protocol.

SOP A: Preparing for Sampling. Tasks completed in the Domain lab in preparation for the sampling event.

SOP B: Field Sampling: Prepare to Collect DHPs from a Plot. Assess plot-level vegetation and determine required photos.

SOP C: Field Sampling: Downward-Facing DHPs. Collect downward-facing Digital Hemispherical Photos from relatively short-stature vegetation. Includes steps for use of an extended monopod.

SOP D: Field Sampling: Upward-Facing DHPs. Collect upward-facing Digital Hemispherical Photos from relatively tall-stature vegetation, or understory that cannot be photographed via downward-facing method.

SOP E: Troubleshooting. Strategies to ensure photographs meet protocol requirements.

SOP F: Post-Field Sampling Tasks. Organize and transfer images to cloud storage, and clean and maintain equipment.

SOP G: Data Entry and Verification. Guidelines and requirements for successful data entry and use of the LAI QC Checklist. This SOP is NOT a substitute for AOS/TOS Protocol and Procedure: Data Management (RD[04]). Staff must read RD[04]:

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

SOP H: Sample Shipment

SOP A Preparing for Sampling

A.1 Preparing for Data Capture

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

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

A.2 Preparing for Field Sampling

1. **Plot Prioritization** (Distributed plots only): Consult the Plot Prioritization list in the TOS Sampling Support Library (e.g., file name = UniquePlotIDsAndSamplingModules.xlsx) and plan to visit plots or groups of plots in the recommended order. Should sampling be incomplete due to unforeseen circumstances, following the Plot Prioritization list ensures a statistically robust sample.
2. **Route planning**: Plan and save sampling routes for field teams using standard site navigation procedures (RD[08]). Route planning enhances sampling efficiency and helps avoid accidental foot traffic within NEON plots.
3. **Mobile device**: Synchronize with cloud
4. **Micro-fiber lens cleaning cloth**: Clean soiled cloth if necessary.
5. **DSLR fisheye lens**: Clean with lens cloth if necessary.
6. **DSLR batteries**: Charge.
7. **DSLR memory card**: Check that any images on memory card are backed up, and empty memory cards of pre-existing images. Bring at least one *extra* memory card into the field.
8. **GPS unit**: Charge and load target plot locations.
9. **Headlamp**: Check batteries.
10. **Compass**: Check/set correct declination.
    a. Declination changes with time and should be looked up annually per site: http://www.ngdc.noaa.gov/geomag-web/
11. **Meter tape**: Calibrate technician pacing: determine # paces equivalent to 4 m (distance between photo points).
    a. Being able to consistently pace off accurate distances in the field speeds collection of LAI data compared to laying out a meter tape in two directions for guidance at each plot.
12. **LAI field datasheets** (RD[05]): Print.

a. The LAI field datasheet is provided as a companion document and is intended as backup for standard data collection via mobile device.

13. **Camera configuration**: Configure the DSLR for DHP image acquisition according to settings below (**Table 8**). See TOS Standard Operating Procedure (SOP): DSLR Configuration (RD[10]) for more detail.

Table 8. Required 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[10].

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
Shutter Delay	2 s – the delay allows time to stabilize the camera on the shoulder before the shutter is released	Set release mode dial to 'timer' symbol; Custom Settings Menu → Self-Timer to select duration
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

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

B.1 Spatially and Temporally Linked Protocols

Biogeochemistry Protocol Suite

Per Section 4.1, collection of DHPs is part of a synchronized suite of protocols that, when implemented together, provide researchers with an enhanced understanding of biogeochemistry dynamics within NEON sites (**Table 2**).

Other than following scheduling guidance, no additional steps are necessary to integrate LAI sampling with other TOS Biogeochemistry protocols.

Plant Diversity

- Plant Diversity sampling occurs in 3 Tower plots each year. Due to the frequent foot traffic associated with DHP collection, ideally Tower plots selected for LAI are NOT the same Tower plots that support Plant Diversity sampling.
- In the event it is necessary to collect DHPs from a Tower plot that also supports Plant Diversity, care must be taken to travel along the cardinal axes carefully and avoid trampling any 1 m^2 nested subplots that are sampled for Plant Diversity.

B.2 Determine Camera Orientation and Height

- Assess required light conditions by photo type (downward/upward, Section 4.1.1).
- Place backpacks and other gear outside the plot and out of the camera's field of view.

1. For each plot, visually survey the vegetation in the entire plot to determine which combination of camera orientation and camera position are required (**Table 9**).
2. The camera position may change throughout the year 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.

Table 9. Guidelines for determining proper camera positioning when collecting DHPs.

Understory Vegetation[1]	Overstory Vegetation	Required Camera Orientations	Camera Position(s)[2]	Protocol Reference
Majority < 0.75 – 1 m height	None, no trees in plot	Single downward-facing photo per point	Shoulder height	SOP C
Majority < 0.75 – 1 m height	Majority < 2 m height and no trees in plot	Single downward-facing photo per point	Extended monopod	SOP C

Understory Vegetation[1]	Overstory Vegetation	Required Camera Orientations	Camera Position(s)[2]	Protocol Reference
Majority > 0.75 – 1 m height	None, no trees in plot	Single downward-facing photo per point	Extended monopod	SOP C
Majority > 0.75 – 1 m height	Majority < 3 m height and no trees in plot	Upward and downward-facing photos per point	Shoulder height (upward) and extended monopod (downward)[3]	SOP C SOP D
Majority < 0.75 – 1 m height	Majority > 3 m height	Upward and downward-facing photos per point	Shoulder height	SOP C SOP D
Majority > 0.75 m height, and < 2 m height	Majority > 3 m height	Upward and downward-facing photos per point	Shoulder height (upward) and extended monopod (downward)	SOP C SOP D
Majority 2-3 m height[4]	Majority > 3 m height	Two upward-facing photos per point	Ground-level (upward) and shoulder height (upward)	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 13** for an example of a researcher holding a camera at shoulder height.

[3] The extended monopod is the preferred method. However, upward-facing ground-level images may be collected if understory vegetation is indistinguishable from overstory vegetation (i.e., forms a continuous gradient) and the extended monopod cannot be elevated above the average vegetation height.

[4] For example, understory is primarily low- to mid-stature shrubs.

B.3 Image Acquisition Guidelines

Downward-facing Images

Configure the camera for acquiring downward-facing DHPs according to the settings specified in **Table 10**. Consult RD[10] for detailed instructions on how to configure the DSLR.

Table 10. 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, no higher than 12,800	Open no longer than 1/30 s; 2 s shutter delay	≥ f/8 best, no lower than f/4
Extended monopod	Aperture priority (A)	Auto-area Auto Focus	ISO-auto = ON Initial = 100, no higher than 12,800	Open no longer than 1/250 s (1/400 s if windy); 2 s shutter delay	Best: f/8 to 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. However, the camera may override the specified minimum shutter speed in low light conditions, so it is necessary to verify that each image meets shutter speed requirements. See RD[10] for explicit instructions.

Upward-facing Images

Configure the camera for acquiring upward-facing DHPs according to the settings specified in **Table 11**. These settings allow as much light as possible to be recorded by the camera while still capturing a high-quality image. Settings in **Table 11** are the initial starting point: Guidelines for modifying these settings are provided in SOP C.

- Auto-focus is not used for upward-facing images. Auto-focus may lock on leaves close to the lens, resulting in out of focus distant leaves. Auto-focus also does not function well in low-light conditions often encountered when collecting upward-facing photos.

