Terrestrial Carbon Observations: Protocols for Vegetation Sampling and Data Submission

GTOS 55

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Cover Photo: California coastal redwoods (by Garrett Meigs)

TCO - Terrestrial Carbon Observations panel of the Global Terrestrial Observing System (GTOS)

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TCO

TCO is the Terrestrial Carbon Observation panel of GTOS, the Global Terrestrial Observing System programme: http://www.fao.org/gtos/.

Main aims of TCO are to: i) better identify the potential end users and the required data and scale; ii) organize and coordinate reliable data and information on carbon; iii) link science community and potential users. TCO has been working at global level, by the coordination of a panel of experts from different continents, and by its participation in international projects and initiatives related to carbon cycle and climate change.

Beverly Law

Beverly Law is Professor of Global Change Forest Science at Oregon State University, USA. Law is the Science Chair of the AmeriFlux network for measurements of biology, meteorology and micrometeorology, where goal is to quantify and understand the response of terrestrial ecosystems to climate and disturbance, and feedbacks to climate. She has been TCO panel member since 2005. She is the author or co-author of over 100 scientific papers and book chapters.

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Contents

Preface

This document is a useful manual for making biology measurements in forests (biomass, primary production, ecosystem processes, etc.) and other vegetation types (such as crops) and for submission of biological data to a database. It has been developed especially for North America forests; however it may serve as guidelines for consistency in measurements at global level, and it can be easily modified for region-specific characteristics.
We believe that it is an important contribution in support of the global terrestrial carbon cycle science and it fulfills the TCO requirements towards a standardization of methods for carbon (and not only) data measurements and submission.

Riccardo Valentini (TCO Chair)
and
Antonio Bombelli (TCO Scientific Secretariat)

1. Introduction

This manual provides detailed guidelines for making biology measurements in forests in support of carbon cycle science, and for submission of biological data to a database.

The field protocols include measurements required to quantify biomass, net primary production (NPP), net ecosystem production (NEP), and to develop ecosystem process model parameters (e.g. canopy and soil carbon and nitrogen) for predicting carbon stocks, NPP and NEP. Some of the basic computations are included in each section.

The field protocols were developed for West Coast U.S. forest ecosystems with various understory components (shrubs, forbs, grasses) in support of the North American Carbon Program. They can be modified for region-specific characteristics, but are intended to serve as guidelines for consistency in measurements globally.

The data submission protocols were developed for the AmeriFlux network in preparing datasets for archive at the Carbon Dioxide Information and Analysis Center (CDIAC). They provide variables recommended for data submission by members of the AmeriFlux network, the data structure, and metadata to accompany the data.

2. Field Plot Layout

The plot design is consistent with the design used by the USDA Forest Service Forest Inventory and Analysis (FIA) program, where there are four subplots within a plot. The design is appropriate for regional scaling and periodic remeasurement cycles (e.g. once per five years; Olsen et al. 1998).

2.1 Marking Subplot Centers and Plot Corners

To identify subplot locations, and corners of the coarse woody detritus (CWD) transects follow instructions below and refer to the plot map shown in Figure 1.

1. Follow written directions, flagged trail and or navigate by GPS to plot center. Plot center shall be marked permanently with center stake topped with orange paint. In addition to being in the center of the 100 x 100 m plot, this stake identifies the center of subplot #1.

2. Using the directions in Table 1, locate and mark plot corners and subplot centers.

Table 1. Directions for locating and marking plot corners and subplot centers

Location	**Distance from plot center (m)**	**Bearing from plot center (degrees from true North)**	**Mark location with…**
NE corner of plot CWD transect	75	45	Pin flag (optional)
SE corner of plot CWD transect	75	135	Pin flag (optional)
SW corner of plot CWD transect	75	225	Pin flag (optional)
NW corner of plot CWD transect	75	315	Pin flag (optional)
Center of subplot 1	0.0	0	orange topped PVC stake
Center of subplot 2	35.0	0	Unpainted PVC stake
Center of subplot 3	35.0	120	Unpainted PVC stake
Center of subplot 4	35.0	240	Unpainted PVC stake

