

<i>Title:</i> TOS Protocol and Procedure: Measurement of Leaf Area Index		<i>Date:</i> 04/10/2014
<i>NEON Doc. #:</i> NEON.DOC.014039	<i>Author:</i> C. Meier	<i>Revision:</i> D

TOS PROTOCOL AND PROCEDURE: MEASUREMENT OF LEAF AREA INDEX

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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
D	04/10/2014	ECO-01792	Added Appendix D with site-specific information

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

TABLE OF CONTENTS

1 DESCRIPTION.....1

1.1 Purpose 1

1.2 Scope..... 1

2 RELATED DOCUMENTS AND ACRONYMS1

2.1 Applicable Documents 1

2.2 Reference Documents..... 2

2.3 Acronyms 2

2.4 Definitions..... 2

3 BACKGROUND AND OBJECTIVES2

3.1 Background 2

3.2 NEON Science Requirements 3

3.3 NEON Data Products 3

4 PROTOCOL4

5 QUALITY ASSURANCE AND CONTROL5

5.1 Decision tree 5

6 SAFETY6

7 PERSONNEL REQUIREMENTS.....6

8 TRAINING REQUIREMENTS.....7

9 SAMPLE FREQUENCY AND TIMING8

9.1 Sampling Timing Parameters 8

10 STANDARD OPERATING PROCEDURES.....10

SOP A: Preparing for Sampling 10

SOP B: Field Sampling: Preparing to Collect DHPs from a Plot..... 12

SOP C: Field Sampling Downward-facing DHPs 14

SOP D: Field Sampling: Upward-facing DHPs..... 17

SOP E: Post-Field-Sampling Tasks..... 22

SOP F: Batch Processing DHPs with Photoshop 25

SOP G: Analyzing JPG Images for Leaf Area Index with Caneye Software 29

SOP H: Entering Data from CanEye Output 40

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

11 REFERENCES	42
APPENDIX A QUICK REFERENCE.....	43
APPENDIX B CHECKLISTS	44
APPENDIX C PROTOCOL CHANGE SUMMARY.....	46
APPENDIX D SITE-SPECIFIC SAMPLING PARAMETERS FOR TAKING DIGITAL HEMISPHERICAL PHOTOS FOR LEAF AREA INDEX	47
APPENDIX E CONFIGURING THE NIKON D800 FOR HEMISPHERICAL PHOTOGRAPHY	50
APPENDIX F DAY OF YEAR CALENDARS.....	60
LIST OF TABLES AND FIGURES	
Table 1. Decision tree associated with the plant leaf area index measurements.....	5
Table 2. Number of plots, frequency of sampling, and sampling start/stop guideline.....	8
Table 3. Actions required to prepare equipment and materials to acquire DHPs in the field.....	10
Table 4. Desired Nikon D800 DSLR settings for collecting DHPs in the field	11
Table 5. Field equipment required for a team of two people to collect DHPs from a plot.....	12
Table 6. Guidelines for determining proper camera positioning when taking DHPs.....	13
Table 7. Camera settings for downward-facing DHPs.	14
Table 8. Initial camera settings for upward-facing DHPs.....	17
Table 9. Strategy for optimizing image exposure while taking upward-facing DHPs.....	18
Table 10. Common issues encountered during acquisition of upward-facing DHPs.....	21
Table 11. Equipment required for transferring DHPs to the NEON Domain server	22
Table 12. Criteria for determining placement of DHP images within folder structure.	23
Table 13. Laboratory equipment required to batch process DHPs.	25
Table 14. Sliders and their effects in the “Basic” panel of Adobe Camera Raw ¹	26
Table 15. Details to examine in JPG images created via batch process from DHP RAW images.	28
Table 16. Laboratory equipment required to JPG images with CanEye software.....	29
Table 17. Creating the optical center and projection function for LAI analysis in CanEye.....	30
Table 18. Elements in each DHP that should be masked prior to LAI estimation with CanEye.	31
Table 19. Guidelines for classifying pixels in downward-facing images.....	33
Table 20. Guidelines for classifying pixels in upward-facing images.....	36
Table 21. Guidelines for transcribing LAI output to the NEON Data Ingest Workbook.	40
Figure 1. Distributed base plot showing the location and spacing of DHP photo points.....	4
Figure 2. Example of a properly exposed downward-facing DHP	16
Figure 3. An example histogram from a properly exposed image.	20
Figure 4. An example of a properly exposed upward-facing DHP	20
Figure 5. A field researcher acquiring an upward-facing DHP with the monopod/camera ensemble	21
Figure 6. Example of an upward-facing hemispherical image successfully classified	39
Figure 7. Example CanEye output.....	41

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

1 DESCRIPTION

1.1 Purpose

The primary purpose of this document is to provide change controlled version of Observatory protocols and procedures for Plot Establishment. This document provides the content for training and field-based materials for NEON staff and contractors. Content changes (i.e. changes in particular tasks or safety practices) occur via this change controlled document, not through field manuals or training materials.

This document is a detailed description of the field establishment process, relevant pre- and post-field tasks, and safety issues as they relate to this procedure and protocol.

1.2 Scope

This document relates the tasks for a specific field sampling and directly associated activities and safety practices. This document does not describe:

- General safety practices
- Site-specific safety practices
- General equipment maintenance

It does identify procedure-specific safety hazards and associated safety requirements such as safe handling of small mammals or safe use of required chemicals and reagents.

2 RELATED DOCUMENTS AND ACRONYMS

2.1 Applicable Documents

Applicable documents contain information that shall be applied in the current document. Examples are higher level requirements documents, standards, rules and regulations.

AD [01]	NEON.DOC.004300	EHS Safety Policy and Program Manual
AD [02]	NEON.DOC.004316	Operations Field Safety and Security Plan
AD [03]	NEON.DOC.000724	Domain Chemical Hygiene Plan and Biosafety Manual
AD [04]	NEON.DOC.001155	NEON Training Plan
AD [05]	NEON.DOC.050005	Field Operations Job Instruction Training Plan

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

2.2 Reference Documents

Reference documents contain information complementing, explaining, detailing, or otherwise supporting the information included in the current document.

RD [01]	NEON.DOC.000008	NEON Acronym List
RD [02]	NEON.DOC.000243	NEON Glossary of Terms
RD [03]	NEON.DOC.000914	TOS Science Design for Plant Biomass, Productivity, and Leaf Area Index
RD [04]	NEON.DOC.005003	NEON Scientific Data Products Catalog
RD [05]	NEON.DOC.014051	Field Audit Plan
RD [06]	NEON.DOC.000824	Data and Data Product Quality Assurance and Control Plan
RD [07]	NEON.DOC.005005	Level 0 Data Product Catalog
RD [08]	Placeholder	AOP flight schedule
RD [09]	NEON.DOC.001398	NEON Raw Data Ingest Workbook for TOS Digital Hemispherical Photos
RD[10]	NEON.DOC.001575	Datasheets for TOS Protocol and Procedure: Measurement of Leaf Area Index

2.3 Acronyms

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

2.4 Definitions

A **protocol** is a formal summary description of a procedure and its related rationale, and includes information on knowledge and resources needed to implement the procedure. A **procedure** is a set of prescribed actions that must take place to achieve a certain result, and can also be called a method. It differs from a science design in that science designs provide a more complete description of the rationale for selecting specific protocols. It differs from a training manual in that training manuals provide materials in support of skills acquisition in the topic areas including information on how to best train staff rather than detailing only the steps of the procedure.

3 BACKGROUND AND OBJECTIVES

3.1 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

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

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 Level 0 data produced by the DHP method is 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.

3.2 NEON Science Requirements

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.

3.3 NEON Data Products

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 [04]).

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

4 PROTOCOL

There are two high-level components to this LAI data collection protocol, which serve to capture LAI data across space and through time : 1) data are collected on the ground every 3-6 years from Distributed and Gradient plots, and these data are used in conjunction with AOP LAI data products to estimate LAI at the site scale; and 2) data are collected every two weeks from a subset of Tower plots (n=3) that will be used to construct a time-series dataset that will complement the spatially-extensive snapshot of LAI generated from AOP data. The plotIDs for the Distributed and Gradient plots that will be used for LAI sampling will be provided by Science Operations. In order to speed data collection from Tower Plots, those selected for LAI measurement should be the three plots that are closest to, or most readily accessed from, the TIS Tower, as determined by Field Operations. For more details of the LAI spatial and temporal sampling strategy, see the Plant Biomass and Productivity Science Design Document (RD [03]).

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 shoulder height, downward-facing images will suffice for a given plot (Table 6). Otherwise, upward-facing images are also required to properly capture LAI for the plot. In the laboratory, image files are processed with Adobe Photoshop to adjust image size and ensure that leaf elements are properly exposed. Sets of 12 images are then analyzed using CanEye (<http://www6.paca.inra.fr/can-eye/>) software to generate plot-level and point-level LAI estimates.

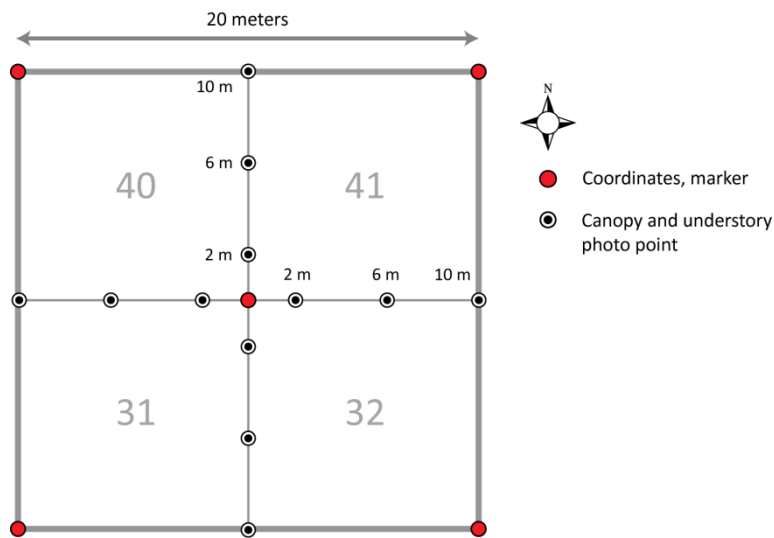


Figure 1. Distributed base plot (or 20 m x 20 m Tower plot) showing the location and spacing of DHP photo points relative to plot center; grey numbers represent subplotIDs.

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

5 QUALITY ASSURANCE AND CONTROL

The field procedures associated with this protocol will be audited according to the Field Audit Plan (RD[05]). Additional quality assurance will be performed on data collected via these procedures according to the NEON Data and Data Product Quality Assurance and Control Plan (RD[06]).

A critical component of image analysis in CanEye is the classification of pixels into plant and non-plant categories. In order to ‘calibrate’ pixel classification across different technicians, technicians performing the CanEye analysis will analyze a standard set of images provided by Science Operations before proceeding to analyze additional images. The standard image set will be analyzed at least three times in order to calculate a CV for the individual technician. The CV must be < 10%, and the mean LAI value produced by the technician with this standard image set must be within ± 10% of the LAI value provided for the standard image set before the technician may proceed to analyze additional images. The CV is calculated as follows:

$$CV = \frac{\sigma}{\mu} \times 100, \text{ where } \sigma = \text{standard deviation, and } \mu = \text{the mean}$$

A combination of hot, cold, and blind checks will be used to ensure that quality hemispherical images are collected in the field, images are repeatably taken from the same locations in each plot, and that images are analyzed properly with the CanEye software.