Table 11. 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	Initial = 1/30 s; 2 s shutter delay	Initial = f/8; adjusting lower may compromise depth of field
Ground level	Manual (M)	Auto-area Auto Focus	ISO-auto = OFF Initial = 400	Initial = 1/30 s; 2 s shutter delay	Initial = f/8

All Images

1. Take DHPs along the cardinal axes that bisect the plot in the following sequence (**Figure 1**):
   a. 1st – North axis
   b. 2nd – East axis
   c. 3rd – South axis
   d. 4th – West axis
2. Along each cardinal plot axis, take DHPs at photo-points in the following sequence (**Figure 1**):
   a. 1st – 2 m photo point
   b. 2nd – 6 m photo point
   c. 3rd – 10 m photo point
3. Adjust the aperture (and/or shutter-speed for upward-facing photos) from point to point and/or plot to plot to accommodate changing light conditions while maximizing depth of field (higher f-stop values).
   a. Aperture must remain within an acceptable range (**Table 10, Table 11**).
   b. ***If using an aperture < f/8***: Check each image for focus. Depth of field is reduced with lower f-stops (wider aperture). Leaf elements must be in focus for successful image analysis.
4. **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.
5. When upward-facing photos are taken with the camera at ground level, minimize disturbance to the vegetation as the camera is placed into position.
6. Collecting DHPs from flooded plots:
   a. Collect downward-facing DHPs if water depth is ≤ 30 cm.
   b. Skip downward-facing photos at points with water deeper than 30 cm.
   c. Upward-facing photos should still be collected if suitable vegetation is present and water depth does not present a safety hazard. Record **Sampling Impractical** = 'flooded' if upward-facing images cannot be collected because water is too deep to safely collect photos.
   d. Do not collect upward-facing ground-level photos.
7. When DHPs are collected on multiple days from the same **plotID**:
   a. Add image records generated on day 2 by editing the record that was created on day 1.
   b. The **Start Date/Time** = start of sampling on day 1, and
   c. The **End Date/Time** = end of sampling on day 2.
   d. Consult the DHP Fulcrum Manual on the Sharepoint SSL for detailed instructions.

SOP C Field Sampling: Downward-Facing DHPs

Overview and Goals

- Collect downward-facing photos from each photo point within the plot at a time of day that minimizes high contrast – i.e., bright foliage and deep shadows (Section 4.1.1). Shadows make it difficult to analyze images.
- Keep the camera lens ≥ 50 cm from foliage and properly expose and focus all images.
- Collect required field sampling metadata in the *DHP: Leaf Area Index [PROD]* mobile application.
  - The Leaf Area Index Fulcrum Manual on the SSL is a detailed data entry guide.

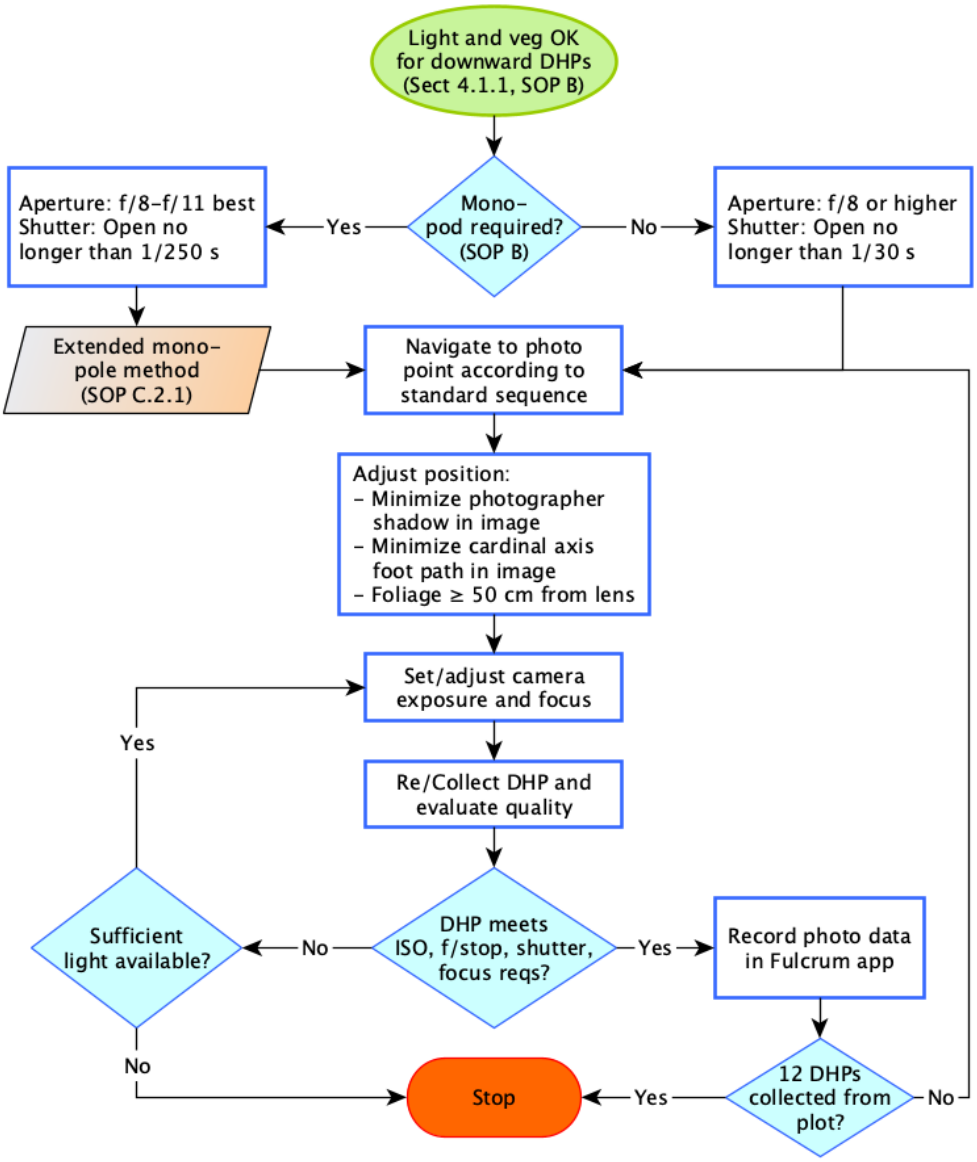

Figure 4. Expanded workflow diagram for downward-facing DHP collection. Diagram supports and does not replace protocol text; most common workflow is outlined.

C.1 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.1.1.

1. Navigate to the plot to be sampled.
    a. Consult RD[08] to plan routes and avoid unnecessary foot traffic in NEON plots.
    b. (*Distributed plots only*) Visit plots according to the Plot Prioritization list (SOP A.2).
2. Create a record in the *DHP: Leaf Area Index [PROD]* app for the plot and enter:
    a. **Domain ID**, **Site ID**, and **Plot ID**.
    b. **Start Date** and **Start Time**: Use *YYYYMMDD* and *HH:mm* 24-h time format.
    c. **Year Bout Began** and **Week Bout Began**: The **Week Bout Began** value is populated automatically and must be manually adjusted for bouts that span > 1 week (typical for Distributed plot bouts scheduled every 5 years).
    d. **Sampling Protocol Version**: Select the version of the protocol used for sampling, typically the currently released version (the default).
    e. **Understory Height**: Visually estimated average understory height for the entire plot, nearest 0.1 m
    f. **Overstory Height**: Visually estimated average overstory height for the entire plot, nearest 1 m. A rangefinder may be used for this purpose but is optional; high accuracy is not required for this measurement.
    g. **Snow Present**: Record 'Yes' if snow if present within the plot. Defaults to 'No'.
    h. **Are All Understory Photos Taken the Same Way?** Answer 'Yes' if the Camera Position will be the same for all understory photos; app will auto-populate the selected value for all understory child records.
    i. **Are All Overstory Photos Taken the Same Way?** Answer 'Yes' if the Camera Position will be the same for all overstory photos; app will auto-populate the selected value for all overstory child records.
    j. **Date Outside Peak Green?** (Distributed plots only) Answer 'Yes' if the Start Date is outside the site-specific peak green window in Appendix C. The Biophysical Criteria field will default to 'date outside peak green' for all photo records.
3. Use a declination-corrected mirror-sight compass and calibrated pacing to locate the target photo point. Make sure that ferrous metal objects are kept ***at least 50 cm away from the compass at all times.*** When at the photo point:
    a. Check to ensure the person recording data is out of the camera's field of view.

b. If the plot is flooded and water depth is ≥ 30 cm at the photo point, skip the downward-facing photo, create a child record for the photo point, and record:

   i. **Biophysical Criteria**: 'conditions not met – no photo taken'

NOTE: If the biophysical criteria of ***'conditions not met – no photo taken'*** is selected, there will be a child record created in the Fulcrum application. This empty child record is needed to ingest the parent record.

