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| Title: TOS Protocol and Procedure: TOS Protocol and Procedure: DHP - Measurement of Leaf Area Index | | Date: 07/21/2021 |
| NEON Doc. #: NEON.DOC.014039 | Author: Courtney Meier | Revision: M |

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_DRAFT | 10/03/2011 | ECO-00280 | Initial Draft Release |
| B | 01/13/2014 | ECO-01140 | Updates from 2013. Will be finalized in next rev |
| C | 03/25/2014 | ECO-01665 | Production release, template change, and other changes as detailed in Appendix C (rev C only) |
| D | 04/10/2014 | ECO-01792 | Added Appendix C with site-specific information |
| E | 11/03/2014 | ECO-02386 | Migration to new protocol template, changes to histogram interpretation and optimizing exposure for upward-facing images. |
| F | 04/14/2015 | ECO-02559 | Update of TOS protocol based on 2014 field experience and budget analysis. |
| G | 9/16/2015 | ECO-03118 | Major revisions: <ul style="list-style-type: none"> • 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: <ul style="list-style-type: none"> • 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 analysis 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. |



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| | | | <ul style="list-style-type: none"> 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 | <p>Major revisions:</p> <ul style="list-style-type: none"> 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 | <p>Major revisions:</p> <ul style="list-style-type: none"> 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 | <p>Major revisions:</p> <ul style="list-style-type: none"> 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. 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). |



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| | | | <ul style="list-style-type: none"> • 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 | <p>Major revisions:</p> <ul style="list-style-type: none"> • 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. |



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1 OVERVIEW

1.1 Background

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

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

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

1.2 Scope

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

1.2.1 NEON Science Requirements and Data Products

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



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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.



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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 | NEON Environmental, Health, Safety and Security (EHSS) Policy, Program and Management Plan |
| AD[02] | NEON.DOC.004316 | Operations Field Safety and Security Plan |
| AD[03] | NEON.DOC.000724 | Domain Chemical Hygiene Plan and Biosafety Manual |
| AD[04] | NEON.DOC.005135 | Training Lesson Plan: TOS Measurement of Leaf Area Index |
| AD[05] | NEON.DOC.050005 | Field Operations Job Instruction Training Plan |
| AD[06] | NEON.DOC.000914 | NEON Science Design for Plant Biomass and Productivity |
| AD[07] | NEON.DOC.014051 | Field Audit Plan |
| AD[08] | NEON.DOC.004104 | NEON Science Data Quality Plan |

2.2 Reference Documents

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

| | | |
|--------|-----------------|--|
| RD[01] | NEON.DOC.000008 | NEON Acronym List |
| RD[02] | NEON.DOC.000243 | NEON Glossary of Terms |
| RD[03] | NEON.DOC.002652 | NEON Data Products Catalog |
| RD[04] | NEON.DOC.001271 | AOS/TOS Protocol and Procedure: Data Management |
| RD[05] | NEON.DOC.001575 | Datasheets for TOS Protocol and Procedure: Measurement of Leaf Area Index |
| RD[06] | NEON.DOC.001398 | NEON Raw Data Ingest Workbook for TOS Digital Hemispherical Photos |
| RD[07] | NEON.DOC.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 | SOP: DSLR Camera Use and Settings |
| RD[11] | NEON.DOC.002984 | 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] |



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|------|---|
| LAI | Leaf Area Index |
| NDVI | Normalized Differential Vegetation Index (a proxy for vegetation greenness) |

2.4 Definitions

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

Leaf Area Index: 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 \geq 10 cm.



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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).



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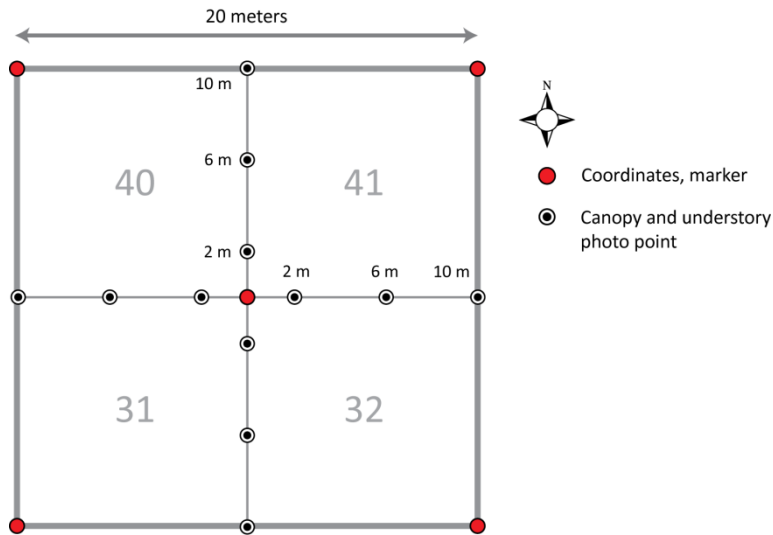


Figure 1. Distributed base plot (or 20 m x 20 m Tower plot) showing the location and spacing of LAI photo points relative to plot center; grey numbers represent subplotIDs. Spacing between points and number of points is the same for both 20 m x 20 m and 40 m x 40 m Tower plots, and photo points are always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

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

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

Quality assurance is performed on data collected via these procedures according to the NEON Science Data Quality Plan (AD[08]).



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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. Number of plots and sampling frequency guidelines for LAI sampling in Distributed and Tower Plots.

| Plot type | Plot Number | Bouts Per Year | Bout Duration | Bout Interval | Yearly Interval | Remarks |
|------------------|-------------|----------------------|---------------|-----------------|-----------------|--|
| Distributed plot | n ≤ 20 | 1X per sampling year | 1 month | NA | Every 5y | Sampling is synchronized with AOP flyover |
| Tower plot | n = 3 | Site specific | 1-2 days | * Every 2 weeks | Annual | Bout duration based on sampling conditions |

* 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.