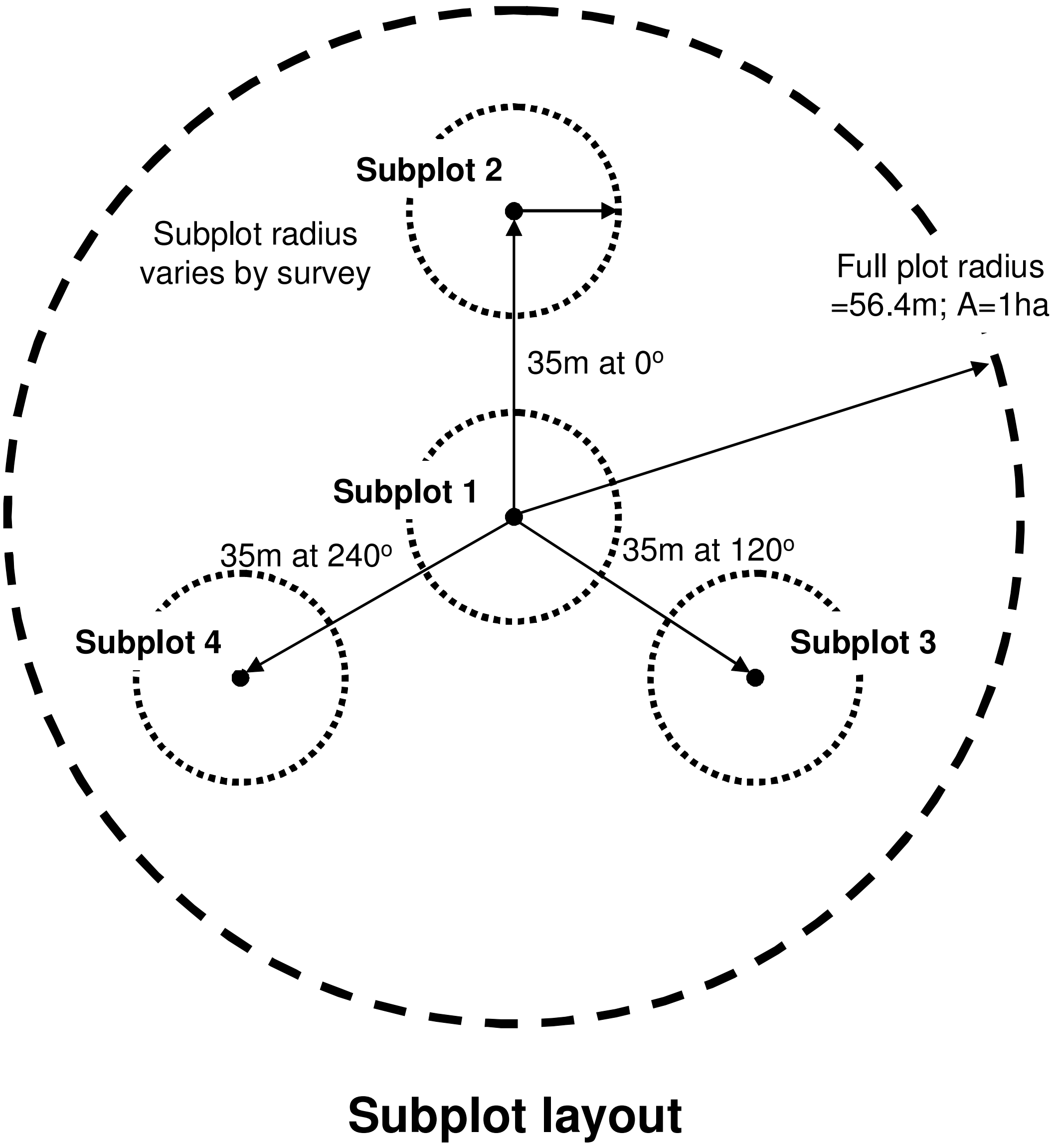