5.1 Decision tree

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 1):

Table 1. Decision tree associated with the plant leaf area index measurements, indicating how to respond to unanticipated delays in field work, and consequences of these delays.

Delay	Action	Adverse outcome	Effect on Data Product
Hours	If 1) Delay interrupts data collection mid-plot: a) stop data collection for the plot, and delete any images taken; b) upon resuming, ensure light conditions are favorable; and c) repeat data collection for entire plot on the same day if possible.	A delay of hours can lead to poor light conditions for collection of LAI data.	Overestimation or imprecise estimation of LAI.
	If 2) Delay occurs between plots: a) Ensure light conditions are favorable for data collection; and b) resume data collection for next plot.	A delay of hours can lead to poor light conditions for collection of LAI data.	Overestimation or imprecise estimation of LAI.

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

Delay	Action	Adverse outcome	Effect on Data Product
1-7 Days	If 1) Delay interrupts data collection mid-plot: a) stop data collection for the plot, and delete any images taken; b) on the next possible sampling day within 7 days of the delay, ensure light conditions are favorable; and c) repeat data collection for the plot.	None	None
	If 2) Delay occurs between plots: a) Return to the field ASAP; b) ensure light conditions are favorable for data collection from an entire plot; and c) resume data collection for the next plot.	None	None
8+ Days	If 1) Delay interrupts data collection mid-plot: a) stop data collection for the plot, and delete any images taken; b) skip sampling for current boutID and continue sampling as part of the next boutID.	Decreased sample size.	Imprecise estimation of LAI.
	If 2) Delay occurs between plots: a) skip sampling for current boutID and continue sampling as part of the next boutID.	Decreased sample size.	Imprecise estimation of LAI.

6 SAFETY

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!

7 PERSONNEL REQUIREMENTS

For analysis of DHP images to calculate LAI, at least one technician is required, and technician(s) must be able to distinguish between yellow, purple, and grey colors. Prior to image analysis with the specified software, it must be verified that the technician is capable of analyzing images within specified QA/QC parameters (see above).

<i>Title:</i> TOS Protocol and Procedure: Measurement of Leaf Area Index		<i>Date:</i> 04/10/2014
<i>NEON Doc. #:</i> NEON.DOC.014039	<i>Author:</i> C. Meier	<i>Revision:</i> D

8 TRAINING REQUIREMENTS

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

Technicians must also be trained to configure, use, and care for the DSLR system when acquiring high-quality hemispherical photos.

Technicians should 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 here: <http://www.ngdc.noaa.gov/geomag-web/>. Additionally, being able to repeatedly pace off accurate distances in the field will speed collection of LAI data considerably, compared to laying out a meter tape in two directions for guidance at each plot.

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. Field technicians must also know how to use a mirror-site compass.

Finally, technicians must be trained to process DHP image files with both Adobe Photoshop and CanEye software. Before technicians analyze any DHP images, image processing technique must be evaluated according to the QA criteria in Section 5 on a per technician basis using standard image sets provided by Science Operations.

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

9 SAMPLE FREQUENCY AND TIMING

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

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

Plot type	Plot Number	Sampling Events	Yearly Interval	Sampling Start	Sampling Stop
Distributed/Gradient plot	n=20	1X per sampling year	Every 3-6y. One site per domain per year (or every other year)	Up to 2 weeks before AOP flight date (or beginning of flight date range) ¹	Up to 2 weeks after actual AOP flight date
Tower plot	n=3	Every 2 weeks (approx. 14 events per year)	Annual	Start of growing season, as new leaves and needles become visible and begin to expand ²	Whichever is first: 1. DOY > 305 (1 st November) 2. Site-specific NDVI returns to pre-growing-season level ³

¹ Provided the flight date (or range of possible dates) is confirmed and not subject to change more than ± 1 week. If no AOP flight is scheduled in a given year, postpone ground LAI sampling at Distributed and Gradient plots to the next year in which an AOP flight is scheduled. The annual schedule for AOP flights is provided by Science Operations RD [08], and Domain Managers should communicate with AOP managers to keep abreast of current flight plans.

² Based on multi-year averages, dates provided by Field Operations.

³ Determined by Science Operations.

9.1 Sampling Timing Parameters

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

- DHP images should not be collected when water droplets will form on the lens (i.e. it is raining, misting, there is heavy condensation, etc.). Check the local weather forecast prior to initiating field work to ensure that data collection will be possible.
- Upward-facing DHPs must only be collected when direct sunlight is NOT visible on the foliage – i.e. 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.
- 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 risen above the horizon or after the sun

<i>Title:</i> TOS Protocol and Procedure: Measurement of Leaf Area Index		<i>Date:</i> 04/10/2014
<i>NEON Doc. #:</i> NEON.DOC.014039	<i>Author:</i> C. Meier	<i>Revision:</i> D

has set below it: low-light makes it difficult to distinguish green from brown colors during image analysis.

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

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

Keep an eye on the lighting condition. It may change while images are being acquired.

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

10 STANDARD OPERATING PROCEDURES

SOP A: Preparing for Sampling

- a. Prepare equipment and materials as specified in Table 3,
- b. Configure the DSLR for DHP image acquisition according to settings listed in Appendix D.

Field Equipment and Materials

Table 3. Actions required to prepare equipment and materials for two technicians to acquire DHPs in the field.

Maximo Number	Item Description	Qty	Conditions Used	Action(s)
S	Micro-fiber lens cleaning cloth	1	All	Clean soiled cloth if necessary
R MX104651	DSLR fisheye lens	1	All	Clean with lens cloth if necessary
R MX104654	DSLR 16Gb memory card	2	All	Empty memory cards of pre-existing images
R MX104657	DSLR memory card reader	1	All	Empty memory cards of pre-existing images
R MX104653	DSLR batteries	2	All	Charge
S	GPS unit	1	All	1. Charge 2. Load target plot locations
S	Headlamp	2	Low-light sampling	Check batteries
S	Compass, mirror-sight	1	All	Check/set correct declination ¹
S	LAI field datasheets	Variable	All	Print ²
S	Meter tape	1	All	Calibrate technician pacing: determine # paces equivalent to 4 m (distance b/t photo points) ³

¹ Declination changes with time and should be looked up annually per site: <http://www.ngdc.noaa.gov/geomag-web/>

² The LAI field datasheet is provided as a companion document, and is intended as an interim data collection medium until a BioPDA application is available (RD[10]).

³ Being able to repeatedly pace off accurate distances in the field will speed collection of LAI data considerably, compared to laying out a meter tape in two directions for guidance at each plot.

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

Table 4. Desired Nikon D800 DSLR settings for collecting DHPs in the field. See Appendix D for more detailed instructions for operating the Nikon D800.

Camera Parameter	Desired Setting	How to Change
Image quality	RAW, compressed Bit-depth = 12	“QUAL” button, primary wheel
White balance	Auto (A)	“WB” button, primary wheel
Shutter Mode	Single shot (S)	Left knob, outer ring
Metering Mode	Matrix	Back knob, upper-right
Focus Mode	Auto-area Auto Focus (AF-S auto)	Focus switch/button, primary and secondary wheels
Playback display options	Overview	Playback Menu
File naming	DXX (where XX is NEON Domain number)	Shooting Menu
Color space	sRGB	Shooting Menu
Active D-lighting	Auto	Shooting Menu
High ISO NR	Normal	Shooting Menu
ISO sensitivity settings	Auto-ISO sensitivity control = ON; Maximum sensitivity = Hi2; 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

Scheduling the Field Day

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

- DHP images should not be collected when water droplets will form on the lens (i.e. it is raining, misting, there is heavy condensation, etc.). Check the local weather forecast prior to initiating field work to ensure that data collection will be possible.
- **Upward-facing DHPs must only be collected when direct sunlight is NOT visible on the foliage** – i.e. 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.
- Downward-facing DHPs may be collected either with or without sunlight on the foliage. However, **DO NOT take downward-facing images either before the sun has come up or after the sun has set:** low-light makes it difficult to distinguish green from brown colors during image analysis.
- On a given measurement day, plan on arriving at the location of the first plot to be measured at least 20 minutes before light conditions are appropriate.

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

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

Field Equipment and Materials

Table 5. Field equipment required for a team of two people to collect DHPs from a plot.

Maximo Number	Item Description	Purpose	Qty	Conditions Used	Special Handling
MX104649	DSLR camera body	Acquire DHP images	1	All	No
MX104651	Hemispherical fisheye lens	Acquire DHP images	1	All	No
MX104654	DSLR memory card, 16 Gb	Store DHP images in the field; one in camera, one for backup	2	All	No
MX104653	DSLR battery	One in camera, one for backup	2	All	No
Required	Camera and lens carry case	Protect camera equipment in the field	1	All	No
Required	Camera monopod	Hold camera steady away from body	1	All	No
Suggested	Microfiber lens cleaning cloth	Clean lens; paper lens cleaning tissues may also be used	1	All	No
Suggested	GPS unit, pre-loaded with plot locations	Aids in navigating to and finding plots	1	All	No
Required	Compass with mirror site, declination adjusted	Orientation for finding photo points	1	All	No
Suggested	Headlamp	Sight aid in low-light conditions	2	Low-light	No
Required	LAI field datasheet	Record sampling event metadata	Variable	All	No
Required	Pencils	Record sampling event metadata	2	All	No
Optional	Rangefinder	Estimate overstory height	1	All	No

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

Determining Camera Orientation and Height

- To decide which combination of camera orientation and camera position are required for a given plot, visually survey the vegetation structure in the **entire** plot and refer to Table 6.
- Keep in mind that the camera orientation and camera position may change throughout the year for a given plot if fast-growing herbaceous plants are present – e.g. in tall-stature grasslands, croplands, etc.
- **Record the visually-estimated average understory and overstory vegetation height for the entire plot** in the “LAI field datasheet”. Record “understoryHeight” to the nearest 0.1 m and “overstoryHeight” to the nearest 1 m (*Note: A rangefinder may be used for this purpose, but is optional as the accuracy is not required for this purpose*).

Table 6. Guidelines for determining proper camera positioning when taking DHPs.

Understory Vegetation ¹	Overstory Vegetation	Required Camera Orientations	Camera Position ²	Protocol Reference
Majority < 0.75–1m height	None	Single downward-facing photo per point	Shoulder height	SOP C
Majority > 0.75–1m height	None, or Majority < 3 m height	Single upward-facing photo per point	Ground level	SOP D
Majority < 0.75–1m height	Majority > 3 m height	Upward and downward-facing photos per point	Shoulder height	SOPs C & D
Majority > 0.75–1m height	Majority > 3 m height	Two upward-facing photos per point	One at shoulder height, one at ground level	SOP C

¹>50% of vegetation is characterized by the specified height criteria

² See Figure 5 for an example of a researcher holding a camera at shoulder height.