4. With the camera and monopod at shoulder height, orient the camera lens relative to the cardinal axis to maximize high-quality image content. In descending order of importance, select a position and orientation relative to the sun such that:

   a. Foliage is ≥ 50 cm from the lens. If foliage is < 50 cm from the lens:

      i. Select an alternate spot as close as possible to the designated photo-point. Alternate point should be ≤ 1 meter from the designated photo-point.

      ii. If foliage is < 50 cm from the lens at all locations, select a location where the distance between lens and foliage is maximized.

      iii. If (a) is not possible at ≥ 50% of points, and you are holding the camera at shoulder height, consider taking extended monopod photos. Upward-facing ground-level photos may also be considered (least preferred option, see SOP A).

   b. The photographer's shadow is minimized within the photo.

   c. The footpath along the cardinal axis is minimized within the photo.

5. 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; above this value images may become grainy and differentiation of soil/litter from leaves can be more difficult.

6. Place the monopod at shoulder height, with the lens facing down.

7. Keep the camera so that the lens is as close to perpendicular to the ground as possible.

8. 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.

9. Press the shutter release button the rest of the way to take the photo. With the 2 s shutter-release delay, you have time to steady the camera before the shutter is released.
10. Check the photo for quality:
    a. Zoom into the image and make sure leaves are in crisp focus (blurriness can occur either due to camera shake or poor focus lock).
    b. Check that shutter speed and f/stop values are within guidelines (**Table 10**).
        i. ***Note:*** When there is too little light, the camera will override minimum shutter-speeds specified via the Auto-ISO Sensitivity Settings menu. This "feature" is a common cause of blurry downward-facing images.
    c. Verify that the image is not over/under-exposed (auto-exposure can occasionally fail under field conditions):
        i. The image is underexposed if green vegetation cannot be clearly distinguished from soil or litter. In an underexposed image, the pixels in the histogram will also be compressed to the left (**Figure 5**).

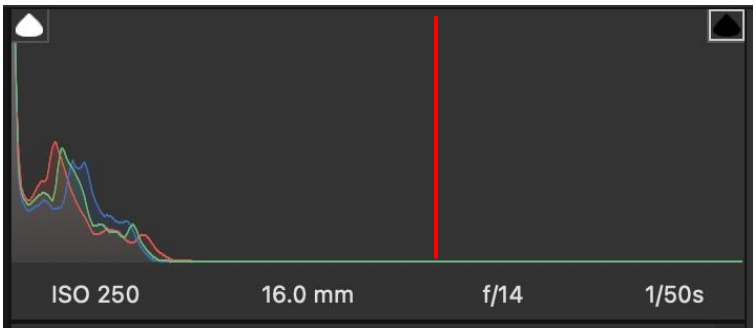

Figure 5. Example histogram from an underexposed image. All pixels are compressed to the left of the half-way point marked by the red line.

        ii. For a properly exposed image, the brightest pixels should extend past the half-way point in the histogram (**Figure 11**).
        iii. The image is overexposed if pixels pile up on the right side of the histogram (**Figure 12**).
    d. Check that the image was taken perpendicular to the ground. Pay attention to the orientation and angle of the horizon relative to the frame, if visible.
    e. If necessary, re-shoot until a satisfactory image is taken (see **Figure 7**). Unsatisfactory images may be deleted in the field as photos are collected but this is not required.
        i. To adjust exposure when collecting an image in the automatic Aperture-priority mode: Press the "+/-" exposure compensation button located next to the shutter-release button, and simultaneously rotate the primary wheel until "-0.7" is displayed in the top LCD screen (**Figure 6**).

Figure 6. Adjusting exposure with the exposure compensation button. Depress the exposure compensation "+/-" button (upper-right red circle) and rotate the primary wheel to initially set the compensation to "-0.7" (center red circle).

ii. Collect a test image, check the histogram, and continue to adjust the exposure compensation from "-0.7" to "-1.0" if needed. It is possible that a more negative value than "-1.0" will be required; positive values are typically not needed but may be helpful in low-light conditions.

f. **If it is not possible to obtain an image that meets the f/stop, ISO, and shutter speed guidelines in Table 10 , collect DHPs when more light is available**. Unlike upward-facing DHPs, downward-facing DHPs may be taken with direct sunlight on the foliage.

11. Create child records in the *DHP: Leaf Area Index [PROD]* application to record required DHP field metadata as images are acquired. ***Use call and response between data recorder and photographer to ensure accurate communication and transcription.*** Refer to the Leaf Area Index Fulcrum Manual on the SSL for detailed data entry guidance. Required data include:

a. **Point ID**: 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 (e.g., N2, E10, etc.)

b. **Image Type**: Select 'Overstory' or 'Understory' depending on the vegetation photographed.

i. Record 'Understory' for all downward-facing images, even if there is no overstory vegetation (e.g., grassland, cropland, etc.)

ii. Record 'Understory' if you are using the Extended Monopole (SOP C.1.1) to photograph a mixture of understory and mid-stature overstory.

c. **Camera Position**: A categorical indicator of where the camera was held. Combined with Image Type, this variable automatically determines the Camera Orientation.

d. **Image File Number**: The numeric portion of the file name automatically generated by the camera.

   i. Example: Record '47' for an image named 'D08_0047.NEF' by the camera.

e. **Image Extension**: Indicate the type of image recorded by the camera. Defaults to 'NEF'; the 'JPG' option is typically only used when the camera is not configured properly and a return visit to the plot is not possible.

f. **Image Remarks**: Photo-specific remarks pertinent to Field Science staff or data end-users.

12. Proceed either to the next photo-point or the next plot, if all points have been photographed.

Figure 7. 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.

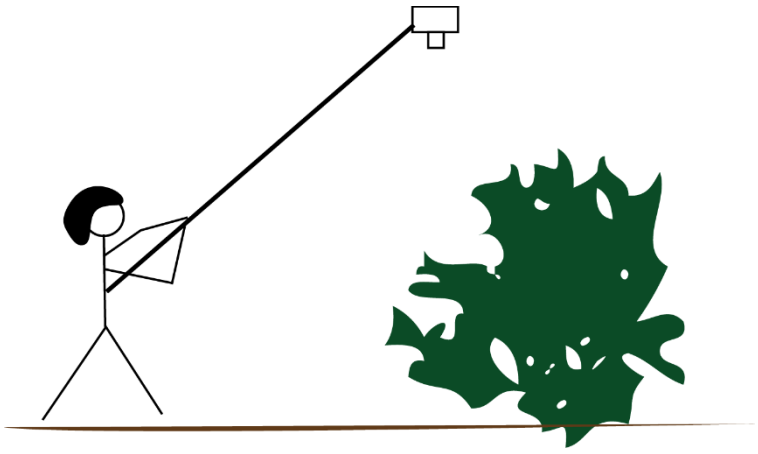

Figure 8. Illustration of using the extended monopole technique to acquire DHPs from mid-stature vegetation.