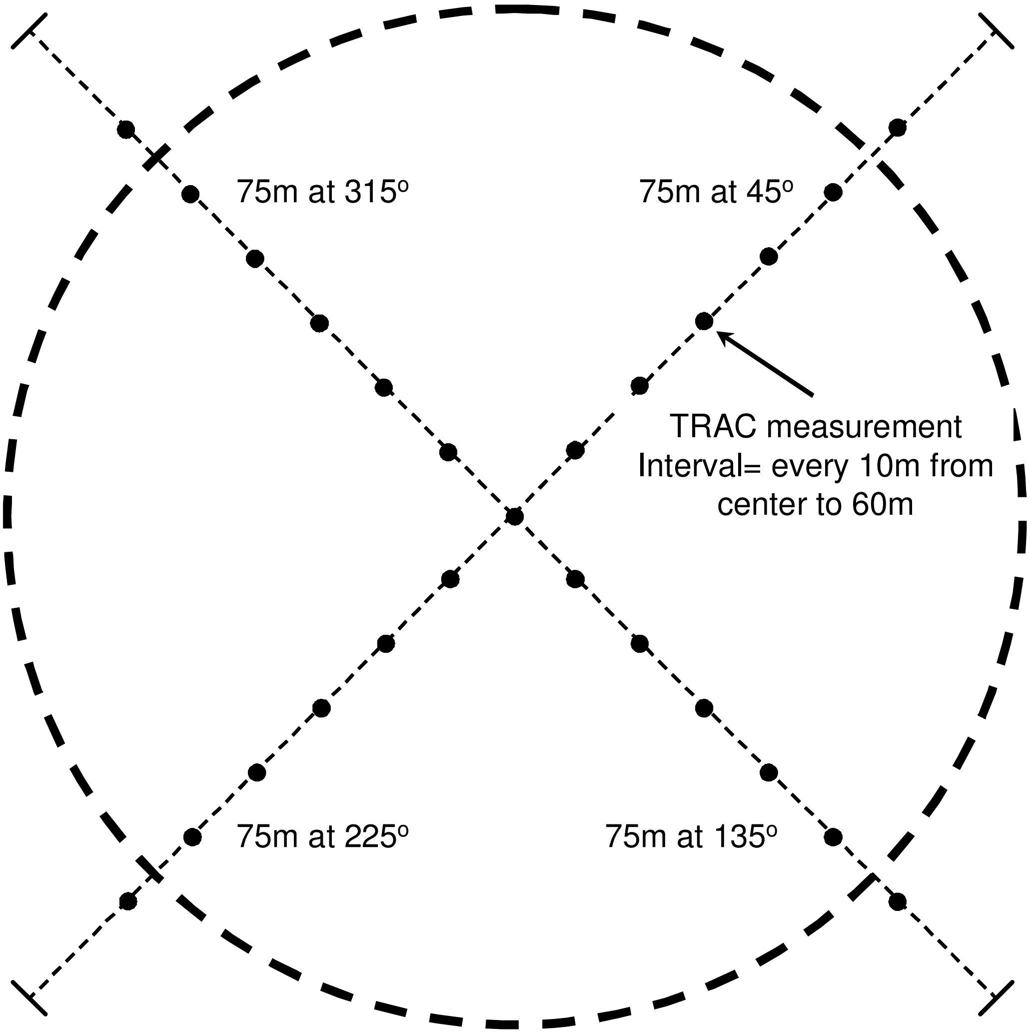