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

SOP C: Field Sampling Downward-facing DHPs

Image Acquisition Guidelines

- Place backpacks and other gear outside the plot and out of the potential field of view of the camera.
- Configure the camera for acquiring downward-facing DHPs according to the settings specified in Table 7. Consult Appendix D for detailed instructions on how to configure the Nikon D800.

Table 7. Camera settings for downward-facing DHPs.

Camera Position	Exposure Mode	Focus	ISO	Shutter	Aperture
Shoulder height	Aperture priority (A)	Auto-area Auto Focus	ISO-auto = ON Initial = 400	Open no longer than 1/30 s	> f/5.6 best, f/4 okay; no lower than f/4

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

Taking Downward-facing DHPs

- 1) Use a declination-corrected mirror-sight compass and calibrated pacing to locate the target photo point. **Make sure that no ferrous metal objects are within at least 50 cm of the compass at all times.**
- 2) Visually assess the distance between the lens and the vegetation. Foliage should be ≥ 50 cm from the lens; if foliage is < 50 cm from the lens:
 - a) Select an alternate spot as close as possible (< 1 meter, perpendicular to the axis) to the designated photo-point.
 - b) If (a) is not possible, consider taking upward-facing photos (SOP C) instead of downward-facing photos.

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

If foliage is within 0.5 m of camera lens, select an alternative location as close to photo point as possible.

- 3) Adjust the camera for proper image exposure:
 - a) Look through the viewfinder while aiming the lens at the ground.
 - 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) Adjust the f/stop value so it is as high as possible, but do not allow the shutter to be open longer than 1/30 s.
- 4) Place the monopod at shoulder height with the lens facing down.
- 5) Stand on the cardinal axis at the selected photo location. To minimize inclusion of trampled vegetation in the photo, point the camera/monopod perpendicular to the cardinal axis (either direction).
 - Choose a direction so that the photographer’s shadow is not in the image.
- 6) Keep the camera so that the lens is as close to perpendicular to the ground as possible.
- 7) Focus the lens every time you change camera position. Press the shutter release button half way. You should hear a “beep” indicating the camera has achieved focus lock.
- 8) Carefully press the shutter release button the rest of the way to take the photo.
- 9) Check the photo for quality:
 - Make sure the image is not blurry.
 - Check that appropriate shutter speed and f/stop values were obtained.
 - If necessary, delete and re-shoot until a satisfactory image is taken (see Figure 2).
 - **If it is not possible to obtain an image with f/stop > 4 and with the shutter open less than 1/30 s, collect DHPs when more light is available.** Unlike upward-facing DHPs, downward-facing DHPs may be taken with direct sunlight on the foliage.
- 10) **Fill out the “LAI field datasheet” as images are acquired** so that sampling metadata and image file data may be linked to specific pointIDs and plotIDs.
 - bout: a two digit number assigned by Field Operations. For Tower plots, bout begins with bout = 01, and increments throughout the season each time the designated Tower plots are photographed. For Distributed/Gradient plots, bout = 00. It is Field Operations responsibility to assign the correct bout number.

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

- pointID: value is derived from the cardinal direction of the plot axis (i.e. N, S, E, W) plus the distance from the plot-center to the photo-point in meters. Examples: N2, E10, etc.
- cameraOrientation: value = D; where D = downward-facing
- cameraPosition: value = S; where S = shoulder height
- imageType: value = U; where U = understory. Record “U” for all downward-facing images, even if there is no overstory vegetation (e.g. grassland, cropland).
- associatedMedia: value = image file name (e.g. D01_0001)
- remarks: value = notes relevant to image; e.g. “moved 1m E of photo-point”

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



Figure 2. Example of a properly exposed downward-facing DHP at the D01 Harvard Forest site (*photo by B. Chemel*). 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 during image analysis.

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

SOP D: Field Sampling: Upward-facing DHPs

Image Acquisition Guidelines

- Place backpacks and other gear outside the plot and out of the potential field of view of the camera.
- Configure the camera for acquiring upward-facing DHPs according to the settings specified in Table 8. Consult Appendix D for detailed instructions on how to configure the Nikon D800. These settings allow as much light as possible to be recorded by the camera while still enabling capture of a “good” quality image. Guidelines for modifying these settings are provided in the SOP below.

Table 8. 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 = 6400	1/30 s	f/5.6
Ground level	Manual (M)	Auto-area Auto Focus	ISO-auto = OFF Initial = 6400	1/30 s	f/5.6

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

Taking Upward-facing DHPs

- 1) Use a declination-corrected mirror-sight compass and calibrated pacing to locate the target photo point. **Make sure that no ferrous metal objects are within at least 50 cm of the compass at all times.**

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

- 2) Find a position at or as close to the photo-point possible with distinct sky and foliage elements overhead and **acquire a test image**. The goal is for the sky to be minimally saturated white, with 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) Configure the Nikon D800 as indicated in Table 8.
 - b) 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.
 - c) With the lens still pointing up, adjust the f/stop, shutter speed, and ISO according to Table 9 until the built-in light meter indicates proper exposure.

Table 9. Strategy for optimizing image exposure while taking upward-facing DHPs in manual exposure “M” mode.

Exposure Problem	Histogram White Peak	Optimization Steps (in order of preference)
Too much light	Too high	Increase f/stop up to f/16
		Decrease time shutter is open to 1/60s
		Decrease ISO and/or further decrease time shutter is open.
Too little light	Too low	Increase ISO to Hi1 or Hi2 (ISO 12800 or 25600)
		Decrease f/stop to f/4
		If still unacceptable, light conditions are too poor.

- d) Press the shutter-release button all the way down to take the test image.
- 3) Check the test image exposure results.
 - a) Press the “Play” button on the back of the camera to review the test image in the large LCD screen.
 - b) Select the “histogram” view using the up/down arrow buttons.
 - c) Check the white saturation levels in the test image. White saturation levels appear as a very thin peak at the right of the histogram – the height of this peak should be between $\frac{1}{4}$ – $\frac{3}{4}$ of the potential height (Figure 3).
 - If the exposure is too bright, the white peak will reach the top of the histogram graph.
 - If the exposure is too dark, there will be little or no white peak on the right side of the histogram.
- 4) If necessary, adjust the exposure according to Table 9 and take another test image until a correctly exposed image is produced (Figure 4). Tips for adjusting exposure:
 - Higher f/stops → reduced light to the sensor, greater depth of field.
 - Shutter open for less time → reduced light to sensor, better ability to “freeze” motion and avoid blurriness associated with subject motion.

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

- Lower ISO → sensor is less sensitive to light; below 6400 means images will not have “noise” artifacts.
- 5) At the designated photo-point, visually assess the distance between the lens and the vegetation. Foliage should be ≥ 50cm from the lens. If foliage is < 50cm from the lens:
 - a) Select an alternate spot as close to the designated photo-point as possible.
 If (a) is not possible, consult the “Troubleshooting” section of this SOP.
 - 6) Stand on the cardinal axis at the selected photo location. 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).
 - 7) Place the monopod either at shoulder height or on the ground (Figure 5).
 - 8) Orient the camera so that the lens is as close to perpendicular to the ground as possible.
 - 9) Press the shutter-release button carefully, to avoid moving the camera too much.
 - 10) Check the photo for quality:
 - Make sure histogram white saturation values are appropriate.
 - Make sure the image is not blurry.
 - Check that appropriate shutter speed and f/stop values were obtained.
 - If necessary, delete and re-shoot until a satisfactory image is taken (see Figure 4).
 - If it is not possible to obtain an image with f/stop > 4 and with the shutter open for less than 1/30 s, collect DHPs when more light is available.
 - 11) **Fill out the “LAI field datasheet” as images are acquired** so that camera placement metadata and image file names may be linked to specific pointIDs and plotIDs.
 - bout: a two digit number assigned by Field Operations. For Tower plots, bout begins with bout = 01, and increments throughout the season each time the designated Tower plots are photographed. For Distributed/Gradient plots, bout = 00. It is Field Operations responsibility to assign the correct bout number.
 - pointID: value is derived from the cardinal direction of the plot axis (i.e. N, S, E, W) plus the distance from the plot-center to the photo-point in meters. Examples: N2, E10, etc.
 - cameraOrientation: value = U; where U = upward-facing
 - cameraPosition: value = S, G, or O; where S = shoulder height, G = ground level, and O = other. If value = O, report camera height in “remarks” field.
 - imageType: value = U or O; where U = understory and O = overstory. Use “U” for images taken at ground level, and “O” for images taken at shoulder height.

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

- associatedMedia: value = image file name (e.g. D01_0001)
- remarks: value = notes relevant to image; e.g. “moved 1m E of photo-point” or “cameraPosition was 0.5 m”

12) Proceed to the next photo-point and return to step (1).

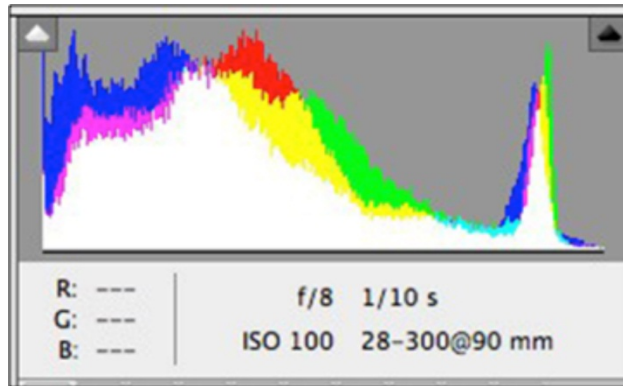


Figure 3. An example histogram from a properly exposed image. The red, green, and blue histograms are shown in their respective colors, and a combined luminance histogram is shown in white.

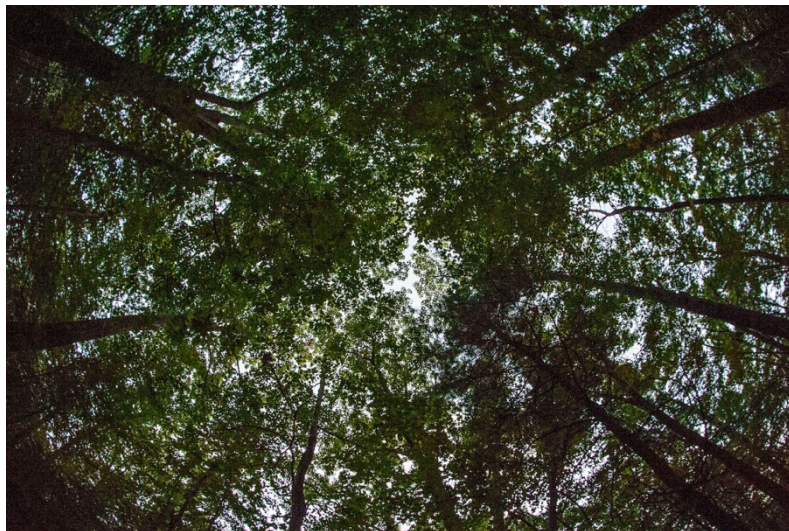


Figure 4. An example of a properly exposed upward-facing DHP taken at the NEON D01 Harvard Forest site.