C.1.1 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 10**).
    a. Check that the camera is configured with a 2 s delay for the shutter-release.
2. Adjust the camera for proper image exposure.
3. Standing at the selected photo location, one person extends the monopod outward above the head with the lens facing down (as in **Figure 8**). Micro-adjust the position and choose a direction such that:
    a. Foliage is ≥ 50 cm from the lens.
    b. The photographer's shadow is minimized in the image.
4. If necessary, adjust the ball-mount so the camera remains perpendicular to the ground.
5. The second person assumes a position next to the person holding the monopod and positions the remote shutter release within range of the receiver.
6. 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.
7. Check the photo for quality as described in SOP C.1, and repeat if necessary.
8. Record required DHP field metadata as in SOP C.1. Ensure that:
    a. **Camera Position** = 'extendedMonopole'.
9. Proceed either to the next photo point, or to the next plot if all points have been photographed.

SOP D Field Sampling: Upward-Facing DHPs

Overview and Goals

- Collect upward-facing photos from plot when direct sunlight is not on foliage (Section 4.1.1).
- Upward-facing photos should be collected if a tree (or palm tree) > 3 m height *exists in the plot*. In this case, collect upward-facing photos even if average vegetation height is < 2 meters.
- Upward-facing images are not required if average vegetation height for the plot is < 2 m and no trees > 3 m height exist in the plot.
- Keep the camera lens ≥ 50 cm from foliage and properly expose and focus all images.
- Collect required field sampling metadata in the *DHP: Leaf Area Index [PROD]* mobile application.
  - The Leaf Area Index Fulcrum Manual on the SSL is a detailed data entry guide.

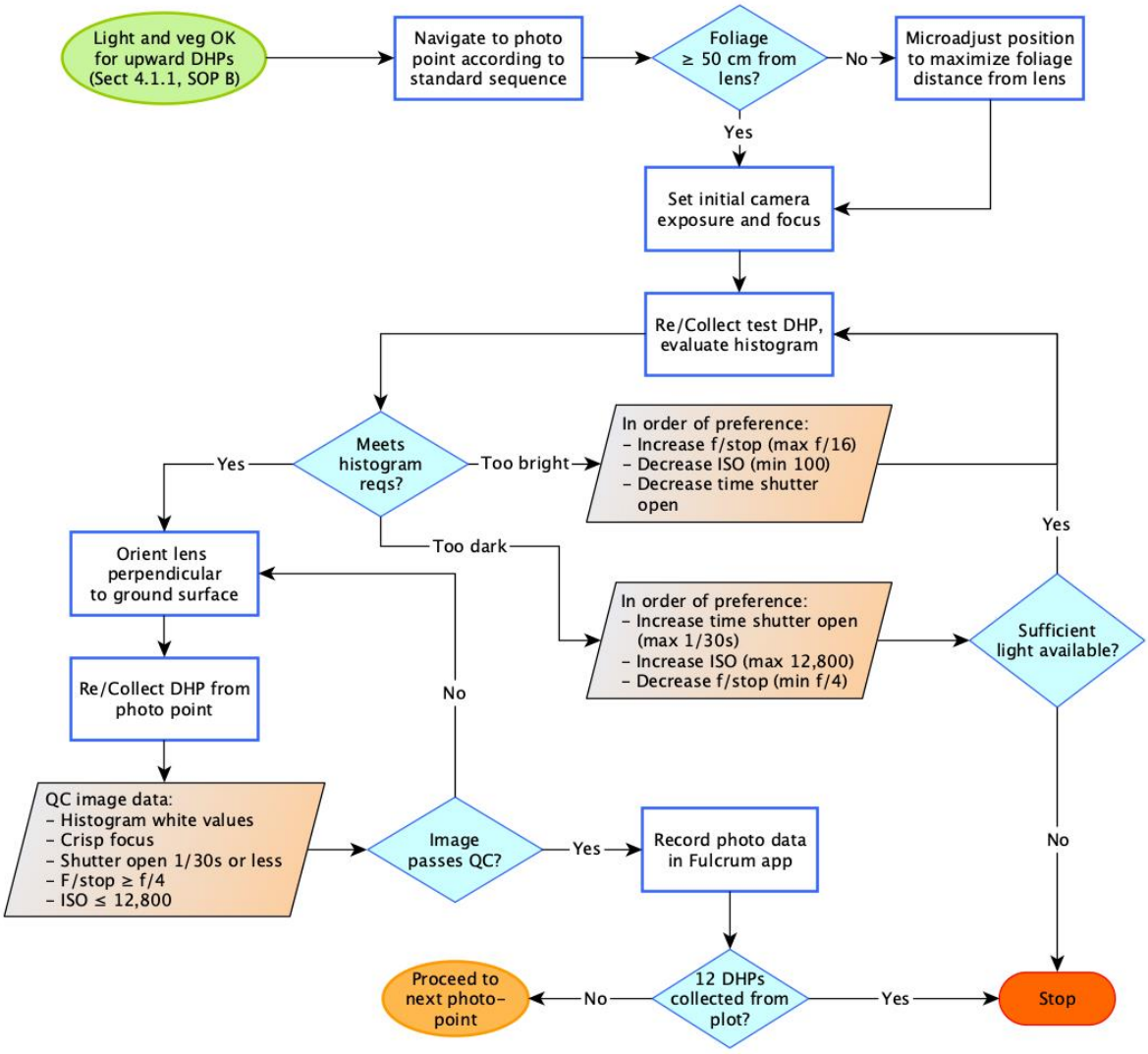

Figure 9. Expanded workflow diagram for upward-facing DHP collection. Diagram supports and does not replace protocol text; most common workflow is outlined.

D.1 Taking Upward-Facing DHPs

1. Navigate to the plot to be sampled.
    a. Consult RD[08] to plan routes and avoid unnecessary foot traffic in NEON plots.
    b. (*Distributed plots only*) Visit plots according to the Plot Prioritization list (SOP A.2).
2. Create a record in the *DHP: Leaf Area Index [PROD]* app for the plot and enter parent-level data (as in SOP C.1). Skip this step if a record has already been created for the plot for downward-facing DHPs.
3. 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 50 cm of the compass at all times.** When at the photo point:
    a. Check to ensure the person recording data is out of the camera's field of view.
4. Find a position at or as close to the photo-point as possible 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 halfway to activate the viewfinder light meter.
    b. With the lens still pointing up, adjust the f/stop, shutter speed, and ISO according to **Table 12** until the built-in light meter indicates proper exposure (also known as the 'exposure indicator' in some camera models).
    c. Press the shutter-release button all the way down to take the test image.

Table 12. Strategy for optimizing image exposure while taking upward-facing DHPs in manual exposure mode. This guidance assumes initial camera settings are as described in **Table 11**.

Exposure Problem	Histogram Characteristics	Optimization Steps (in order of preference)
Too much light	Pixels "pile up" against right edge	Increase f/stop to a maximum of f/16
		Decrease ISO to a minimum of 100
		Decrease time shutter is open.
Too little light	Large gap between brightest pixels and right edge	Ensure shutter is open the maximum allowed time (1/30 s)
		Increase ISO to a maximum of 12,800
		Decrease f/stop to a minimum of f/4
		If still unacceptable, light conditions are too poor.

5. 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.
        i. 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.
        i. **Figure 10** illustrates the general components of a histogram as it pertains to digital photography.
        ii. **Figure 11** shows a histogram from a properly exposed image. Note there is no significant “pile-up” of pixels at the right edge. It is good practice for a gap to exist between the brightest pixels and the right-most edge.
        iii. **Figure 12** 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.