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 |
| CDW | 5 | tower | 20 or 30 [†] | | | | X | | | |
| VST | 5 | tower | 20 or 30 [†] | | | | | X | | |

* Protocol codes and definitions: **BBC** = Plant Belowground Biomass sampling; **CFC** = Canopy Foliar Chemistry sampling; **LAI** = Leaf Area Index sampling; **LTR-bgc** = Litterfall biogeochemistry analysis; **NTR** = soil nitrogen



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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.

4.1.1 Scheduling the Field Day

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

- a. 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.
- b. **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**.
- c. 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 deep shadows. If possible, select overcast or mid-day conditions when shadows are minimal.
 - Shadows and low-light make it difficult to distinguish green from brown colors during image analysis.
- d. On a given measurement day, plan on arriving at the location of the first plot to be measured at least 20 minutes before light conditions are appropriate.

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 2015), and are provided as a guide for scheduling purposes only. To determine actual start dates in a given year:



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- **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: <ol style="list-style-type: none"> 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 |

¹ Provided the flight date (or range of possible dates) is confirmed and not subject to change more than ± 1 week.

4.3 Timing for DHP Image Transfer

Once DHPs have been collected for a given sampling bout, they must first be organized into directories according to SOP F and validated against their corresponding Fulcrum records using a QC verification tool ('Warbler' DHP QAQC Shiny application, see RD[04]), then copied to an approved network location in the Domain Support Facility (DSF) for electronic transfer and ingest into NEON's centralized cloud storage system. **Failure to do so in a timely manner** will result in parser error messages (**Table 4**).



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Table 4. Timing requirement for DHP image transfer.

| Sample type | Activity | Holding Time |
|-------------|------------------------------|------------------------------------|
| DHP Images | QC and copy 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 C and SOP D, 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 | <u><i>If delay interrupts data collection mid-plot:</i></u> a) stop data collection for the plot, and delete partial image sets – i.e., delete images if the delay prevented a full set of 12 upward- or downward-facing photos from being collected; b) upon resuming, ensure light conditions are favorable; and c) repeat data collection for interrupted image set(s) on the same day if possible. | A delay of hours can lead to poor light conditions for collection of LAI data. This can lead to overestimation or imprecise estimation of LAI. |
| | <u><i>If delay occurs between plots:</i></u> a) Ensure light conditions are favorable for data collection; and b) resume data collection for next plot. | A delay of hours can lead to poor light conditions for collection of LAI data. This can lead to overestimation or imprecise estimation of LAI. |
| 1-7 days | <u><i>If delay interrupts data collection mid-plot:</i></u> a) stop data collection for the plot, and delete partial image sets – i.e., delete images if the | None |



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

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



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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 provided in 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 – e.g., one missed sampling record per plotID.
- **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**).



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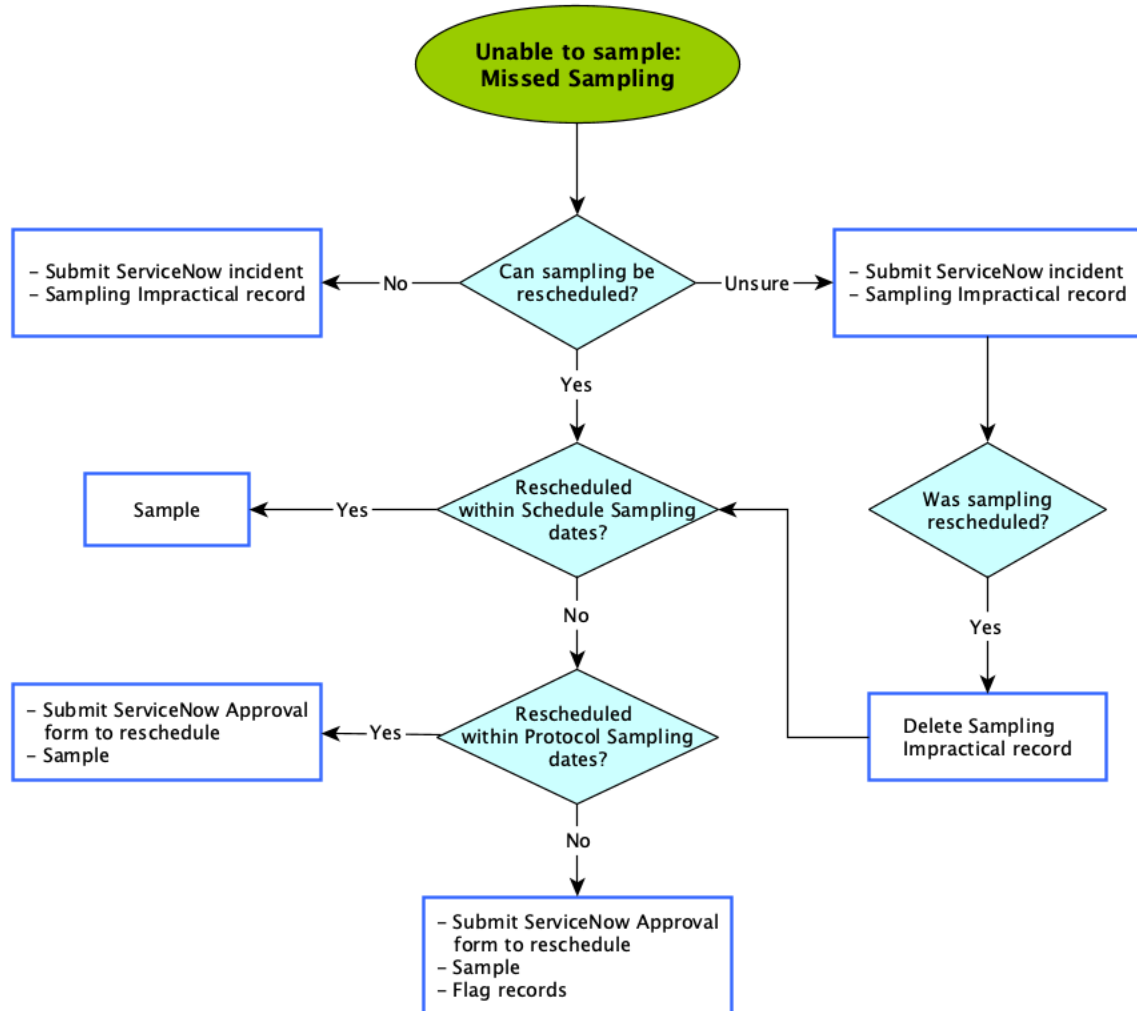