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D



Figure 5. Image of a field researcher acquiring an upward-facing DHP with the monopod/camera ensemble held at shoulder height at the NEON D03 Ordway-Swisher site.

Troubleshooting

Table 10. Common issues encountered during acquisition of upward-facing DHPs, and available solutions.

Issue(s) Encountered	Camera Placement	Solution(s)
1) $f/stop < 4$ and/or 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 nearby location where vegetation is ≥ 50 cm from the lens.	Shoulder height	<i>Preferred:</i> Lower the camera height until foliage is ≥ 50 cm from the lens. Record alternate photo height in “Notes” 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 “Notes” column of field datasheet.
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.

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

SOP E: Post-Field-Sampling Tasks

Equipment and Materials

Table 11. Equipment required for transferring DHPs from the Nikon D800 to the NEON Domain server, and for handling field-collected sampling metadata.

Maximo Number	Item Description	Purpose	Qty	Conditions Used	Special Handling
MX104654	DSLR 16Gb memory card	Contains field-collected DHPs	2	All	No
MX104657	DSLR memory card reader	Transfer images from memory card to server following sampling event	1	All	No
Required	Completed LAI field datasheets	Contains field-collected DHP metadata	Variable	All	No
Required	Laptop with USB port	Connect to DSLR card reader and NEON Domain server	1	All	No

DHP Handling

- 1) Attach the DSLR card reader to the laptop, and make the NEON Domain Lab server available.
 - Consult the NEON IT department for instructions for connecting to the Domain Lab server.
- 2) On the Domain Lab server, create the following folders and sub-folders if they do not exist already:

\\...\LAI_data\LAI_RAW_images\YYYY\boutID\plotID\imageType

where:

- YYYY = the current year
 - boutID = XXXXZZ, where XXXX is the unique 4-letter NEON site code, and ZZ = bout # from the “LAI field datasheet”; bout # = 00 for Distributed or Gradient plots. Field Operations is responsible for keeping track of and creating the correct bout # for Tower Plots.
 - plotID = a separate sub-folder for images from each plot
 - imageType = a subfolder named either “understory” or “overstory”
- 3) Copy images from the camera card to the folders just created on the NEON Domain Lab server according to Table 12.

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

Table 12. Criteria for determining placement of DHP images within required file path and folder structure.

Camera Orientation	Camera Position	File Path
Downward	Shoulder	...\boutID\plotID\understory
Upward	Ground	...\boutID\plotID\understory
Upward	Shoulder	...\boutID\plotID\overstory

- 4) After successfully copying all of the images from the sampling event to the NEON Domain Lab server, images files on the camera memory card may be deleted.

Data Handling

Data recorded in the “LAI field datasheet” must be transcribed into a spreadsheet for ingest into NEON’s Cyberinfrastructure (CYI). There should be one Excel file containing Leaf Area Index data ingest sheets (RD[09]). This file contains at least the following spreadsheets:

- **dhpTableSummary_in:** Table briefly describing the purpose of each data ingest table, and indicating the measurement resolution for data that are entered.
- **dhpFieldSummary_in:** For each field in each ingest table, provides a description, data type, ingest validation rule, indication of null acceptability, and example data entry.
- **dhp_perplot_in:** Data and metadata recorded on a per plot, per bout basis.
- **dhp_perimagefile_in:** Data and metadata linking DHP file names to plotID, pointID, camera orientation, camera position, image type, and per image remarks.

- 1) Transcribe data from the header table on the “LAI field datasheet” into the “dhp_perPlot_in” ingest table.

- Consult the “dhpFieldSummary_in” table to determine appropriate values and formats for each field, and to see correctly formatted examples.
- Create “boutID” in XXXXZZ format, where XXXX = 4-letter siteID code, and ZZ = the “bout” number recorded on the “LAI Field Datasheet.”

- 2) Transcribe data from the main table on the “LAI field datasheet” into the “dhp_perImageFile_in” ingest table.

- Consult the “dhpFieldSummary_in” table to determine appropriate values and formats for each field, and to see correctly formatted examples.

<i>Title:</i> TOS Protocol and Procedure: Measurement of Leaf Area Index		<i>Date:</i> 04/10/2014
<i>NEON Doc. #:</i> NEON.DOC.014039	<i>Author:</i> C. Meier	<i>Revision:</i> D

- 3) Once all data from the most recent bout have been collected and transcribed, save only the data from the most recent bout to a .csv file for ingest by NEON CYI.

Refreshing the Sampling Kit

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

Equipment Maintenance, Cleaning and Storage

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

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

SOP F: Batch Processing DHPs with Photoshop

Important: The following SOP should only be performed on DHP images that have passed through QA/QC tests described in the NEON DHP QA/QC Algorithm and Theoretical Basis Document (ATBD). Tests described in the ATBD will be carried out by the NEON CyberInfrastructure.. Field Ops will receive an automatically generated report indicating when directories of DHPs have passed through the ATBD.

Once DHP images have been processed through the QA/QC ATBD (conducted on the Domain Lab server), DHPs in RAW image format (.NEF) must be resized, adjusted to improve visible detail in shadows, and converted to JPG format for analysis in CanEye.

Equipment and Materials

Table 13. Laboratory equipment required to batch process DHPs.

Maximo Item No.	Item Description	Purpose	Qty	Conditions Used	Special Handling
Required	Adobe Photoshop (version CS5 or CS6 are suitable)	Perform batch resize, shadow adjust, and format conversion on DHPs.	1	All	No
Required	Virtual machine running on Domain Lab server	Hosts installation of Photoshop on Domain Lab server.	1	All	No

Sample Processing Timing

DHP images collected in the field may be processed for LAI with Photoshop and CanEye any time after images have passed automated QA/QC tests. However, it requires approximately 30-60 min per plot to process and analyze the images (depending on whether 12 or 24 images were taken per plot), so it is good practice not to amass a large volume of un-analyzed images.

Creating a Photoshop Batch Processing “Droplet”

In Photoshop, a “Droplet” is an icon onto which files can be dragged, dropped, and then processed according to a standard set of actions encoded in the Droplet. Following the instructions below, you will create a Droplet that processes DHP RAW files into JPG files with Quality = 10 (out of 100).

- 1) Login to the virtual machine on the Domain Lab server that runs Adobe Photoshop, and make available the share that is used for DHPs copied from the camera.
- 2) Select a test image file – either upward or downward-facing. Create a test image by copying a DHP file to the Desktop.
 - It is important that the test image is exposed similarly to the .NEF images for which processing is desired.

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

- 3) Open Adobe Photoshop.
- 4) Make sure the “Actions” pane is visible: from the drop-down menus click “Window → Action” (Alt-F9).
- 5) Within the “Actions” pane, create a new set of actions by clicking the folder icon at the bottom of the pane, and name the new action set “CanEye processing”.
- 6) Create a new action within the “CanEye processing” set by clicking the “Create New Action” button at the bottom of the pane (post-it icon).
- 7) Name the new action “RAW to JPG Q10”. Click “OK” to begin recording the new action – from this point onward, until you click the “Stop” button at the bottom of the Action pane, Photoshop will record everything you do as part of the new action.
 - The “Q10” indicates the JPG files will be generated with quality set to 10 out of 100, which should be a relatively small, low-quality JPG image.
- 8) Open the test image file: “File → Open”
- 9) In the “Camera RAW” plug-in that opens with the image, adjust the exposure using the sliders in Table 14 below. The goal is to obtain good tonal information and detail in darker areas of the image, and avoid losing information in any very bright, highly exposed portions of the image.

Table 14. Sliders and their effects in the “Basic” panel of Adobe Camera Raw¹.

Slider	Effect	Reason to Use
Exposure	Adjusts brightness of mid-tones to shadows	Image is underexposed across the tonal range
Contrast	Adjusts contrast of mid-tones, some shadows, some highlights	Detail in a broadly mid-tone range are washed out
Highlights	Manipulates tonal values for the upper ¼ of the image tonal range	Decreasing highlights can bring out detail in an overexposed sky
Shadows	Manipulates tonal values for the lower ¾ of the image tonal range	Brings out color tones and detail previously cloaked in shadow
Whites	Manipulates the very brightest white pixels in the image.	Image contains highly overexposed areas.
Blacks	Manipulates the very darkest black pixels in the image.	Image contains deeply underexposed areas.
Clarity	Adjusts contrast on image mid-tones, but not shadows and highlights	Improves the ability to discern fine details in the image.

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

¹ Multiple Droplets may be created in order to accommodate variation in image exposure for image sets taken at different times of day, or with different shadow strengths, etc.

- 10) To adjust the size of the photo, click the link at the bottom of the Camera RAW window that states the image size, and in the “Workflow Options” window that opens, make the following selections, then click “OK”:

Parameter	Desired Setting
Space	sRGB IEC61966-2.1
Depth	8 bits/channel
Size	2048 x 1368 pixels (2.8 MP)
Resolution	240 pixels per inch
Sharpen for	None; amount = standard

- 11) In the Camera RAW window, click “Open Image” in the bottom-right.
- 12) Verify that the image has changed size by clicking “Image → Image size” from the drop-down menus. Click “OK”.
- 13) Select “File → Save for web”, which will open a new “Save for Web & Devices” window. In the top-right of this window, select “Quality = 10”.
- 14) Click “Save”, and save the image to the Desktop.
- 15) When saving is complete, click “Stop Recording” at the bottom of the Photoshop “Action” pane.
- 16) To create the Droplet, select “File → Automate → Create Droplet” and name the Droplet “RAW to JPG Q10 [light condition]”; where [light condition] = dusk, strongShadowsDay, softShadowsDay, etc. (when unique light conditions arise for which existing droplets do not produce images with acceptable exposure, define the light condition in a useful manner; e.g. “dusk” may be broken out into “closedCanopyDusk” and “openCanopyDusk”. *Note*: camelCase has been suggested here as a naming convention to be consistent with data ingest sheets, but is not required.
- 17) Click “Save”. The Droplet can be saved to the Desktop for ease of use, or to any other location.
- 18) A new menu will appear requesting you to assign an Action to the Droplet. Select the Action that you just created above.
- 19) Check the “Override action ‘Open’ commands” box. This ensures that Photoshop will batch process photos without opening the Camera RAW plugin.
- 20) Set the destination folder.
- First create a “Batch Output” folder on the Desktop.
 - Select the “Batch Output” folder as the destination.

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

- 21) Check the “Override action ‘Save as’ commands” box.
- 22) Set the file naming scheme so that the original file names are preserved.
- 23) The Droplet will now be saved to your Desktop and be available for use.

Processing DHP images with a Photoshop Droplet

- 1) To batch process a group of 12 RAW .NEF images from:

 \\...\boutID\plotID\imageType\
 First create a create a subfolder in “imageType” named “processed”.
- 2) Select .NEF photos from the “imageType” folder within Windows Explorer, and drag onto the Droplet. Processed JPG photos will appear in the “Batch Output” folder.
- 3) Check batch processed images to determine whether the Droplet created satisfactory JPGs (Table 15).

Table 15. Details to examine in JPG images created via batch process from DHP RAW images.