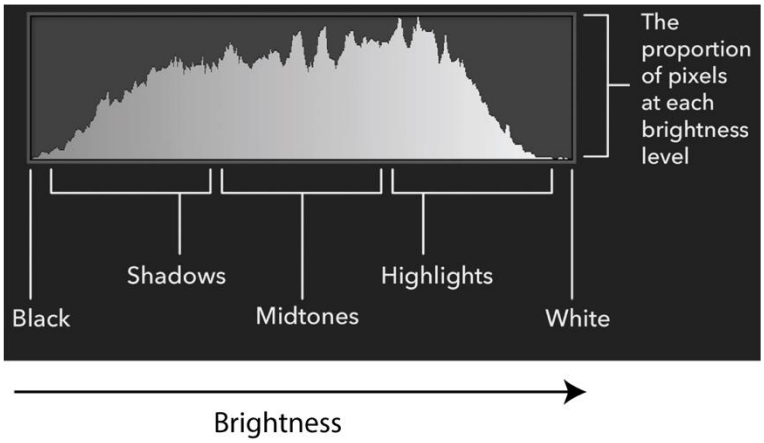

Figure 10. The general components of a histogram produced from a digital photograph. Brightness increases from left to right along the x-axis and the y-axis represents the number of pixels in the image at a given brightness level.

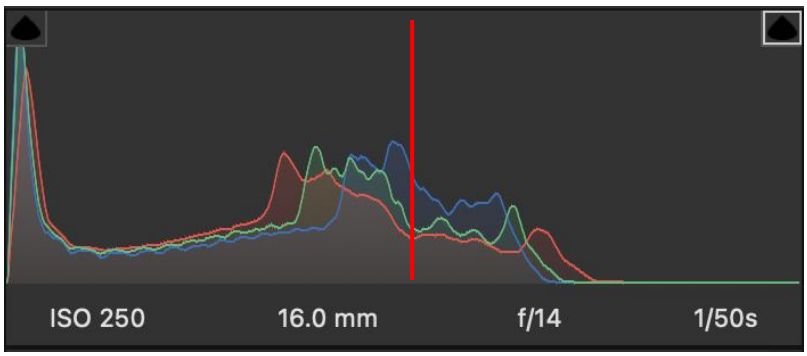

Figure 11. An example histogram from a properly exposed upward-facing image. Note that the brightest pixels extend past the half-way point in the histogram (red line) but do not "pile up" on the right.

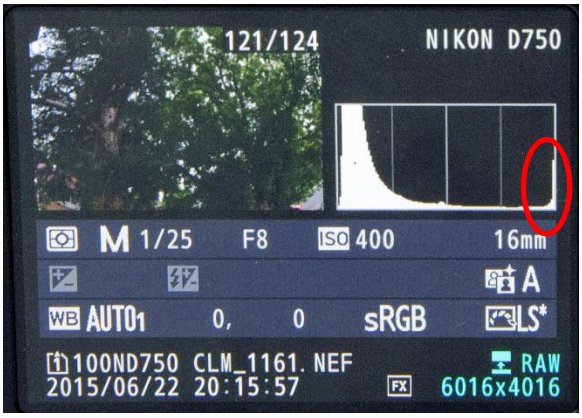

Figure 12. An example image and histogram of an overexposed upward-facing DHP. Note that the brightest pixels "pile-up" into a peak at the right-most edge of the histogram (red circle).

6. If necessary, adjust the exposure according to **Table 12** and take another test image until a correctly exposed image is produced (**Figure 11**). When adjusting exposure, aim for:
   a. Higher f/stops →reduced light to the sensor, greater depth of field, more of the subject in focus.
   b. Shutter open for less time → reduced light to sensor, better ability to "freeze" motion and avoid blurriness associated with subject motion or camera shake.
   c. Lower ISO → sensor is less sensitive to light but image grain is less prominent; below ISO 12,800, images will have fewer "noise" artifacts.
7. 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 (SOP D, **Table 13**).

8. Stand at the selected photo location.
9. 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).
10. Place the monopod either at shoulder height or on the ground (**Figure 13**).

Figure 13. A field researcher acquiring an upward-facing DHP with the monopod/camera held at shoulder height.

11. Orient the camera so that the lens is as close to perpendicular to the ground as possible.
12. 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.
13. Check the photo for quality:
    a. Make sure histogram white saturation values are appropriate (not too bright/dark).
    b. Make sure the image is not blurry.
    c. Check that appropriate shutter speed and f/stop values were obtained.
    d. Check that there is clear distinction between foliage and sky.
    e. If necessary, delete and re-shoot until a satisfactory image is taken (see **Figure 11**).
    f. 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.
14. Create child records in the *DHP: Leaf Area Index [PROD]* application to record required DHP field metadata as images are acquired. ***Use call and response between data recorder and photographer to ensure accurate communication and transcription.*** Refer to the Leaf Area Index Fulcrum Manual on the SSL for detailed data entry guidance. Required data include:
    a. **Point ID**: 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 (e.g., N2, E10, etc.)

b. **Image Type**: Select 'Overstory' or 'Understory' depending on the vegetation photographed.

   i. Record 'Understory' for upward-facing images taken at ground level.

   ii. Record 'Overstory' for all other upward-facing images.

c. **Biophysical Criteria**: Select the applicable biophysical criteria.

NOTE: If the biophysical criteria of ***'conditions not met – no photo taken'*** is selected, there will be a child record created in the application. This empty child record is needed to ingest the parent record.

d. **Camera Position**: A categorical indicator of where the camera was held. Combined with Image Type, this variable automatically determines the Camera Orientation.

e. **Image File Number**: The numeric portion of the file name automatically generated by the camera.

   i. Example: Record '47' for an image named 'D08_0047.NEF' by the camera.

f. **Image Extension**: Indicate the type of image recorded by the camera. Defaults to 'NEF'; the 'JPG' option is typically only used when the camera is not configured properly and a return visit to the plot is not possible.

g. **Image Remarks**: Photo-specific remarks pertinent to Field Science staff or data end-users.

SOP E Troubleshooting

Table 13. 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	*Preferred:* If feasible, collect photos of the understory with an extended monopole.
		Second choice: Choose a location that maximizes the distance between the foliage and the lens. Record approximate distance to foliage in "remarks".
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 Document Incomplete Sampling Within a Site

Leaf Area Index sampling is scheduled to occur at all prescribed sampling locations according to the frequency and timing described in Section 4 and Appendix C. Ideally, sampling will occur at these sampling locations for the lifetime of the Observatory (core sites) or the duration of the site's affiliation with the NEON project (gradient sites). However, sampling may be shifted from one location to another when sampling is compromised. In general, a sampling location is compromised when sampling becomes so limited that data quality is significantly reduced.

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

For Leaf Area Index sampling, criteria for considering a plot compromised include:

- ***For Distributed plots***: If sampling cannot be completed at a plot for 2 consecutive bouts. Because bouts are scheduled every 5 years, it is necessary to examine **Sampling Impractical** information using Portal data from previous bouts to determine whether a plot has been compromised.
- ***For Tower plots***: If sampling cannot be completed at a plot for 4 or more bouts within a year.
- ***For all plots***: Canceling sampling at a plot for internal logistical or management reasons does not count (e.g., lack of staff resources).

If sampling at a given plot is not possible during a given bout a problem ticket should be submitted by Field Science staff.