Figure 2. The documentation to account for a MissedSampling event depends on the situation for each sampling unit not sampled per bout that is not sampled. Diamonds represent decision points and boxes describe the required action. Required actions may include: a) Submitting a ServiceNow incident, b) 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



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Activities – Delays and Cancellations’ spreadsheet in the Sharepoint All Collaboration Library.

2. 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.
 - a. Record the **Start Date** as the scheduled date, and record the **Start Time** as 12:00 noon.
3. Select a value for the **Sampling Impractical** field that best fits the reason sampling did not occur (**Table 6**).
 - a. The **Sample Fate** field should populate to ‘not a physical sample’ and remain locked.
 - b. It is not necessary to create child records.
4. For Rescheduled sampling events 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.



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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 |
| SOP E: Post-Sampling Tasks | 0.75 h | 1 | 0.75 h |



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5 SAFETY

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

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

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



Make sure headlamp is turned off during data collection!



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6 PERSONNEL

6.1 Training Requirements

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

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.



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7 STANDARD OPERATING PROCEDURES

SOP Overview

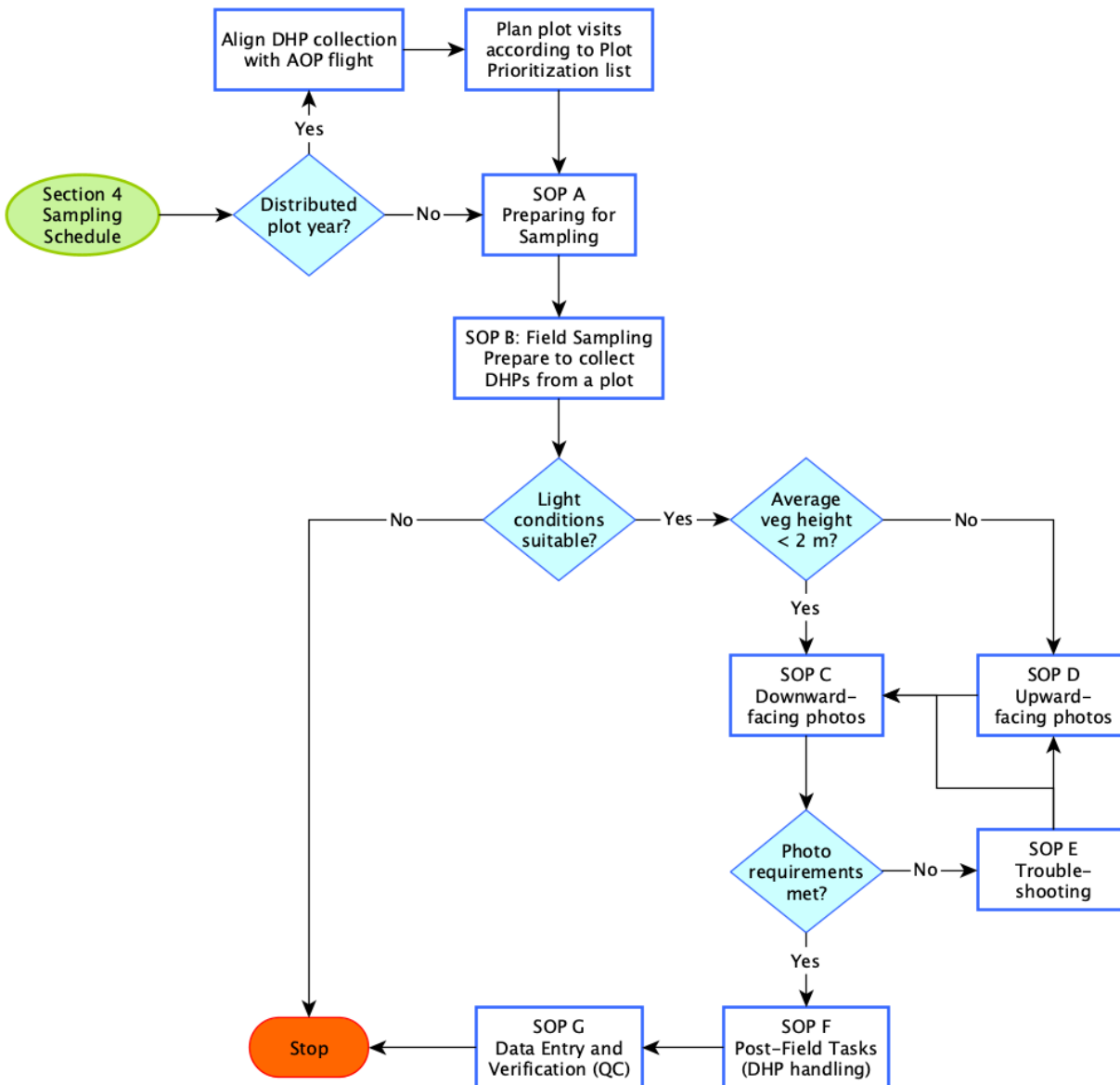


Figure 3. High-level workflow diagram illustrating major components and decision points within the Leaf Area Index protocol.

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

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



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

SOPD: 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.

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

SOPG: Data Entry and Verification. Guidelines and requirements for successful data entry and use of 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.