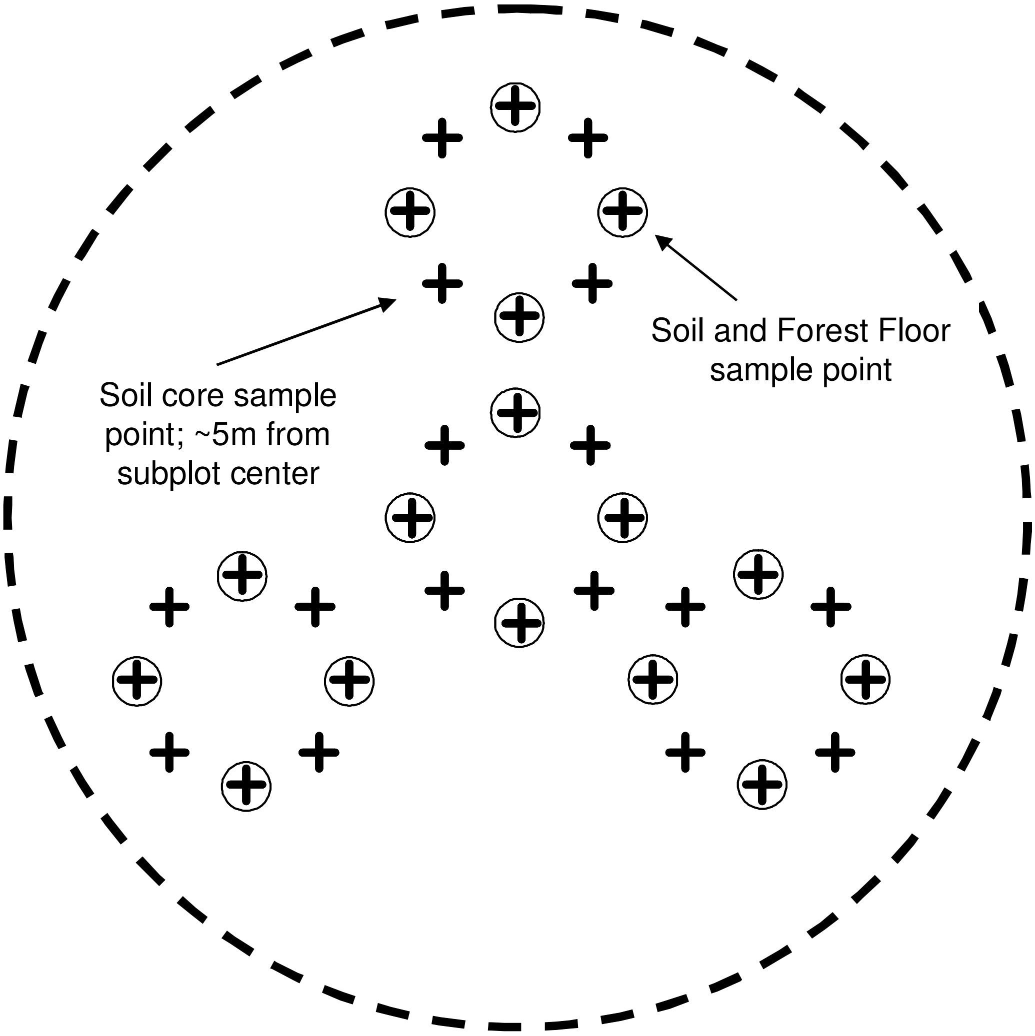