<u>To document locations not sampled during the current bout:</u>

1. Review the completed sampling effort and create **Sampling Impractical** records as described in Section 4.5 for plots at which sampling was scheduled but was not completed.
2. To document whether a location is compromised according to the criteria above:
    a. Review **Sampling Impractical** records from the *DHP: Leaf Area Index [PROD]* application and Portal data to identify locations where sampling was scheduled but was not completed due to environmental or site management factors.
3. Create an incident with the following naming convention to document the missed sampling and compromised location: 'TOS Sampling Incomplete: DHP – [Root Cause Description]'
    a. Example: 'TOS Sampling Location Compromised: DHP – Could not access plot for 2 consecutive bouts due to persistent flooding'

Staff scientists review incident tickets periodically to determine whether a sampling location is compromised.

F.2 DHP Handling

1. ***As soon as possible*** following field sampling, copy images from the camera memory card(s) to a dedicated, labeled external HDD/SSD that is stored in a secure, labeled location in the Domain Support Facility.
    a. The NEON network 'LAI_RAW_images' folder should only be used to temporarily store images in the event an external SSD is unavailable. Copying/pasting images to the 'LAI_RAW_images' folder may be plagued by file transfer issues (e.g., corrupted files).
2. ***As soon as possible after returning from the field*** use the Warbler QAQC Shiny tool to perform file organization (per **Table 14**), as well as image QC checks.
    a. The Warbler tool validates that each data record from the field can be matched with a DHP, and that there are no duplicate DHPs with different extensions (e.g., DXX_0001.JPG and DXX_0001.NEF both exist).
    b. Rectify any data entry errors that are identified.
    c. Select an external drive (preferred) or a local laptop folder as the destination for the organized images.
        i. Image organization may stall if the 'LAI_RAW_images' folder on the N-drive is selected. If needed, images may be copy/pasted to 'LAI_RAW_images' after organizing locally with Warbler.
    d. For photos that do not meet protocol requirements for aperture, ISO, or shutter-speed, or for images that are out of focus: Return to the field and collect high-quality images (preferred), or create an incident to document protocol requirements not being met.

Table 14. Criteria for determining placement of DHP images within required file path and folder structure.

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

3. Following initial file organization with Warbler, visually inspect images to verify that DHP image content matches the directory structure in the selected target volume – i.e., verify that images in 'understory' and 'overstory' folders really are of understory or overstory vegetation.
4. Once images pass QC, use the Warbler 'File Transfer' tab to upload organized DHPs to the cloud.

a. Use the "Bucket Check" button in Warbler to verify successful upload to the cloud. Submit an Incident if Warbler generates an upload Quality Flag.

   Note: The "Bucket Check" button can be used before upload if it is unclear whether images may have already been uploaded for a given bout.

b. ***Failure to copy images to cloud storage within 30 days of Fulcrum record creation will result in parser error messages***.

5. After DHPs from a given bout are copied to an external drive (HDD or SDD), AND have been uploaded to the cloud, image files on the camera memory card(s) may be deleted.

6. Keep DHPs on the labeled external drive for the current year, as well as all images from the prior year. Images older than the prior year may be deleted.

   a. *Example*: If it is December 2025, almost two years of images should be saved to the external drive – all of 2025 and all of 2024. Once image collection begins for 2026 (often in March), images from 2024 would be deleted from the external drive.

F.3 Refreshing the Sampling Kit

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

F.4 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 and Verification

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

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

Quality Assurance

Data Quality Assurance (QA) is an important part of data collection and ensures that all data are accurate and complete. Certain QA checks can be conducted in the field (i.e., before a field team leaves a plot or site), while others can be conducted later in the office (typically within a week of collection). Field QA procedures are designed to prevent the occurrence of invalid data values that cannot be corrected later, and to ensure that data and/or sample sets are complete before the sampling window closes. Invalid metadata (e.g., collection dates, plotIDs) are difficult to correct when field crews are no longer at a sampling location.

Office QA procedures are meant to ensure that sampling activities are ***consistent*** across bouts, that sampling has been carried out to ***completion***, and that activities are occurring in a ***timely*** manner. Office QA will also identify inadvertently duplicated data and transcription errors to maintain data ***validity*** and ***integrity***. See the Data Management Protocol (RD[04]) for more discussion of QA measures.

Before digital records load to the NEON database, the data must undergo thorough quality checks. The steps needed to accomplish this are outlined in the DHP QC Checklist, which is linked via the 'QF Definitions' tab in the Warbler QAQC Shiny app and is also available via the NEON SSL.

G.1 Data Quality Control

Use the Leaf Area Index 'QC Checklist' documents linked via the SSL to guide and focus QC activities. Below is a high-level summary of important QC activities for the parent- and child-level data in the *DHP: Leaf Area Index [PROD]* Fulcrum application.

1. Parent-level data
    a. The **yearBoutBegan**, **weekBoutBegan**, and **plotID** fields are used to construct the **sampleID** for the plot and the **Subsample ID** for each image. *Make sure these are entered correctly before creating child records for each photo.*

b. If corrections to any of the above parent-level fields need to be made and child records for photos have already been created, you will need to open each child record for editing and then save to propagate the change and update the **subsampleID**.

2. Child-level data

   a. The **PointID** and **Image Type** fields are used to complete the **Subsample ID** for each image. *Make sure these are entered correctly for each child record.*

   b. The **Image File Number** and **Image Extension** are used to complete the **Image File Path** that allows each image to be downloaded by data users. *Incorrect data entry in these fields will generate a VERIFY_URL parser error.*

3. Consult the Leaf Area Index Fulcrum Manual linked via the SSL for more data entry details.

G.2 Field Datasheets

1. Transcribe data from the Leaf Area Index Data Sheets (RD[05]) to the *DHP: Leaf Area Index [PROD]* application.

2. Consult the Leaf Area Index Fulcrum Manual linked via the SSL to determine appropriate values and formats for each field in the data sheet.

SOP H Sample Shipment

Not applicable to the Measurement of Leaf Area Index protocol.

8 REFERENCES

Brown, L.A., Meier, C., Morris, H., Pastor-Guzman, J., Bai, G., Lerebourg, C., Gobron, N., Lanconelli, C., Clerici, M. and Dash, J., 2020. Evaluation of global leaf area index and fraction of absorbed photosynthetically active radiation products over North America using Copernicus Ground Based Observations for Validation data. Remote Sensing of Environment, 247, p.111935.

Didan, K. 2023. *MODIS/Terra Vegetation Indices 16-Day L3 Global 250m SIN Grid V061*. 2021, distributed by NASA EOSDIS Land Processes Distributed Active Archive Center, https://doi.org/10.5067/MODIS/MOD13Q1.061.

APPENDIX A QUICK REFERENCES

A.1 Acquiring and Publishing Digital Hemispherical Photos

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 and focus. Delete and reshoot as needed.
7. Record pointID and other required information in the *DHP: Leaf Area Index [PROD]* application.
8. Continue collecting 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.
13. Copy images to an external drive for storage (preferred). Images may be temporarily copied to the NEON network **LAI_RAW_images** folder if an external drive is unavailable.
14. ***Within 30 days*** perform image QC with the Warbler Shiny QAQC tool and upload image files to the NEON cloud.
15. Delete images from the external hard drive that are more than 2 years old.

APPENDIX B REMINDERS

At least two days before field effort: Make sure…

- ☑ Fisheye lens is clean and not scratched.
- ☑ Primary and backup batteries for camera are charged.
- ☑ A minimum of one backup SD card is available.
- ☑ 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 backup datasheets are printed.
- ☑ All equipment is gathered and in working order.

B.1 Taking Quality Hemispherical Images

When you arrive at site: Make Sure…

- ☑ Direct sunlight is NOT visible on foliage before you begin to acquire 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 compass.
- ☑ You've determined number and type of photographs needed.