SOPH: Sample Shipment.



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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 along with the mobile devices to sampling locations 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.



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13. **Camera configuration:** Configure the DSLR for DHP image acquisition according to settings below (**Table 8**). See TOS SOP: DSLR Camera Use and Settings (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 |



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



- Assess required light conditions by photo type (downward/upward, Section 0).
- Place backpacks and other gear outside the plot and out of the camera’s field of view.

B.1 Determine camera orientation and height

- 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**).
- 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 | Single downward-facing photo per point | Shoulder height | SOP C |
| Majority < 0.75–1 m height | Majority < 2 m height | Single downward-facing photo per point | Extended monopod | SOP C |
| Majority > 0.75–1 m height | None | Single downward-facing photo per point | Extended monopod | SOP C |
| Majority > 0.75–1 m height | Majority < 3 m height | Upward and downward-facing photos per point | Shoulder height (upward) and extended monopod (downward) ³ | SOP C SOP D |
| Majority < 0.75–1m height | Majority > 3 m height | Upward and downward-facing photos per point | Shoulder height | SOP C SOP D |
| Majority > 0.75 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 | SOP D |



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| Understory Vegetation ¹ | Overstory Vegetation | Required Camera Orientations | Camera Position(s) ² | Protocol Reference |
|------------------------------------|----------------------|------------------------------|---------------------------------|--------------------|
| | | | shoulder height (upward) | |

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 11** 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.2 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 m² nested subplots that are sampled for Plant Diversity.

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.



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| 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 “good” quality image. Settings in **Table 11** are the initial starting point: Guidelines for modifying these settings are provided in SOP D.

- 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



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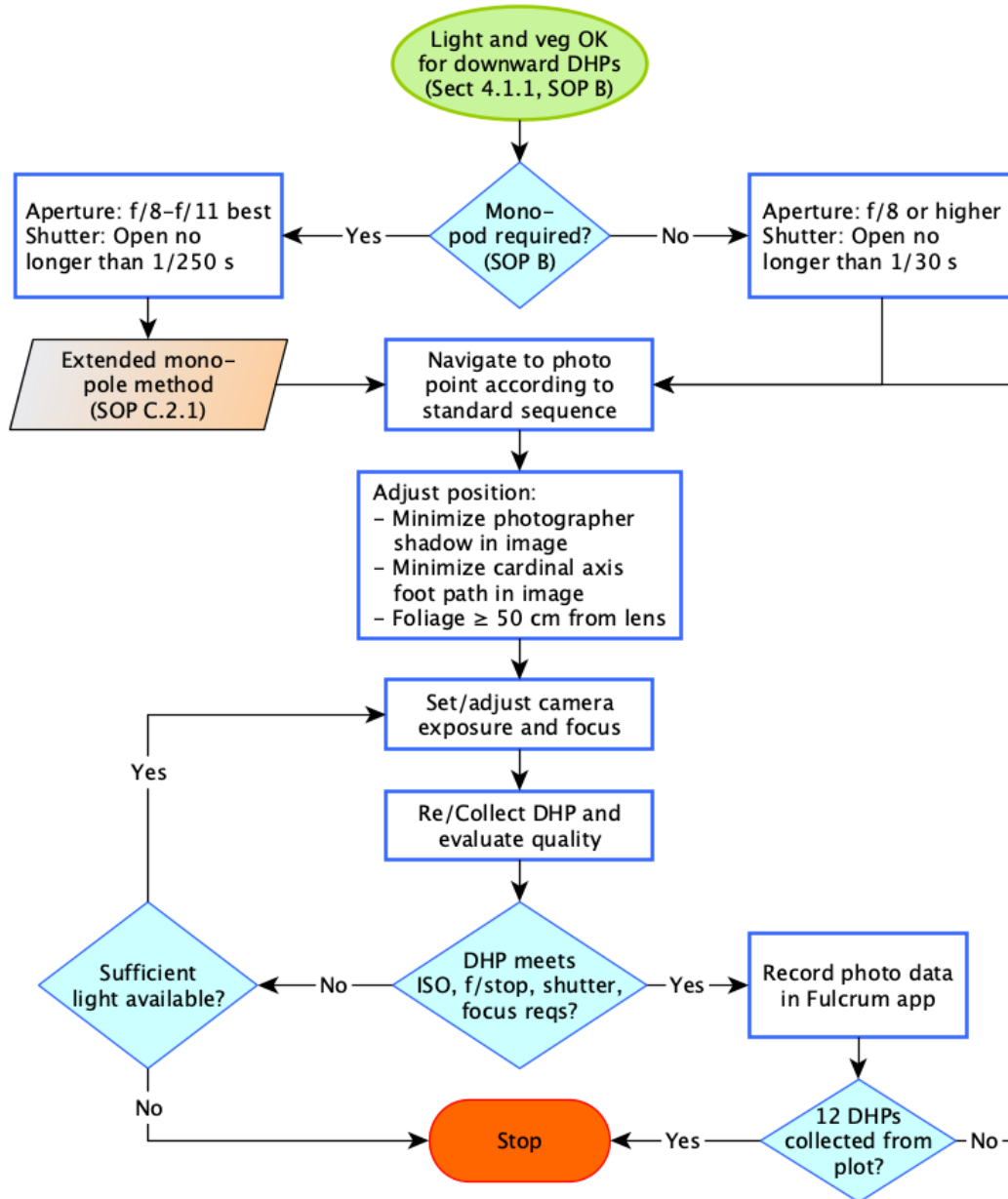
- c. 3rd – South axis
 - d. 4th – West axis
2. Along each cardinal plot axis, take DHPs at photo-points in the following sequence (**Figure 1**):
 - a. 1st – 2 m photo point
 - b. 2nd – 6 m photo point
 - c. 3rd – 10 m photo point
3. Adjust the aperture (and/or shutter-speed for upward-facing photos) 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**).
 - 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 deep shadows (Section 0). 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.