Camera Orientation	Potential Issue
Downward	Inability to distinguish green leaves from soil, litter, rocks, etc. in areas of strong shadow.
	Inability to discern fine detail in mid-tones
	Overexposed areas lacking tonal detail – i.e. photos of a grassland taken during the day. Difficult to distinguish green from other colors in everexposed areas.
Upward	Inability to distinguish green leaves from underexposed sky in areas of strong shadow.
	Inability to discern fine detail in mid-tones
	Inability to distinguish leaves from sky in overexposed areas

- 4) If processed images are satisfactory:
 - a) Move processed images from “Batch Output” to:

\\...\boutID\plotID\imageType\processed\

Otherwise,

Create a Photoshop droplet (or use a different existing one) that will produce a quality test image, and re-process the batch of .NEF files. A subset of images may also be re-processed if desired.

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

SOP G: Analyzing JPG Images for Leaf Area Index with Caneye Software

Important: The following SOP should only be performed on DHP images that have passed through QA/QC tests described in the NEON DHP QA/QC Algorithm and Theoretical Basis Document (ATBD). Tests described in the ATBD will be carried out by the NEON CyberInfrastructure team. Field Ops will receive an automatically generated report indicating when directories of DHPs have passed through the ATBD.

Once DHP images have been processed through the QA/QC ATBD (which will be conducted on the Domain Server), use CanEye software to analyze the overstory and understory photos from a given plot in separate batches.

It is necessary to analyze a minimum of 8 distinct images per batch in CanEye. The software makes assumptions about the distribution of canopy gaps in the images, and these assumptions are violated when the image sample size drops below n=8. Images will first be analyzed in batches of n=12, and sample size will be reduced only if necessary (details on which images to exclude are provided below).

Equipment and Materials

Table 16. Laboratory equipment required to JPG images with CanEye software.

Maximo Number	Item Description	Purpose	Qty	Conditions Used	Special Handling
Required	CanEye (current version) with associated Matlab libraries	Calculate plot and point-level LAI from JPG images.	1	All	No
Required	Virtual machine running on Domain Lab server	Hosts installation of CanEye on Domain Lab server.	1	All	No

Starting and Parameterizing CanEye

The following steps are performed each time images are analyzed in CanEye. Do not reuse existing parameter files from past sessions.

- 1) Login to the virtual machine on the Domain Lab server that runs CanEye image analysis software.
- 2) Launch CanEye using the “Run as Administrator” command. To do this, R-click on the CanEye program icon and select “Run as Administrator”.
- 3) From the menu bar, select “Hemispherical Images → RGB images”, and then select either “Upward” or “Downward,” depending on the type of images to be analyzed.

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

- The program may indicate “No directory selected” and return to the launch screen. This is a known bug, and if this happens, simply re-select the image type according to the step above, and a “Browse for Folder” window will appear.
- 4) Select the directory containing the JPG images to be analyzed. A “Can-Eye Parameterization” window will appear. The generalized directory path will be:
- \\...\boutID\plotID\imageType\processed\
- 5) In the “comment” field, enter the following:
- boutID
 - plotID
 - “overstory” or “understory”, depending on imageType
- 6) In the “Calibration Parameters” portion of the window, click “Create” under “Optical Center and Projection Function”. **DO NOT reuse a pre-existing Calibration Parameter file.** In the window that opens, enter the following values, then click “OK”:

Table 17. Creating the optical center and projection function for LAI analysis in CanEye.

Field	Field Description	Desired Value
Lines	Pixel number corresponding to the image center (vertical direction)	Lines = (Total vertical pixel #)/2; Lines = 1363/2 = 681.5 for a 2048 x 1363 pixel JPG
Columns	Pixel number corresponding to the image center (horizontal direction)	Columns = (Total horizontal pixel #)/2; Columns = 2048/2 = 1024 for a 2028 x 1363 pixel JPG
Projection Function Slope	The relationship between zenith angle (y-axis) and column pixel # (x-axis)	For an image with 2048 px showing a 180° zenith view: Slope = 180/1024 = 0.08789

- 7) Returning to the “Calibration Parameters” window, enter the following values, overwriting existing values where necessary:
- COI (Circle of Interest) = 75°
 - For “Angular Resolution”, Azimuth = 5°
- 8) Enter the day-of-year (DOY) the images were collected.
- a) Obtain the correct date by checking the file creation date on one of the RAW (.NEF) image files.
 - b) Convert the date from YYYY-MM-DD format to DOY by checking: <http://www-air.larc.nasa.gov/tools/jday.htm>

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

- 9) Enter the latitude (nearest 0.1 degrees) of the site at which images were collected. Latitude can be estimated using Google Earth and the current version of the NEON site .kmz file.
- 10) Click “Save”. A window will open as the images are processed.
- 11) Click “Save” parameter file.
- 12) A grid of images will appear. Click “OK”, and proceed to “Image Masking” below.

Image Masking and Color Reduction

Ultimately, you will assign image pixels to three categories: green, sky/soil, and mixed. In this step, you will mask features in each DHP image that do not fit into these categories (see masking guidelines in Table 18).

Table 18. Elements in each DHP that should be masked prior to LAI estimation with CanEye.

Camera Orientation	Masking Guidelines
Downward	Mask “large”, vertically oriented trunks, boles, stems, or branches. Look at the edges of the photos for vertical stems.
	Photographer’s feet, plot markers/flags, other objects that are neither litter/soil/rock nor green plant matter.
	DO NOT mask understory leaves that are attached to overhanging branches.
Upward	Mask “large” trunks in each image.
	Stop masking an individual trunk BEFORE it becomes difficult to discern trunk from branches and leaves.
Both	Stay within the boundary of the element being masked in order to avoid masking sky, soil, or green plant matter.
	“Large” is relative: use time as a guide. Do not spend more than 1 min per image masking trunks.

To create masks using CanEye:

- 1) On the screen with the grid of open images, click the “Select” button at the bottom. Then click on the first image to which you want to apply masks, and click “Mask”.
- 2) Choose the first object to mask.
 - a) L-click around the perimeter of the object to create the mask.
 - b) R-clicking will close the mask polygon and complete the mask.

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

- 3) Continue masking objects in the selected image until:
 - a) All “large” objects are masked, or
 - b) 1 min has elapsed
- 4) Click “Done” in the bottom ribbon after masking is complete. You should return to the gridded display screen showing all the images in the set.
- 5) Repeat steps 1 through 4 for each image in the set, as needed.
- 6) Select “Done” from the bottom ribbon.
 - A color reduction process bar appears. When processing is done, a new window opens.
 - Be patient... the processing takes time. When done, the “Class Definition” window opens. If after 15 min this window does not open:
 - Proceed to step (7).
 - Otherwise, once the “Class Definition” window opens, proceed to step (8).
- 7) If CanEye has crashed, it appears to depend on the total amount of masked area, and/or the total number of masks created. The solution is to reduce the number of images analyzed, one at a time:
 - Randomly remove an image from one of the 2m photo-points (i.e. N2, E2, S2, or W2) and return to step (1) under “Starting and Parameterizing CanEye”.
 - If the crash re-occurs, remove another randomly selected 2m photo-point image, and try again.
 - You may remove the photos from all 4 of the 2m photo-points, but DO NOT analyze fewer than n=8 images.
 - **If images are removed from the analysis**, record the pointID associated with the removed images in the “remarks” field of the “lai_plot” ingest sheet.
 - **If CanEye crashes with n=8 images**, record “NA” in the “laiPlot” field of the “lai_plot” ingest sheet, and note “CanEye crash” in the “remarks” field.
- 8) In the “Class Definition” window, select “This Option” from the right-hand pane, and click “Done”.
 - A array of images with a color grid on the right will appear. This is the “Classification Window”.

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

- 9) Set the colors used to represent pixels classified into “Soil” (or “Sky”) and “Green” classes. Colors are chosen so that they stand out in relation to background colors. To assign a color:
- a) Click on a category box (i.e. “Soil” or “Sky”, or “Green”). DO NOT click on either the round or square radio buttons on either side of the box. A color strip window opens.
 - b) Click on the desired color. The following colors provide good contrast with multiple backgrounds:
 - Soil/Sky = Yellow or Orange
 - Green = Purple
- 10) Proceed to either the “Downward-facing” or “Upward-facing” pixel classification section.

Downward-facing Image Pixel Classification

The procedures for processing downward- and upward-facing images, although similar, have some critical differences. To process upward-facing images, follow the procedure in the “Upward-facing Image Pixel Classification” section.

Pixel classification is an iterative process, in which you move back and forth classifying pixels into either the “Green” or “Soil” categories (Table 19). In these directions, we will begin with “Green” plant matter, but you may begin with soil if you prefer. See digital tutorial “Classifying Pixels” for a demonstration of assigning pixels to classes in CanEye.

Table 19. Guidelines for classifying pixels into “Green” and “Soil” categories in downward-facing images.

Pixel Category	Qualifying Material
Green	Live leaves, needles, green moss, and flowers
	Other material capable of performing photosynthesis
Soil	Lichen, brown moss, litter, downed woody debris
	Bare soil, rocks
	Other material not capable of photosynthesizing
	Senesced leaves (yellow, orange, brown) that are on the ground or still attached to stems.

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

Classifying Pixels as Green or Soil

- 1) First, zero-out pre-classification of pixels into the “Soil” category.
 - a) Click on the round radio button to the left of the “Soil” box. This opens the “Class Pre-classification” window.
 - b) In the “Class Pre-classification” window, move the “Brightness Index” option slider all the way to the left, to a value of 0.000
 - c) Click “OK”.
- 2) L-click on one of the images in the grid; it does not matter which one.
- 3) Zoom in (L-click) on a leaf or dense leafy area in the image.
 - Zoom in until individual pixels are clearly visible and the entire screen is filled with the leaf.
- 4) Select the radio button next to “Green.”
- 5) L-click on the lots of pixels in the image that are unambiguously plant matter (this should be everything on your screen if you zoomed in on a leaf).
 - You do not need to be systematic in your L-clicking. By randomly clicking on pixels that are all part of the leaf, you will have selected a variety of the true colors that should be classified as “Green.”
- 6) R-click to apply the purple color to the selected pixels.
 - CanEye automatically assigns all pixels in the entire set of images with the same color to the “Green” class.
 - The category boxes (lower right) keeps a tally of the percent of pixels assigned to each class.
 - The color palette (upper right) shows the true colors placed into the “Green” class in the region bounded by purple lines on three sides and a gray line on the bottom.
- 7) Zoom out to verify that your classification makes sense for the entire image. Use “Select All” to verify that it also makes sense for all the images in the set.
- 8) Repeat Steps 2 through 7, zooming in on different parts of multiple images until all obvious and unambiguous plant leaf pixels are classified as “Green.”
- 9) After classifying the obvious/easy plant elements, classify the obvious and unambiguous soil elements. Proceed in the same manner as for plant matter (Steps 2 through 8 above).