B.2 Image Acquisition Checklist

Check for the following:

- ☑ Camera settings are correct. Make sure to lock the manual aperture ring at f/22.
- ☑ 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. For downward-facing photos, avoid high-contrast between bright leaves and deep shadows.
- ☑ Camera is recording NEF photo format, not JPG.
- ☑ 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 ≥ 50 cm from the camera lens.
- ☑ Camera is held as close to perpendicular to ground surface as possible.
- ☑ ***Most important***: Using the LCD on the back of the camera, zoom in to individual leaves/twigs and check for crisp focus on foliage, both near and far. Also check that f/stop, shutter speed, and ISO are within required ranges.
- ☑ **Week Bout Began** (parent record) and **Point ID** (child) are correctly recorded.
- ☑ Any deviations from protocol are described in **remarks**.

B.3 Data QA/QC Checklist

Data QA/QC checklists developed by Field Operations are linked via the SSL. Important data QA/QC checks include:

- ☑ Fulcrum Data Entry: Ensure **Plot ID, Year Bout Began**, and **Week Bout Began** are correctly entered into the parent record. These data are used to construct the **Sample ID.** Correct values in Fulcrum prevent duplicate errors.
- ☑ Fulcrum Data Entry: For child-record data entry, review and ensure all required fields are correct. Required fields are used to construct the **Subsample ID** and the **Image File Path**. Correct values will prevent 'Sample does not exist' and 'VERIFY_URL' errors from the parser.
- ☑ Image Number: Are the required number of images accounted for? (12 or 24 per plot)
- ☑ Image Quality: Are images in focus? Is ISO within required range? Is f/stop within required range? Is Shutter Speed within required range?
- ☑ Image Organization: Use the Warbler Shiny application to perform QC checks on Fulcrum records. Once QC checks have passed, use Warbler to move images into required directory structure.
- ☑ Image Publication: When images pass QC checks and are organized as required, upload images to the NEON cloud ingest bucket to be published via the NEON Data Portal. *Failure to do this within 30 days of creating linked Fulcrum records will result in VERIFY_URL parser errors.*

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 15** provides estimated Start and End Dates for LAI sampling in Tower plots based on MODIS-EVI phenology data, averaged for 2012-2021 (Didan 2023). 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. For sites with two greenness peaks, the dominant peak according to MODIS-EVI is noted and Distributed Plot sampling is scheduled for the dominant greenness peak. Note dates below are intended for initial scheduling purposes only and actual flight dates may be outside Peak Greenness windows; the high-level requirement is that Distributed plot LAI sampling should be scheduled within a 1 month window that includes the actual AOP flight date.

Table 15. Site-specific sampling start and end dates for LAI time course sampling in Tower Plots, and peak greenness sampling date ranges for spatially-intensive Distributed Plot LAI sampling. Sampling on a 4-week interval during peak green applies only to Tower plots.

Domain Number	Site ID	Start Date	End Date	Peak Greenness	Peak Green 4-week interval	Additional Sampling Information
01	BART	04/21	11/01	06/18-08/16	Y	
	HARV	04/21	11/01	06/15-08/13	Y	
02	BLAN	03/23	11/01	06/01-08/19	Y	Variable peak greenness window; may end by 06/30. Visual estimates from MODIS time-course data for end date and end of peak greenness window.
	CASE	03/21	11/01	06/01-08/28	NA	Visual estimate from MODIS time-course data for end of peak greenness window.
	SCBI	04/02	11/01	05/30-08/04	Y	
	SERC	03/27	11/01	06/02-08/11	Y	
03	DSNY	03/07	NA	05/24-07/28	N	• 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 11/19 – 3/07 (instead of every 2 weeks).

Domain Number	Site ID	Start Date	End Date	Peak Greenness	Peak Green 4-week interval	Additional Sampling Information
	JERC	04/05	NA	06/24–08/18	N	• Distributed Plots: Variable peak greenness window; may end by 07/14. • Tower Plots: Year-round sampling, shifting to every 4 weeks between 11/11 – 04/05 (instead of every 2 weeks).
	OSBS	03/12	NA	05/23-07/25	N	• 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 11/09 – 03/12 (instead of every 2 weeks).
04	GUAN	NA	NA	NA	NA	• Distributed Plots: No peak greenness according to MODIS, schedule to overlap with AOP flight. • Tower Plots: Year-round sampling on 4-week interval.
	LAJA	NA	NA	NA	NA	• Distributed Plots: No peak greenness according to MODIS, schedule to overlap with AOP flight. • Tower Plots: Year-round sampling on 4-week interval.
05	CHEQ	NA	NA	06/21-08/12	NA	Start and End Dates not supplied since CHEQ does not support Tower Plots.
	STEI	04/26	10/28	NA	Y	Peak Greenness dates not supplied because STEI does not support Distributed plots.
	TREE	04/26	10/28	06/21-08/12	Y	
	UNDE	04/29	10/23	06/22-08/13	Y	
06	KONA	04/05	11/01	06/11-08/11	Y	Variable peak greenness window; may end by 07/09.
	KONZ	04/14	11/01	06/17-08/11	N	Variable peak greenness window; may end by 07/09.

Domain Number	Site ID	Start Date	End Date	Peak Greenness	Peak Green 4-week interval	Additional Sampling Information
	UKFS	03/28	11/01	06/10-08/11	Y	Variable peak greenness window; may end by 07/04.
07	GRSM	04/03	11/01	06/06-08/09	Y	
	MLBS	04/15	11/01	06/10-08/11	Y	
	ORNL	03/24	11/01	05/18-07/23	Y	
08	DELA	03/14	11/01	05/15-07/22	Y	Earlier start date than MODIS-EVI based on Field Science phenology observations.
	LENO	03/18	11/01	05/16-07/25	Y	Earlier start date than MODIS-EVI based on Field Science phenology observations.
	TALL	03/24	11/01	05/19-07/20	N	Earlier start date than MODIS-EVI based on Field Science phenology observations.
09	DCFS	05/04	11/01	07/05-08/19	N	
	NOGP	04/20	11/01	06/27-08/14	N	
	WOOD	05/12	11/01	07/12-08/24	N	
10	CPER	04/06	10/04	*06/16-07/22*	N	Two greenness peaks, first is dominant. Variable peak1 greenness window; may begin by 06/16, or end by 06/16. Visual estimate from MODIS time-course data for start date.
	RMNP	05/01	10/24	07/03-08/02	N	Visual estimate from MODIS time-course data for start date.
	STER	03/27	09/23	05/26-08/14	N	Variable peak greenness window; may end by 06/04 (early crop harvest?). Visual estimate from MODIS time-course data for all dates.
11	CLBJ	03/13	11/11	*05/15-07/21*	N	Two greenness peaks, first is dominant. Variable peak1 greenness window; may end by 06/09.
	OAES	03/08	12/06	*05/06-11/01*	N	Two greenness peaks, first is dominant. Visual estimate from MODIS time-course data for all dates.

Domain Number	Site ID	Start Date	End Date	Peak Greenness	Peak Green 4-week interval	Additional Sampling Information
12	YELL	07/01	11/01	06/16-07/23	N	Late Start Date reflects Bear Management Area closure around Tower plots from 03/10 to 06/30. Visual estimate from MODIS time-course data for end date; sampling may end earlier if snow prevents site access.
13	MOAB	04/30	10/18	*05/26-09/11*	N	Two greenness peaks, MODIS data difficult to interpret. Distributed plot timing should be coordinated with AOP, field verification required. Visual estimate from MODIS time-course data for peak greenness start date and end date.
	NIWO	05/04	10/02	07/10-08/17	N	Start date and end date may be affected by snow blocking site access.
14	JORN	03/22	11/01	05/05-09/07	N	Variable peak greenness window; may begin by 05/05, end by 07/31. Visual estimate from MODIS time-course data for start date and peak greenness window.
	SRER	03/01	11/01	*08/03-09/13*	N	Two greenness peaks, second is dominant; Distributed plot timing should be coordinated with AOP; adjust dates earlier/later as needed based on AOP flight date. For Tower plots, variable start and end dates, pay attention to within-year phenology. Visual estimate from MODIS time-course data for start date, end date, and start of peak greenness window.
15	ONAQ	03/31	09/23	05/06-06/10	N	Variable peak greenness window; may begin by 04/10, end by 05/15. Visual estimate from MODIS time-course data for peak greenness window.