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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 is 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:



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- i. **Biophysical Criteria:** ‘conditions not met – no photo taken’
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 $\geq 50\%$ 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 D).
 - b. The photographer’s shadow is minimized within the photo.
 - c. The foot-path 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. Make sure the image is not blurry (either due to camera shake or poor focus lock).
 - b. Check that shutter speed and f/stop values are within guidelines (**Table 10**).



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- c. Make sure the exposure is such that vegetation is clearly distinguishable from soil or litter.
 - 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, delete and re-shoot until a satisfactory image is taken (see **Figure 5**).
 - 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.2.1) 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.



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Figure 5. 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.

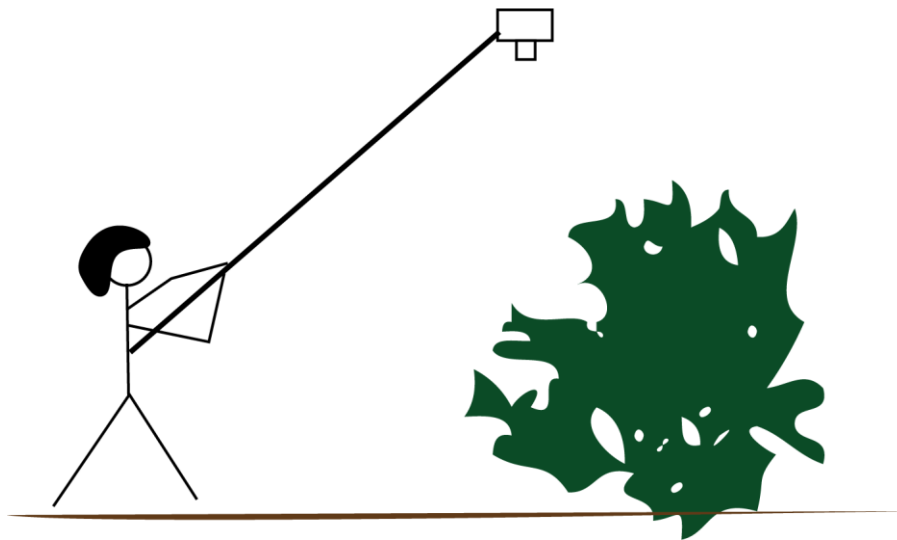


Figure 6. Illustration of using the extended monopole technique to acquire DHPs from mid-stature vegetation.

SOP 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.



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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 6**). 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.

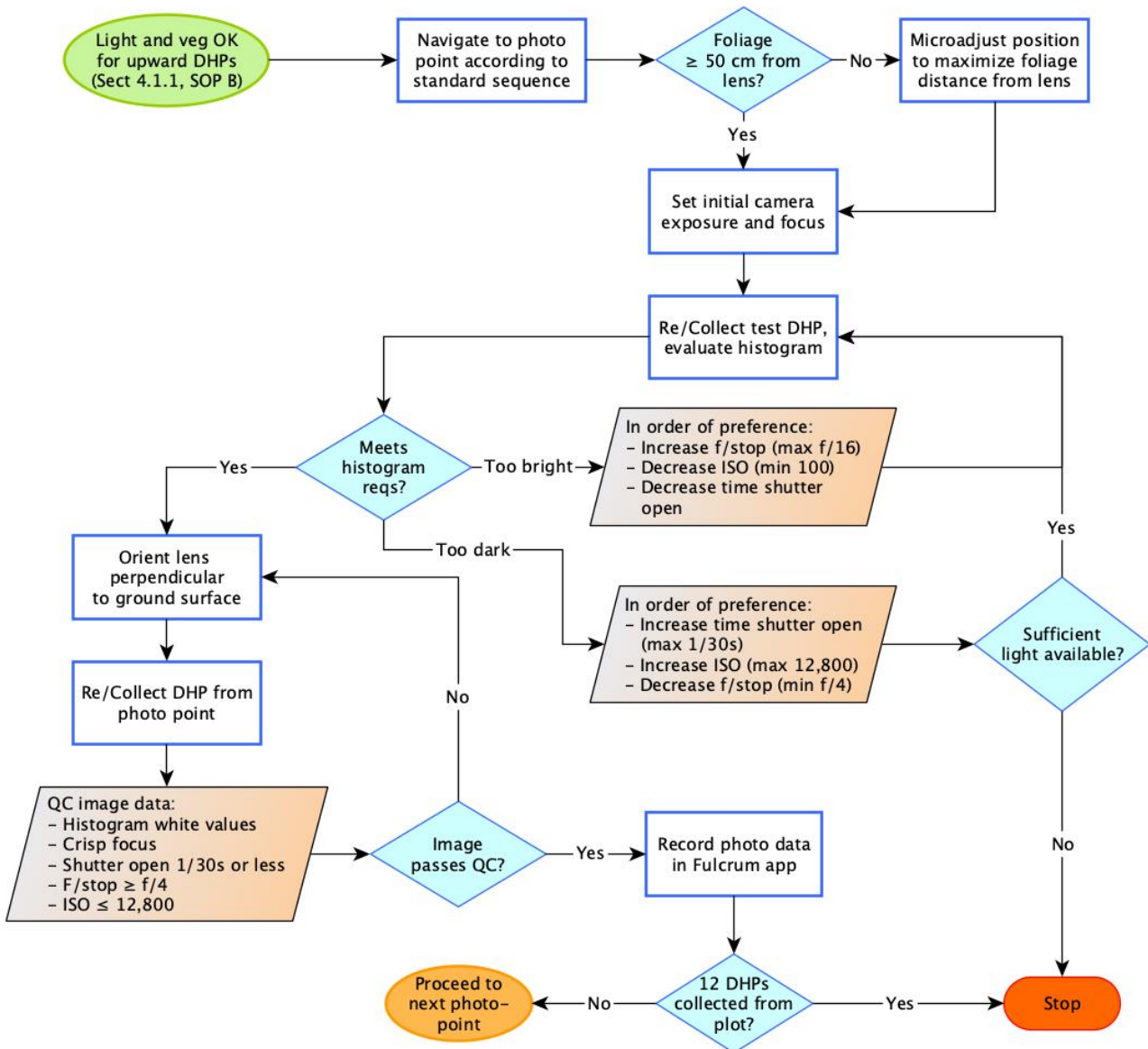


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SOP D Field Sampling: Upward-Facing DHPs

Overview and Goals

- Collect upward-facing photos from plot when direct sunlight is not on foliage (Section 0).
- Upward-facing images are not required if average vegetation height is < 2 m AND no single- or multi-bole trees are within the camera field of view.
- 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.