Strategies for Classifying Additional Pixels

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

After classifying the easily identifiable plant and soil elements in an image set, finding additional pixels to classify can be difficult. The strategies below will aid in identifying and classifying additional pixels. See the digital tutorial “Classifying Pixels” for demonstrations on using these techniques. **In general, it is best to err on the side of caution: Classify a pixel/color as “Mixed” rather than misclassify it as “Soil” or “Green”.**

- 1) Look closely at the edges of foliage for pixels to assign to “Green” or “Soil” classes.
 - Toggling back and forth between true colors and classified colors is a good way to locate unassigned pixels.
 - Move your head (or angle of computer screen) to change the angle of your view – colors look a little different at different angles.

- 2) Use the color palette to identify colors to move from “Mixed” to either the “Green” or “Soil” class.
 - For example, look at the colors in the “Green” class, then look for similar colors that are in the “Mixed” class. These are good candidates for colors to move in the “Green” class.
 - Focus particularly on colors with red dots, as these represent the greatest number of pixels in the image set.

- 3) Look at all the images in a set: There may be a group of easily classified pixels in one image that is not present in the other images.

- 4) Look at the color palette. Does anything look out of place? If yes, move it to the “Mixed” class, and be conservative.

- 5) Look carefully at commonly misclassified colors that are often mistakenly placed in the “Soil” or “Green” class (rather than “Mixed”). In particular:
 - Greenish, even olive to drab olive colors in the “Soil” class.
 - Grays and browns in the “Green” class.

NOTE: It may be helpful to toggle back and forth between true colors and classified colors to identify suspect areas.

- 6) To move a color that has been assigned to “Soil” or “Green” back to the “Mixed” class:
 - Select round radio button next to “Mixed.”
 - L-click on suspect true color(s) in the color palette.
 - R-click.
 - Repeat as needed.

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

7) Determining when you are finished with pixel classification:

- a) Keep an eye on the percent of pixels assigned to the “Mixed” category. Once “Mixed” pixels represent between 15%-20% of the total, classification is complete.
- b) Click “Done” at the bottom of the image grid.
- c) Click “Yes”.
 - A series of computations occur. When computations are complete, the screen returns to the CanEye launch screen.
 - LAI results from the image analysis are stored in a subfolder located in the folder with DHP images that was initially selected.

Upward-facing Image Pixel Classification

The procedures for processing downward- and upward-facing images, although similar, have some critical differences. To process downward-facing images, follow the procedure in the “Downward-facing Image Pixel Classification” section.

Pixel classification is an iterative process, in which you move back and forth classifying pixels into either the “Green” or “Sky” categories (Table 20). In these directions, we will begin with “Green” plant matter, but you may begin with sky if you prefer. See digital tutorial “Classifying Pixels” for a demonstration of assigning pixels to classes in CanEye.

Table 20. Guidelines for classifying pixels into “Green” and “Sky” categories in upward-facing images.

Pixel Category	Qualifying Material
Green	Live leaves, needles, green moss, and flowers
	Other material capable of performing photosynthesis
	Twigs, branches, and “small” trunks that were not previously masked
	Senesced leaves (yellow, orange, red, brown) still attached to living stems
Sky	Open sky, clouds

Pre-Classifying Sky Pixels

Classifying pixels in a set of upward-facing images begins with pre-classification of sky pixels. Pre-classification provides a first cut at classifying pixels as sky. The goal is to assign pixels that are CLEARLY and UNAMBIGUOUSLY sky to the “Sky” category. You will then refine the auto-classification performed in this step by manually classifying additional pixels.

- 1) L-click on one of the DHP images.

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

- 2) Zoom in on an area in the image that has lots of sky as well as some small branches and leaves.
 - Zoom in until the image is only slightly pixelated and leaves and branches are still easily discerned -- two L-clicks is typically enough.
- 3) Click on the round radio button to the left of the “Sky” box. This opens the “class pre-classification” window.
- 4) On the “class pre-classification” window, move the “Brightness Index” option slider all the way to the right, for a value of 1.000.
 - It is helpful to move the window so that it does not cover the DHP image.
- 5) Adjust the slider, moving it in small increments to the left.
 - As you move the slider, pixels that are classified as “Sky” will be highlighted in orange (or whatever color you selected for the “Sky” class). Keep nudging the slider to the left.
 - When it appears that pixels that are not sky (i.e., branches or leaves) are becoming orange, back off the slider and click “OK.”

NOTE: Once you click “OK” the “pre-classification” window can only be re-opened by clicking the “reset” button (on the bottom ribbon), which undoes all classifications.

- 6) Click “Display All” on the bottom ribbon.
- 7) Check that pre-classification produced satisfactory results for ALL images.

Classifying Pixels as Green or Sky

- 1) L-click on one of the images in the displayed grid; it does not matter which one.
- 2) Zoom in (L-click) on a leaf, dense leafy area, or stem in the image.
 - Zoom in until individual pixels are clearly visible and the entire screen is filled with the selected plant matter.
- 3) Select the radio button next to “Green.”
- 4) L-click on the numerous pixels in the image that are unambiguously plant matter.
 - If you zoomed in on a stem so that it fills the entire screen, you do not need to be systematic in your L-clicking. By randomly clicking on pixels that are all part of the stem, you will have selected a variety of the true colors that should be classified as “Green.”

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

- For dense leafy areas, you need to be more intentional with your L-clicking. The lighter/light gray pixels may be sky filtering through the leaves. If in doubt, do not classify a pixel as “Green,” leave it in the “Mixed” class. (See series of images on page 24 for an example of classifying pixels in a dense leafy area.)
- 5) R-click to apply the purple color to the selected pixels.
 - CanEye automatically assigns all pixels in the entire set of images with the same color to the “Green” class.
 - The category boxes (lower right) keep a tally of the percent of pixels assigned to each class.
 - The color palette (upper right) shows the true colors placed into the “Green” class in the region bounded by purple lines on three sides and a gray line on the bottom.
 - 6) Zoom out to verify that your classification makes sense for the entire image. Use “Select All” to verify that it also makes sense for all the images in the set.
 - 7) Repeat Steps 1 through 6, zooming in on different parts of the image until all obvious and unambiguous plant leaf pixels are classified as “Green.”
 - 8) Check other images in the set to make sure all unambiguous elements in the set are classified as “Green”.
 - 9) After classifying the obvious/easy plant elements, classify the obvious and unambiguous sky elements. Proceed in the same manner as for plant matter (Steps 1 through 8 above).

Strategies for Classifying Additional Pixels

After classifying the easily identifiable plant and sky elements in an image set, finding additional pixels to classify can be difficult. The strategies below will aid in identifying and classifying additional pixels. See the digital tutorial “Classifying Pixels” for demonstrations on using these techniques. **In general, it is best to err on the side of caution: Classify a pixel/color as “Mixed” rather than misclassify it as “Sky” or “Green”.**

- 1) Look closely at the edges of foliage elements for pixels to assign to the “Green” or “Sky” classes.
 - Toggling back and forth between true colors and classified colors is a good way to locate unassigned pixels.
 - Compare the true colors of the unclassified pixels to those in the color palette. If they are not similar, then leave the pixels in the “Mixed” class.
- 2) Use the color palette to identify colors to move from “Mixed” to either the “Green” or “Sky” class if it seems to make sense. In particular look for:

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

- Bright/light grays to move into the “Sky class.
 - Dark greens, very dark greys, and black to move into the “Green” class.
 - Focus particularly on colors with red dots, as these represent the greatest number of pixels.
- 3) Look at the color palette. Does anything look out of place? If yes, move it to the “Mixed” class.
 - 4) Look at all the images in a set: There may be a group of easily classified pixels in one image that is not present in the other images.
 - 5) Determining when you are finished with pixel classification:
 - a) Keep an eye on the percent of pixels assigned to “Mixed” category. Once it is down to 15% - 20%, classification is complete (Figure 6).
 - b) Click “Done” at the bottom of the image grid.
 - c) Click “Yes”
 - A series of computations occur. When they are done, the screen returns to the CanEye launch screen.
 - LAI results from the image analysis are stored in a subfolder located in the folder with DHP images that was initially selected.

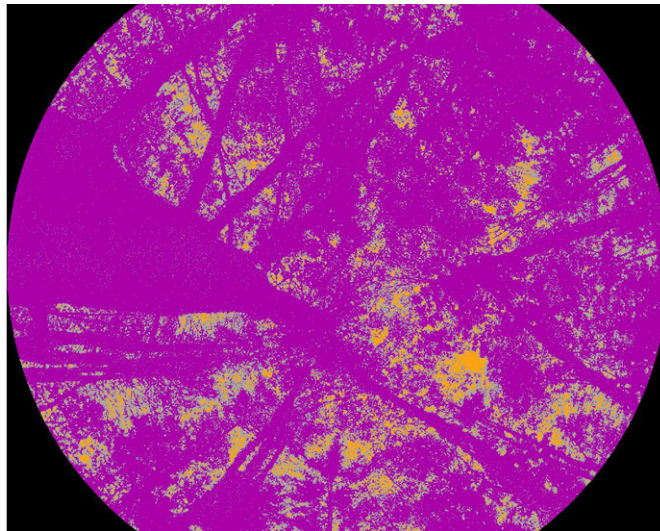


Figure 6. Example of an upward-facing hemispherical image successfully classified into sky (orange) and plant material (purple). Grey represents ambiguous pixels in the “Mixed” category that the user has not classified.

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

SOP H: Entering Data from CanEye Output

Results from the CanEye image analysis are automatically stored in a subfolder within the “processed” folder created earlier. Data from the CanEye Excel output file are manually transcribed into the NEON Ingest Workbook for Digital Hemispherical Photos (RD[09]).

- 1) Navigate to the folder containing the CanEye output files:

\\...\boutID\plotID\imageType\processed\CE_P180_processed\

- 2) Open the Excel file (.xls) that CanEye produced. There should be several tabs within this file.
- 3) Click on the “PAI, ALA” tab. These data are calculated LAI values for the entire plot.

NOTE: CanEye actually reports “PAI” – i.e. Plant Area Index – rather than LAI. PAI is roughly equivalent to LAI, but includes the contribution of non-leaf plant parts such as twigs, branches, and some trunks. In practice, LAI is rarely calculated, and PAI is reported and referred to as LAI.

- 4) Transcribe values from the “PAI, ALA” tab into the “plotLAI” field in the “lai_perPlot_in” table in the Ingest Workbook (RD[09]). Consult Table 21 to determine which values in the “PAI, ALA” tab are required (see Figure 7 for an example “PAI, ALA” tab).