Domain Number	Site ID	Start Date	End Date	Peak Greenness	Peak Green 4-week interval	Additional Sampling Information
16	ABBY	03/28	11/01	06/09-07/29	Y	
	WREF	03/21	11/01	06/09-08/01	Y	
17	SJER	10/05	06/11	03/03-04/10	N	• 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	03/26	10/27	05/27-06/26	N	Start date and peak greenness window earlier than MODIS dates due to recent fires.
	TEAK	04/17	10/31	06/22-08/08	N	
18	BARR	05/21	09/29	07/22-08/13	N	End of peak greenness window earlier than MODIS date based on Field Science feedback. Late-season bouts may be cancelled if herbaceous plants senesce before end date.
	TOOL	05/07	09/16	07/08-08/07	N	Late-season bouts may be cancelled if herbaceous plants senesce before end date.
19	BONA	05/03	10/01	06/23-08/03	Y	Late-season bouts may be cancelled if herbaceous plants senesce before end date.
	DEJU	05/01	10/03	06/25-08/05	Y	Late-season bouts may be cancelled if herbaceous plants senesce before end date.
	HEAL	04/25	10/05	06/28-08/07	Y	Late-season bouts may be cancelled if herbaceous plants senesce before end date.
20	PUUM	NA	NA	NA	NA	• Distributed Plots: No peak greenness, time to coincide with AOP. • Tower Plots: Year-round sampling on 4-week interval.

APPENDIX D SITE-SPECIFIC INFORMATION

D.1 D10 – STER– North Sterling

Specific issues: Herbicide application kills plants

Solution: Do not alter photo strategy due to herbicide application. Important for dataset to contain zero LAI points.

D.2 D18 – TOOL – Toolik

Specific issues: Sun may not set during summer months.

Solution: Upward-facing photos: Light is as indirect as possible. Take photos as late or early in the day as is feasible. Avoid collecting photos from 10:00 – 16:00 when the sun is likely to be directly behind foliage. Mid-day photo collection may be acceptable if standard cloud-cover criteria are met.

Downward-facing photos: Light must be strong enough to differentiate greens from browns. Avoid collecting photos mid-day with direct sunlight; photos collected under these conditions may have high contrast between bright leaves and deep shadows that makes analysis for LAI difficult.

D.3 D19 – DEJU – Delta Junction

Specific issues: Sun may not set during summer months.

Solution: Upward-facing photos: Light is as indirect as possible. Take photos as late or early in the day as is feasible. Avoid collecting photos from 10:00 – 16:00 when the sun is likely to be directly behind foliage. Mid-day photo collection may be acceptable if standard cloud-cover criteria are met.

Downward-facing photos: Light must be strong enough to differentiate greens from browns. Avoid collecting photos mid-day with direct sunlight; photos collected under these conditions may have high contrast between bright leaves and deep shadows that makes analysis for LAI difficult.

D.4 D19 – HEAL – Healy

Specific issues: Sun may not set during summer months.

Solution: Upward-facing photos: Light is as indirect as possible. Take photos as late or early in the day as is feasible. Avoid collecting photos from 10:00 – 16:00 when the sun is likely to be directly behind foliage. Mid-day photo collection may be acceptable if standard cloud-cover criteria are met.

Downward-facing photos: Light must be strong enough to differentiate greens from browns. Avoid collecting photos mid-day with direct sunlight; photos collected under these conditions may have high contrast between bright leaves and deep shadows that makes analysis for LAI difficult.

D.5 D19 – BONA – Caribou-Poker Creeks Research Watershed

Specific issues: Sun may not set during summer months.

Solution: Upward-facing photos: Light is as indirect as possible. Take photos as late or early in the day as is feasible, avoid collecting photos from 10:00 – 16:00 when the sun is likely to be directly behind foliage. Mid-day photo collection may be acceptable if standard cloud-cover criteria are met.

Downward-facing photos: Light must be strong enough to differentiate greens from browns. Avoid collecting photos mid-day with direct sunlight; photos collected under these conditions may have high contrast between bright leaves and deep shadows that makes analysis for LAI difficult.

APPENDIX E 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 16. Equipment list – A team of two people collecting DHPs from a plot.

Supplier/Item No.	Exact Brand	Description	Purpose	Quantity
Ben Meadows/213379, Forestry Suppliers/ 37184 or 37036	N	Compass with mirror and declination adjustment	Orient to image locations	1
B&H Photo Corp/NID750	Y	DSLR camera body	Capture DHP images	1
B&H Photo Corp/ SAEPSD16GB	N	DSLR SD memory card (16 Gb minimum)	Store and backup DHP images on camera	2
B&H Photo Corp/ NI1628DAF	Y	Fisheye lens, 16 mm	Capture DHP images	1
Amazon/010007810 1 Cabelas/IK270217 or REI/895022	N	GPS receiver, recreational accuracy	Navigate to sampling location	1
Forestry Suppliers/2224	N	Headlamp	Hands-free lighting at dusk and dawn	2
Forestry Suppliers/91567	Y	Laser rangefinder	Measure overstory height	1
B&H Photo Corp/ SECCMF77G	N	Microfiber or paper lens cleaning cloth	Clean camera lens	1
B&H Photo Corp/ VERWIIN	N	Wireless remote shutter release (Vello FreeWave Plus for Nikon or similar)	Remotely focus camera and trip shutter release on Nikon D800/D810 camera models. Also compatible with D750.	1
B&H Photo Corp/ MAPMXPROA3US	N	Camera monopod	Hold camera steady away from body	1
	N	U-bolt with rubber feet	Affix to monopod to hold camera above the ground surface when shooting upward-facing photos from ground level	1

Supplier/Item No.	Exact Brand	Description	Purpose	Quantity
B&H Photo Corp/ MA496RC2	N	Ball-head tripod mount	Attach to monopod for downward-facing 'extended monopod' photos of mid-stature vegetation	1
B&H Photo Corp/ LOFTBP450AWB	N	Camera bag, weather resistant	Protect DSLR camera body and lenses	1
Consumable items				
	N	AA battery	Spare battery for GPS receiver	
B&H Photo Corp/ NIENEL15	N	EN-EL15 lithium ion battery	Spare battery for DSLR camera	2
Resources				
		LAI field data sheet	Record sampling event metadata in the event of tablet failure	Varies

Table 17. Equipment list – Transferring DHPs from the camera to the server, and handling field-collected sampling metadata.

Supplier/ Item No.	Exact Brand	Description	Purpose	Quantity
B&H Photo Corp/ SAEPSD16GB	N	DSLR memory card	Contains field-collected DHPs	2
B&H Photo Corp/ SAIAIOR3.0	N	DSLR memory card reader	Transfer images from memory card to temporary storage on external hard-drive following sampling event	1
	NA	Completed LAI field datasheets	Contains field-collected DHP metadata in the event of mobile device failure	Varies
B&H Photo Corp/ SAE612TB	N	External hard-drive, USB drive, or equivalent storage media	Store and backup images both before and after they are uploaded to NEON cloud storage.	1