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Figure 7. 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 at least 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 half way to activate the viewfinder light meter.
 - b. With the lens still pointing up, adjust the f/stop, shutter speed, and ISO according to **Table 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.

| 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.



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- 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 8** illustrates the general components of a histogram as it pertains to digital photography.
 - ii. **Figure 9** shows a histogram from a properly exposed image. Note there is no significant peak of pixels, or “pile-up” at the right edge. It is also acceptable for a gap to exist between the brightest pixels and the right-most edge.
 - iii. **Figure 10** 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.

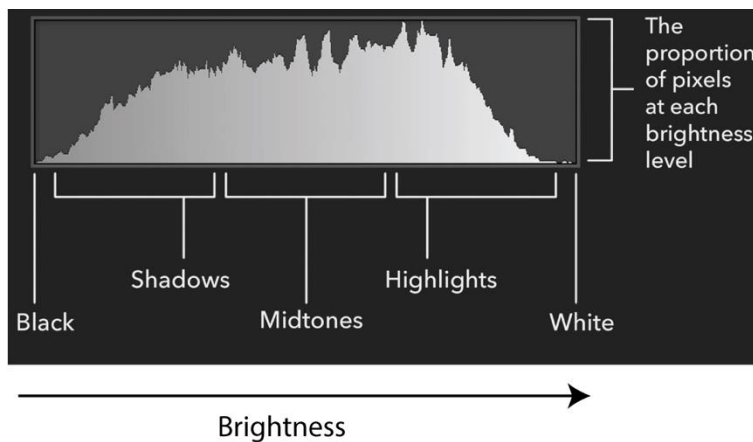


Figure 8. The general components of a histogram produced from a digital photograph. Brightness increases from left to right along the x-axis and the y-axis represents the number of pixels in the image at a given brightness level.



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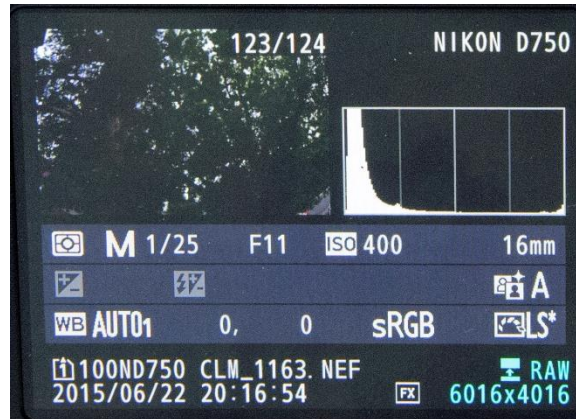


Figure 9. An example histogram from a properly exposed upward-facing image.

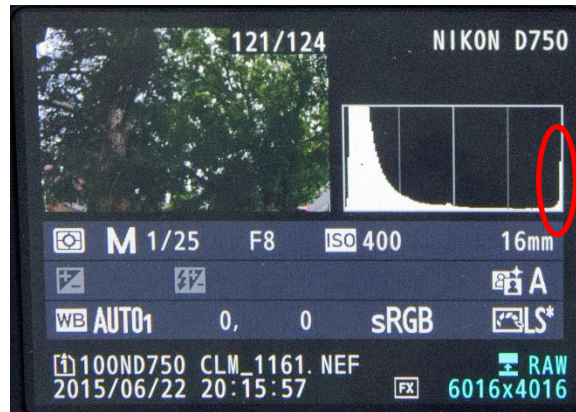


Figure 10. An example image and histogram of an overexposed upward-facing DHP. Note that the brightest pixels “pile-up” into a peak at the right-most edge of the histogram (red circle).

6. If necessary, adjust the exposure according to **Table 12** and take another test image until a correctly exposed image is produced (**Figure 9**). 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 $\geq 50\text{cm}$ from the lens. If foliage is $< 50\text{cm}$ 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 SOP E, **Table 13**).
8. Stand at the selected photo location.



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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 11**).



Figure 11. 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 9**).
 - f. If it is not possible to obtain an image with $f/stop \geq 4$ 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.)



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



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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 | <i>Preferred:</i> Lower the camera height until foliage is ≥ 50 cm from the lens. Record alternate photo height in “remarks” column of field datasheet. |
| | | <i>Second choice:</i> Maximize the distance between the foliage and lens. Record alternate photo height and distance to foliage in “remarks”. |
| | Shoulder height, downward-facing | <i>Preferred:</i> If feasible, collect photos of the understory with an extended monopole. |
| | | <i>Second choice:</i> 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. |



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SOP F Post-Field- Sampling Tasks

F.1 Document Incomplete Sampling Within a Site

Leaf Area Index sampling occurs on the schedule described in Section 4.1 at 20 Distributed plots and 3 Tower plots per site. Ideally, sampling occurs at these sampling locations for the lifetime of the Observatory. However, circumstances may arise that require that sampling within a site be shifted from one location to another. In general, a plot is considered compromised when sampling at the plot becomes so limited that data quality is significantly reduced. If sampling at a plot becomes compromised, an incident should be submitted.

There are two main pathways by which sampling can be compromised. Sampling locations can become unsuitable to answer meaningful biological questions (e.g., a terrestrial sampling plot becomes permanently flooded). Alternatively, sampling locations may be located in areas that are logistically impossible to sample on a schedule 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).