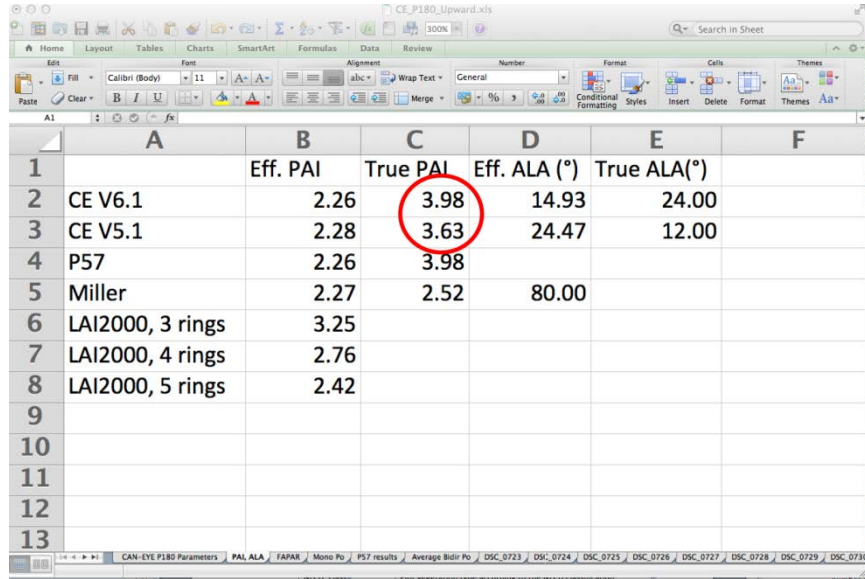
Table 21. Guidelines for transcribing LAI output from the CanEye Excel file to the NEON Data Ingest Workbook.

Camera Orientation	Vegetation Type	Transcribed Value
Downward	All	Column = True PAI Row = CE V6.1
Upward	Forest overstory (> 3m average height for the plot)	Column = True PAI Row = CE V5.1
	All others	Column = True PAI Row = CE V6.1

- 5) Record the number of images CanEye analyzed in the “imageNumber” field in the “lai_perPlot_in” table.
- 6) Transcribe values from **column C** in the “P57 results” tab into the “pointLAI” field in the “lai_perPoint_in” table in the Ingest Workbook (RD[09]). These data are calculated LAI values for each image (and hence each pointID).
 - Assign the appropriate “pointID” value to each value of “pointLAI”.
 - To assign the correct “pointID” to values of “pointLAI,” use previously entered data from the “associatedMedia” and “pointID” fields in the “dhp_perImageFile_in” ingest table.

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

- 7) Once data have been transcribed from all plots for a given bout, create a .csv file for each ingest table containing *only the newly entered data* in that table. These .csv files will be processed by the NEON CYI team.



	A	B	C	D	E	F
1		Eff. PAI	True PAI	Eff. ALA (°)	True ALA(°)	
2	CE V6.1	2.26	3.98	14.93	24.00	
3	CE V5.1	2.28	3.63	24.47	12.00	
4	P57	2.26	3.98			
5	Miller	2.27	2.52	80.00		
6	LAI2000, 3 rings	3.25				
7	LAI2000, 4 rings	2.76				
8	LAI2000, 5 rings	2.42				
9						
10						
11						
12						
13						

Figure 7. Example CanEye output from the “PAI, ALA” tab. Values that may be transcribed are circled in red.

<i>Title:</i> TOS Protocol and Procedure: Measurement of Leaf Area Index		<i>Date:</i> 04/10/2014
<i>NEON Doc. #:</i> NEON.DOC.014039	<i>Author:</i> C. Meier	<i>Revision:</i> D

11 REFERENCES

N/A

<i>Title:</i> TOS Protocol and Procedure: Measurement of Leaf Area Index		<i>Date:</i> 04/10/2014
<i>NEON Doc. #:</i> NEON.DOC.014039	<i>Author:</i> C. Meier	<i>Revision:</i> D

APPENDIX A QUICK REFERENCE

Taking Hemispherical Images

STEP 1 - Determine number and type(s) of images needed for sample plot.

STEP 2 – Assess if lighting conditions are favorable.

STEP 3 – a) Dawn sampling: Start with upward-facing images

b) Dusk sampling: Start with downward-facing images

STEP 4 – Take test image to assess lighting conditions.

STEP 5 – Begin on north axis, taking downward-facing photos at 2 m, 6 m, and 10 m.

STEP 6 - Check each image for exposure. Delete and reshoot as needed.

STEP 7 – Record Point ID and other required information on Data Sheet.

STEP 8 – Continue taking downward-facing images, moving sequentially to east, south, and then west axes, always starting at the photo point closest to the plot origin.

STEP 9 – Take images of other required camera Orientation (if needed) and test image.

STEP 10 – Check for correct exposure, white saturation, and focus. See table previous page for criteria.

STEP 11 – Begin on north axis, take pictures sequentially at 2 m, 6m, and 10 m and continue sequentially to east, south, and then west axes.

STEP 12 – Check white saturation, exposure, and focus of each image. Delete and reshoot as needed.

STEP 13 – Record Point ID and other required information on Data Sheet.

STEP 14 – Transcribe Data Sheet and download camera images to NEON computer.

<i>Title:</i> TOS Protocol and Procedure: Measurement of Leaf Area Index		<i>Date:</i> 04/10/2014
<i>NEON Doc. #:</i> NEON.DOC.014039	<i>Author:</i> C. Meier	<i>Revision:</i> D

APPENDIX B CHECKLISTS

Getting Ready for Image Collection

At least two days before field effort: Make sure...

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

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

Taking Quality Hemispherical Images

When you arrive at site: Make sure...

- Direct sunlight is NOT visible on foliage.
- 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.

When taking images: Check that...

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

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

APPENDIX C PROTOCOL CHANGE SUMMARY

The following changes to SOPs have been made between Rev B and Rev C protocols:

SOP Change	JIRA Ticket or V2 comment ID(s)
Evaluation of equipment for indirect measurement of LAI no longer mentioned. Comment was addressed to the best degree possible, as it is not feasible to change the past circumstances surrounding the equipment evaluation.	KR01
Original movement of text by KR was rejected in favor of a re-organization of the text that now better reflects the purpose of the protocol.	SC05
Deleted text specifying technicians must have prior working knowledge of manual image exposure with a DSLR; expanded Appendix D to provide camera use and configuration instructions; expanded training requirements in Section 8.	SC08, KR10
More specific guidance with respect to the timing of sampling in Distributed/Gradient plots is provided as a table footnote in Section 9.	KR16
It is no longer required that technicians pay attention to orientation with respect to the sun while taking upward- and downward-facing images.	FOPS-241
The minimum distance between foliage and lens was reduced from 1m to 50cm.	NA
Understory vegetation heights used to determine camera orientation have been increased from 0.5 m to 0.75-1m (Table 7, Section 10, SOP B). A range of heights is provided because not all technicians are the same height, and technicians should aim or vegetation to be < 50 cm from the lens.	NA
Section 9: Downward-facing DHPs may now be taken during daylight hours, and should NOT be taken at the same time as upward-facing photos (i.e. at dawn or dusk). Rationale: it is too difficult to distinguish between greens and browns in downward-facing photos taken when light is low, and statistical analysis indicates no effect of image capture time of day on LAI for downward-facing photos.	NA
SOP C: Table 9 added to provide guidance for optimizing image exposure when using manual exposure "M" mode.	NA
SOP D: Sampling "boutID" values, used to create file paths for DHP storage on the NEON server among other things, are now constructed according to a new format that should prevent duplicate IDs across sites within a domain. Clear and revised instructions are now provided for file path structure.	FOPS-606
SOP D: Clear instructions are now provided for file transfer.	FOPS-606
SOP E and F: Only DHPs that have passed through the QA/QC ATBD are to be processed in Photoshop and CanEye.	FOPS-660
SOP E: All DHPs are processed to create JPG files with quality = 10.	FOPS-660
SOP E: A new procedure is introduced to reduce and document the number of images analyzed when CanEye crashes.	FOPS-660
Appendix E: Updates to required settings to address auto-image rotation, and Nikon's introduction of a 16mm fisheye lens with a manual f/stop ring. Reorganization into two sections: "Settings Adjusted Prior to Field Work" and "Settings Adjusted in the Field"	NA

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

APPENDIX D SITE-SPECIFIC SAMPLING PARAMETERS FOR TAKING DIGITAL HEMISPHERICAL PHOTOS FOR LEAF AREA INDEX

In Table 22 below, Start Date and End Date fields are relevant to temporally-intensive LAI sampling in Tower plots; the Peak Greenness field represents the date range during which AOP is expected to fly each site, and during which spatially-intensive LAI sampling in Distributed plots is expected to occur. An additional contingency for Distributed plot LAI sampling is that all plots should be measured within a 1 month window that includes the actual AOP flight date. All dates in Table 1 are estimated from MODIS-EVI phenology data averaged from 2001-2009. See Appendix E for “day-of-year → Gregorian date” conversions.

Table 22. 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. All dates are provided in day-of-year format. Site ID values that are bold/italic are sites in Operations in 2014.

Domain Number	Site ID	Start Date	End Date	Peak Greenness	Additional Sampling Information
01	BART	120	300	170-220	
	BURL	110	315	160-220	
	HARV	110	300	160-220	
02	BLAN	75	310	150-210	Variable peak greenness window; may end by day 180.
	SCBI	85	320	150-220	
	SERC	80	325	155-220	
03	DSNY	60	320	140-190	Variable peak greenness window; may begin by day 120, end by day 155.
	JERC	90	310	175-220	Variable peak greenness window; may end by day 195.
	OSBS	70	315	150-190	Variable peak greenness window; may begin by day 120, end by day 145.
04	GUAN	0	365	NA	Year-round Tower plot sampling; no peak greenness.
	LAJA	0	365	NA	Year-round Tower plot sampling; no peak greenness.
	MAME	0	365	NA	Year-round Tower plot sampling; no peak greenness.
05	STEI	120	250	165-215	
	TREE	120	250	165-215	
	UNDE	125	285	170-215	
06	KONA	90	300	160-210	Variable peak greenness window; may end by day 190.
	KONZ	90	300	160-210	Variable peak greenness window; may end by day 190.
	KUFS	75	330	160-210	Variable peak greenness window; may

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

Domain Number	Site ID	Start Date	End Date	Peak Greenness	Additional Sampling Information
					end by day 185.
07	GRSM	90	310	155-215	
	MLBS	110	310	160-220	
	ORNL	90	315	140-210	
08	CHOC	70	335	145-200	
	DELA	60	330	135-205	
	TALL	75	330	135-195	
09	DCFS	120	290	180-205	
	NOGP	115	290	170-200	
	WOOD	120	290	180-210	
10	CPER	90	350	165-210	Variable peak greenness window; may begin by day 135, end by day 165.
	RMNP	120	285	180-210	
	STER	90	270	150-190	Variable peak greenness window; may end by day 155 (early crop harvest?)
11	CLBJ	60	325	135-180	Variable peak greenness window; may end by day 160.
	KLEM	75	310	130-165	
	<i>TBD</i>				
12	BOZE	105	285	<i>TBD</i>	
	PARA	105	285	<i>TBD</i>	
	YELL	120	280	165-190	
13	MOAB	85	300	165-225	
	NIWO	140	270	190-220	
	<i>TBD</i>				
14	JORN	80	320	185-245	Variable peak greenness window; may begin by day 140, end by day 210.
	SRER	150	330	190-240	Variable start and end dates, pay attention to within-year phenology. Variable peak greenness window; may begin by day 90, end by day 120.
	<i>TBD</i>				
15	ONAQ	75	280	130-170	Variable peak greenness window; may begin by day 100, end by day 135.
	RBUT	105	310	150-190	
	<i>TBD</i>				
16	ABBY	110	300	165-205	
	THAY	110	300	165-205	
	WREF	115	290	165-210	
17	SJER	270	155	65-95	Mediterranean system: End Date and Peak Greenness dates are in same growing season as Start Date, but next

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

Domain Number	Site ID	Start Date	End Date	Peak Greenness	Additional Sampling Information
					calendar year. Start and End dates are variable, pay attention to within year phenology.
	SOAP	90	290	155-185	
	TEAK	120	300	180-205	
18	BARO	175	220	195-210	
	TOOL	160	240	185-205	
	<i>TBD</i>				
19	DEJU	130	250	170-210	
	HEAL	135	245	180-210	
	POKE	135	250	180-205	
20	OLAA	0	365	NA	Year-round Tower plot sampling; no peak greenness.
	PUFO	0	365	NA	Year-round Tower plot sampling; no peak greenness.
	PUGR	0	365	NA	Year-round Tower plot sampling; no peak greenness.