To document plots not sampled in a bout:

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 plot 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 plots 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 Location Compromised: LAI – [Root Cause Description]'
 - a. Example: 'TOS Sampling Location Compromised: LAI – 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 and should be replaced.



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F.2 DHP handling

1. **As soon as possible** following field sampling, copy images from the camera memory card(s) to a temporary storage location.
 - a. First choice: External media (e.g., external hard-drive, USB drive, or equivalent).
 - b. Second choice: The NEON network 'LAI_RAW_images' folder.
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 as a destination for the organized images (preferred, for performance reasons) or the 'LAI_RAW_images' folder on the N-drive.
 - 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.
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 tool to copy organized DHPs into the domain 'LAI_RAW_validated' folder.
 - a. The Warbler tool also creates the required '**dhpBreadcrumb.txt**' file within the bout-level folder to keep track of which images have been copied to the cloud.
 - b. **Failure to copy images to cloud storage within 30 days of Fulcrum record creation will result in parser error messages.**

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 |

5. In the 'LAI_RAW_validated' folder, Warbler automatically organizes images into this generalized directory structure: '**//.../DXX/YYYY/boutID/plotID/imageType/[12 DHP.NEF files]**', where



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- a. **DXX**: The domainID in which photos were collected (already exists, do not create)
 - b. **YYYY**: The year the bout began (typically the current year; create for the first bout of the year, otherwise this folder already exists).
 - c. **boutID**: XXXXWW format, where XXXX is the unique 4-letter NEON site code, and WW = the relevant 'weekBoutBegan' value from the *DHP: Leaf Area Index [PROD]* application.
 - d. **plotID**: A sub-folder for images from each plot, *SITE_###* format.
 - e. **imageType**: A sub-folder named either 'understory' or 'overstory', case-sensitive.
 - f. *The final validated directory structure looks exactly like this example: '//.../neon/DSF/CI Dropbox/Domain 16/TOS/LAI_RAW_validated/D16/2022/ABBY01/ABBY_067/overstory/[12 DHP NEF files]'*
 - g. A script automatically moves validated DHPs to NEON cloud storage every day, and subsequently deletes the image files from the folder once transfer is complete. The script does NOT move .txt files, so the **dhpBreadcrumb.txt** file will be left in the **boutID** folder; **boutID** folders that only contain the breadcrumb and have NO DHPs in **plotID** folders indicate successful DHP transfer.
6. After DHPs from a given bout are copied to NEON cloud storage, image files on the camera memory card(s) may be deleted. That is, if only the **dhpBreadcrumb.txt** file exists in the **boutID** folder, and the **plotID** folders contain no DHPs, images on the camera card(s) may be deleted.
 7. Delete DHPs from local external storage or the **LAI_RAW_images** folder only after records and images have passed the parser and are successfully LOADED into the NEON database.
 - a. The LOAD_STATUS field in the *DHP: Leaf Area Index [PROD]* application indicates whether records have passed the parser and are loaded.
 - b. Images associated with records that are LOADED must be deleted from the **LAI_RAW_images** folder.

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.



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SOP G Data Entry and Verification

The importance of thorough, accurate data entry cannot be overstated; the value of field efforts are only manifested once the data are properly entered for publication via the NEON Data Portal.

Mobile applications are the preferred mechanism for data entry. Whenever possible, data should be entered into the *DHP: Leaf Area Index [PROD]* application as they are being collected in order to minimize data transcription errors 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.

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

G.1 Data Quality Control

Data Quality Control (QC) is a very important task for all data entered into Fulcrum applications. ***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 in order 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 detail.



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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.



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SOP H Sample Shipment

Not applicable to TOS Protocol and Procedure: LAI – Measurement of Leaf Area Index.



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8 REFERENCES

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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. Dusksampling: 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 a temporary storage location, either an external drive (preferred) or the NEON network **LAI_RAW_images** folder.
14. **Within 30 days** perform image QC and copy image files to the NEON network **LAI_RAW_validated** folder.
15. Delete images from the temporary storage location after successful ingest into the NEON database (i.e., parser checks have passed and record status is LOADED).



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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 site-mirror 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.
- Camera is recording NEF photo format, not JPG (and corresponding file type is correctly recorded in mobile application).
- 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.
- Quality of every image is assessed immediately after taking it. **Most important:** 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**.



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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, copy folders/images to the **LAI_RAW_validated** folder to be moved to the cloud and 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.*



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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 2005-2014 (Didan 2015). 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 timecourse sampling in Tower Plots, and peak greenness sampling date ranges for spatially-intensive Distributed Plot LAI sampling.

| Domain Number | Site ID | Start Date | End Date | Peak Greenness | Additional Sampling Information |
|---------------|---------|------------|----------|----------------|---|
| 01 | BART | 04/28 | 10/22 | 06/12-08/09 | |
| | HARV | 04/22 | 10/31 | 06/06-08/07 | |
| 02 | BLAN | 03/13 | 11/01 | 05/23-07/13 | Variable peak greenness window; may end by 06/30. |
| | CASE | 03/21 | 11/01 | 05/24-07/28 | |
| | SCBI | 03/27 | 11/01 | 05/27-08/03 | |
| | SERC | 03/17 | 11/01 | 06/02-08/09 | |
| 03 | DSNY | 03/04 | NA | 05/30-07/19 | <ul style="list-style-type: none"> • 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 11/14 – 03/04 (instead of every 2 weeks). |
| | JERC | 03/23 | NA | 06/26-08/10 | <ul style="list-style-type: none"> • Distributed Plots: Variable peak greenness window; may end by 07/14. • Tower Plots: Year-round sampling, shifting to every 4 weeks between 10/23 – 03/23 (instead of every 2 weeks). |



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| Domain Number | Site ID | Start Date | End Date | Peak Greenness | Additional Sampling Information |
|---------------|---------|------------|----------|--------------------------|---|
| | OSBS | 03/05 | NA | 06/01-07/15 | <ul style="list-style-type: none"> 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 11/22 – 03/05 (instead of every 2 weeks). |
| 04 | GUAN | NA | NA | NA | <ul style="list-style-type: none"> Distributed Plots: No peak greenness according to MODIS, schedule to overlap with AOP flight. Tower Plots: Year-round sampling |
| | LAJA | NA | NA | NA | <ul style="list-style-type: none"> Distributed Plots: No peak greenness according to MODIS, schedule to overlap with AOP flight. Tower Plots: Year-round sampling. |
| 05 | CHEQ | NA | NA | 06/17-08/07 | Start and End Dates not supplied since CHEQ does not support Tower Plots. |
| | STEI | 04/29 | 10/12 | NA | |
| | TREE | 04/27 | 10/15 | 06/16-08/07 | |
| | UNDE | 04/30 | 10/09 | 06/16-08/08 | |
| 06 | KONA | 04/03 | 10/31 | 06/16-07/31 | Variable peak greenness window; may end by 07/09. |
| | KONZ | 04/02 | 11/01 | 06/12-07/30 | Variable peak greenness window; may end by 07/09. |
| | UKFS | 03/22 | 11/01 | 06/09-07/28 | Variable peak greenness window; may end by 07/04. |
| 07 | GRSM | 04/02 | 11/01 | 06/02-08/03 | |
| | MLBS | 04/17 | 11/01 | 06/06-08/08 | |
| | ORNL | 03/17 | 11/01 | 05/18-07/24 | |
| 08 | DELA | 03/01 | 11/01 | 05/13-07/17 | |
| | LENO | 03/09 | 11/01 | 05/14-07/17 | |
| | TALL | 03/16 | 11/01 | 05/15-07/14 | |
| 09 | DCFS | 04/30 | 10/11 | 06/28-07/28 | |
| | NOGP | 04/18 | 10/12 | 06/17-07/21 | |
| | WOOD | 05/05 | 10/09 | 07/05-08/02 | |
| 10 | CPER | 03/29 | 11/01 | 06/14-07/26, 08/20-09/14 | Two greenness peaks, first is dominant. Variable peak1 greenness window; may begin by 06/14, or end by 06/14. |



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| Domain Number | Site ID | Start Date | End Date | Peak Greenness | Additional Sampling Information |
|---------------|---------|------------|----------|--------------------------|--|
| | RMNP | 05/09 | 10/11 | 07/03-08/02 | |
| | STER | 03/27 | 09/07 | 05/31-07/10 | Variable peak greenness window; may end by 06/04 (early crop harvest?) |
| 11 | CLBJ | 02/27 | 11/01 | 05/05-06/13, 08/19-08/28 | Two greenness peaks, first is dominant. Variable peak1 greenness window; may end by 06/09. |
| | OAES | 03/09 | 11/01 | 05/08-06/13, 09/19-11/11 | Two greenness peaks, first is dominant. |
| 12 | YELL | 07/01 | 09/17 | 06/18-07/12 | Late Start Date reflects Bear Management Area closure around Tower Plots from 03/10 to 06/30. |
| 13 | MOAB | 03/15 | 10/26 | 05/10-05/30, 08/08-09/17 | Two greenness peaks, first may be dominant. Field verification required. |
| | NIWO | 05/30 | 09/23 | 07/14-08/10 | |
| 14 | JORN | 03/21 | 11/01 | 07/16-09/03 | Variable peak greenness window; may begin by 05/20, end by 07/31. |
| | SRER | 03/01 | 11/01 | 03/21-04/20, 08/23-09/07 | Two greenness peaks, second is dominant. Variable start and end dates, pay attention to within-year phenology. |
| 15 | ONAQ | 03/17 | 09/09 | 05/12-06/15 | Variable peak greenness window; may begin by 04/10, end by 05/15. |
| 16 | ABBY | 04/18 | 10/20 | 06/19-07/23 | |
| | WREF | 04/21 | 10/19 | 06/20-07/27 | |
| 17 | SJER | 10/07 | 06/03 | 03/09-04/06 | <ul style="list-style-type: none"> 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 | 03/30 | 11/01 | 06/05-07/08 | |
| | TEAK | 05/04 | 10/09 | 07/01-07/27 | |
| 18 | BARR | 06/26 | 08/10 | 07/13-07/27 | |
| | TOOL | 06/06 | 08/26 | 07/04-07/26 | |
| 19 | BONA | 05/13 | 09/07 | 06/27-07/26 | |
| | DEJU | 05/12 | 09/10 | 06/22-07/27 | |
| | HEAL | 05/18 | 09/06 | 06/27-07/28 | |



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| Domain Number | Site ID | Start Date | End Date | Peak Greenness | Additional Sampling Information |
|---------------|---------|------------|----------|----------------|---|
| 20 | PUUM | NA | NA | NA | <ul style="list-style-type: none">• Distributed Plots: No peak greenness, time to coincide with AOP.• Tower Plots: Year-round sampling |



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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 photos with the sun directly behind foliage.

Downward-facing photos: Light must be strong enough to differentiate greens from browns; avoid strong shadows if possible.

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 photos with the sun directly behind foliage.

Downward-facing photos: Light must be strong enough to differentiate greens from browns; avoid strong shadows if possible.

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 photos with the sun directly behind foliage.

Downward-facing photos: Light must be strong enough to differentiate greens from browns; avoid strong shadows if possible.

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 photos with the sun directly behind foliage.

Downward-facing photos: Light must be strong enough to differentiate greens from browns; avoid strong shadows if possible.



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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/0100078101 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 |



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| 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/ STFR2000800 | N | External hard-drive, USB drive, or equivalent storage media | Available disk space to temporarily store and backup images before they are transferred to NEON cloud storage. | 1 |