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

APPENDIX E CONFIGURING THE NIKON D800 FOR HEMISPHERICAL PHOTOGRAPHY

The Nikon D800 must be configured appropriately in order to take satisfactory images for LAI analysis with the CanEye software. There are several suites of settings that need to be adjusted prior to shooting, and these can be grouped into a few general categories:

- Settings adjusted with physical buttons and knobs
- Settings adjusted with the camera software (playback, shooting, and setup menus).
- A customizable menu called “My menu” can also be modified so that frequently adjusted settings are readily available.

Settings Adjusted Prior to Field Work

Shutter-release Mode

Desired setting = S (single shot). To adjust, press the button near the left control knob (below left), and rotate the outer-ring of the control knob until “S” is selected (below right).



Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

Image Quality

Desired setting = RAW. To adjust, press the “QUAL” button on the left control knob (below left), and rotate the primary wheel until “RAW” is displayed in the top LCD (below right).



White Balance

Desired setting = Auto. To adjust, press the “WB” button on the left control knob (below left), and rotate the primary wheel until “WB A” is displayed in the top LCD (below right).



Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

Metering Mode

Desired setting = Matrix Metering. To adjust, rotate the outer ring of the “AE-L/AF-L” button to the center position (see below).



Fisheye Lens f/stop Ring

Newer models of the Nikkor 16mm Fisheye lens may have a manually-adjustable f/stop ring, and a switch that toggles manual lens control versus control through the D800 body. We wish to maintain control of f/stops through the D800 body. To do this:

- 1) Rotate the f/stop ring on the lens to f/22 (the “f22” text printed on the lens should be red).
- 2) Toggle the lens switch to the red dot. This will prevent further manual movement of the lens f/stop ring, and allow changes to f/stops to only occur via the camera.

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

Playback Display Options

Desired settings = show “Overview”. With this option enabled, it is possible to evaluate the histogram of each image after it is acquired. To adjust,

- 1) Press the “Menu” button, then use the “Multi-selector” button (circled below-right) to navigate to “Playback Menu → Playback display options”.



- 2) Use the Multi-Selector to check the box next to “Overview”.
- 3) Navigate to “Done” and press the “OK” button (the latter is located in the lower left of the image above).
- 4) To view histogram information for an image, press the “Play” button (circled in red below).



- 5) Use the L and R arrow keys on the Multi-Selector to select the desired image.

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

6) Press the Up and Down arrow keys on the Multi-Selector to bring up the “Overview” histogram information (below). The red circle indicates the file name.



File Naming

Desired setting = DXX, where XX = the unique NEON Domain number. To adjust, press the “Menu” button, and select “Shooting Menu → File naming”. Enter the appropriate alpha-numeric characters. When finished, “DSC” should no longer be displayed, and your custom characters should be.



Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

Color Space

Desired setting = sRGB. To adjust, press “Menu”, and select “Shooting Menu → Color space”. Select “sRGB” and press the “OK” button.



Active D-Lighting

Desired setting = AUTO. To adjust, press “Menu”, and select “Shooting Menu → Active D-Lighting”. Select “Auto” and press the “OK” button.



High ISO Noise Reduction (NR)

Desired setting = Normal. To adjust, press “Menu” and select “Shooting Menu → High ISO NR”. Select “Normal” and press the “OK” button.



Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

ISO sensitivity settings

Desired setting: Minimum shutter speed = 1/30; Maximum sensitivity = Hi2. To adjust, use the “Multi-Selector” and press the “OK” button on the desired settings.



Time Zone and Date

The following settings must be adjusted:

- Time Zone
- Local time and date
- Date format = Y/M/D
- Daylight savings time – i.e. ON/OFF depending on time of year



Image Auto-Rotation

Desired setting: Auto-Rotation = OFF. Required in order to force all captured images to Landscape orientation for compatibility with CanEye analysis. To adjust, use the multi-selector to navigate to “SETUP MENU → Auto image rotation → OFF” and press the “OK” button.

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

Customizing “My Menu”

Any settings for which quick access is desired can be added to the customizable “My Menu” screen (image below). To add a setting to “My Menu”,

- 1) Press “Menu”, then select “My Menu → Add items” (image below).
- 2) Scroll through the available settings menus until you find the setting you want to add to “My Menu”.
- 3) With the setting highlighted, press the “OK” button.
- 4) Press “OK” again. The “My Menu” screen should now be modified.



Settings Adjusted in the Field

Exposure Mode

To adjust, press the Mode button, and rotate the primary wheel until the top LCD shows the desired mode (A or M, depending on camera orientation that will be used).



Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

Auto Focus Mode (Downward-facing photos)

Desired setting = AF-S Auto. To adjust,

- 1) Move focus switch to “AF”, then press and hold the button in the middle of the switch (below left).
- 2) Spin the primary and secondary wheels so the top LCD reads “AF-S” with “auto” above (below right).



Manual Focus Mode (Upward-facing photos)

Desired setting = Manual. To adjust, set the focus switch to “M” (below left), and rotate the focus ring on the lens to “∞” (below right).



Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

ISO (Sensor light sensitivity)

- *Downward-facing DHPs:* Desired setting = “ISO-auto”, initial ISO = 400. To adjust, press the “ISO” button on the left control knob (below left), then rotate the secondary wheel until “ISO-auto” is displayed (below right). Then, still pressing the “ISO” button, rotate the primary wheel until ISO = 400 is displayed in the top LCD.
- *Upward-facing DHPs:* Desired setting = “ISO” (manual), initial ISO = 6400. To adjust, press the “ISO” button on the left control knob (below left), and rotate the secondary wheel until “ISO” is displayed (not “ISO-auto”). Then, still pressing the “ISO” button, rotate the primary wheel until ISO = 6400 is displayed in the top LCD.



Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

APPENDIX F DAY OF YEAR CALENDARS

Day of Year Calendar for Non-Leap Years

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Day
1	001	032	060	091	121	152	182	213	244	274	305	335	1
2	002	033	061	092	122	153	183	214	245	275	306	336	2
3	003	034	062	093	123	154	184	215	246	276	307	337	3
4	004	035	063	094	124	155	185	216	247	277	308	338	4
5	005	036	064	095	125	156	186	217	248	278	309	339	5
6	006	037	065	096	126	157	187	218	249	279	310	340	6
7	007	038	066	097	127	158	188	219	250	280	311	341	7
8	008	039	067	098	128	159	189	220	251	281	312	342	8
9	009	040	068	099	129	160	190	221	252	282	313	343	9
10	010	041	069	100	130	161	191	222	253	283	314	344	10
11	011	042	070	101	131	162	192	223	254	284	315	345	11
12	012	043	071	102	132	163	193	224	255	285	316	346	12
13	013	044	072	103	133	164	194	225	256	286	317	347	13
14	014	045	073	104	134	165	195	226	257	287	318	348	14
15	015	046	074	105	135	166	196	227	258	288	319	349	15
16	016	047	075	106	136	167	197	228	259	289	320	350	16
17	017	048	076	107	137	168	198	229	260	290	321	351	17
18	018	049	077	108	138	169	199	230	261	291	322	352	18
19	019	050	078	109	139	170	200	231	262	292	323	353	19
20	020	051	079	110	140	171	201	232	263	293	324	354	20
21	021	052	080	111	141	172	202	233	264	294	325	355	21
22	022	053	081	112	142	173	203	234	265	295	326	356	22
23	023	054	082	113	143	174	204	235	266	296	327	357	23
24	024	055	083	114	144	175	205	236	267	297	328	358	24
25	025	056	084	115	145	176	206	237	268	298	329	359	25
26	026	057	085	116	146	177	207	238	269	299	330	360	26
27	027	058	086	117	147	178	208	239	270	300	331	361	27
28	028	059	087	118	148	179	209	240	271	301	332	362	28
29	029		088	119	149	180	210	241	272	302	333	363	29
30	030		089	120	150	181	211	242	273	303	334	364	30
31	031		090		151		212	243		304		365	31

Title: TOS Protocol and Procedure: Measurement of Leaf Area Index		Date: 04/10/2014
NEON Doc. #: NEON.DOC.014039	Author: C. Meier	Revision: D

Day of Year Calendar for Leap Years

Day	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Day
1	001	032	061	092	122	153	183	214	245	275	306	336	1
2	002	033	062	093	123	154	184	215	246	276	307	337	2
3	003	034	063	094	124	155	185	216	247	277	308	338	3
4	004	035	064	095	125	156	186	217	248	278	309	339	4
5	005	036	065	096	126	157	187	218	249	279	310	340	5
6	006	037	066	097	127	158	188	219	250	280	311	341	6
7	007	038	067	098	128	159	189	220	251	281	312	342	7
8	008	039	068	099	129	160	190	221	252	282	313	343	8
9	009	040	069	100	130	161	191	222	253	283	314	344	9
10	010	041	070	101	131	162	192	223	254	284	315	345	10
11	011	042	071	102	132	163	193	224	255	285	316	346	11
12	012	043	072	103	133	164	194	225	256	286	317	347	12
13	013	044	073	104	134	165	195	226	257	287	318	348	13
14	014	045	074	105	135	166	196	227	258	288	319	349	14
15	015	046	075	106	136	167	197	228	259	289	320	350	15
16	016	047	076	107	137	168	198	229	260	290	321	351	16
17	017	048	077	108	138	169	199	230	261	291	322	352	17
18	018	049	078	109	139	170	200	231	262	292	323	353	18
19	019	050	079	110	140	171	201	232	263	293	324	354	19
20	020	051	080	111	141	172	202	233	264	294	325	355	20
21	021	052	081	112	142	173	203	234	265	295	326	356	21
22	022	053	082	113	143	174	204	235	266	296	327	357	22
23	023	054	083	114	144	175	205	236	267	297	328	358	23
24	024	055	084	115	145	176	206	237	268	298	329	359	24
25	025	056	085	116	146	177	207	238	269	299	330	360	25
26	026	057	086	117	147	178	208	239	270	300	331	361	26
27	027	058	087	118	148	179	209	240	271	301	332	362	27
28	028	059	088	119	149	180	210	241	272	302	333	363	28
29	029	060	089	120	150	181	211	242	273	303	334	364	29
30	030		090	121	151	182	212	243	274	304	335	365	30
31	031		091		152		213	244		305		366	31

USE IN 2004, 2008, 2012, 2016, 2020, 2024, ETC.