Figure 1a. Field plot layout of subplots.



Woody Debris transects and TRAC transect nodes

Figure 1b. Field plot layout of woody debris and TRAC gap measurement transects.



Soil and Forest Floor sample points

Figure 1c. Field plot layout of soil core and litter sample points.

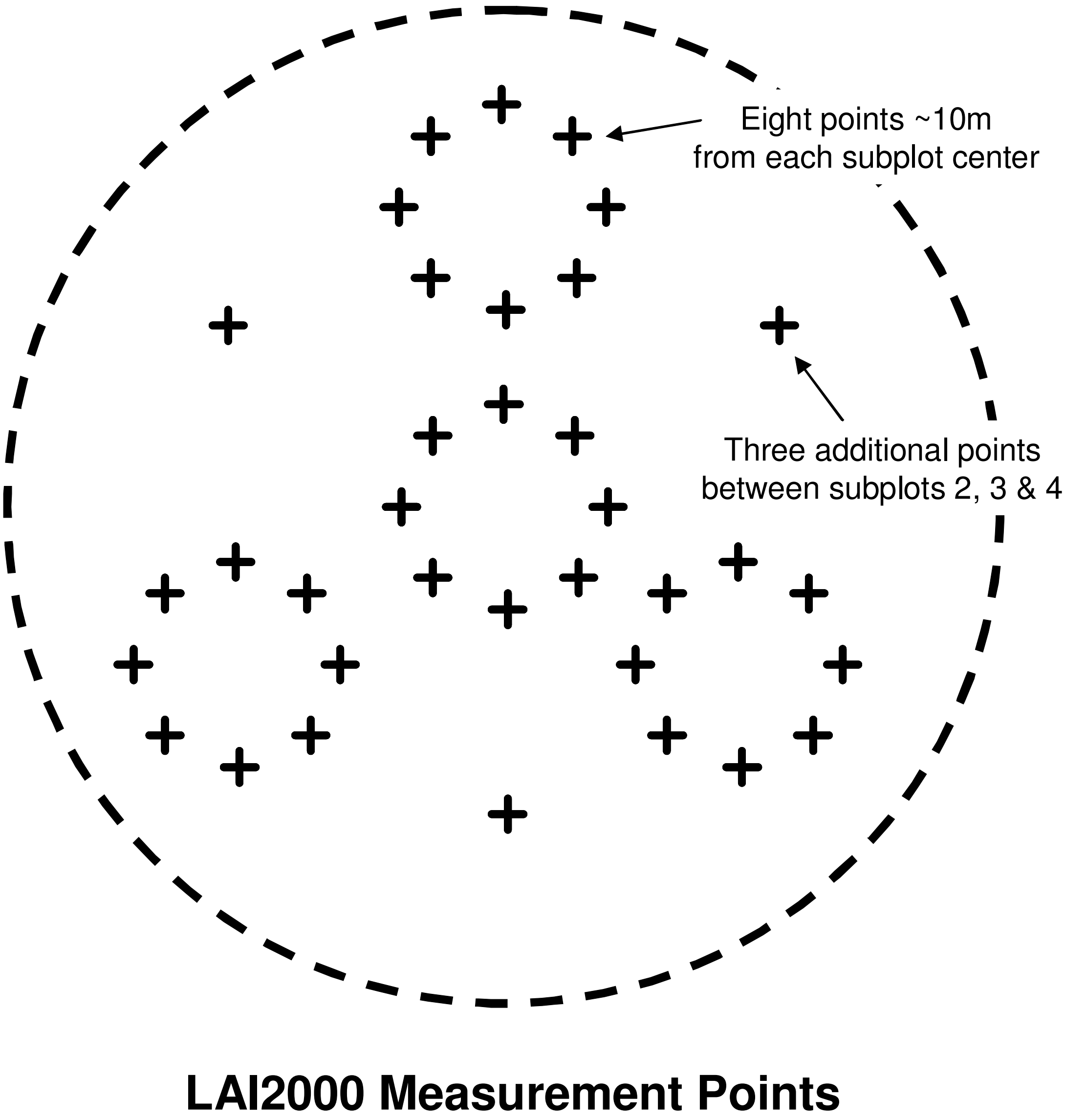


Figure 1d. Field plot layout of light interception measurements.

3. Stem Surveys

3.1 Rationale

The standing biomass of trees and their annual growth increment will be estimated for each plot using a combination of stem surveys, increment coring, and allometric equations. Allometric equations are empirically derived, species-specific formulas that relate the mass of a tree to its stem diameter and height. It is recommended that site-specific allometry, or allometry for the same species, tree sizes, and ecoregion (climate zone, soil characteristics) are used from published allometry. To estimate the total mass of trees on a given plot, you need to determine the number of tree stems per unit area, the size of each stem, and species. Since it is impractical to count all of the trees in each hectare plot, the stem survey is conducted in the four fixed-area subplots (with the exception of very large trees) scaled to approximate average diameter breast height (DBH) of trees present.

3.2 Diameter at breast height

Diameter at breast height (DBH) is the tree stem diameter 1.37 m. This stem height of 1.37m is measured along the central axis of the stem beginning at the mid-slope base of the tree (i.e. not from either the up-slope or down-slope side and not necessarily vertical or perpendicular to ground). Should formal breast height fall on a branch or uncharacteristic bulge modify breast height the minimal amount to avoid these bole abnormalities. Diameters are measures perpendicular from the central axis of the stem. For forked trees, if the crotch of fork is at or above 1.37 m, consider as a single tree, and measure diameter below the swell caused by the fork. If the crotch of fork is below 1.37 m, consider each fork as a separate tree.

Photo 1. Diameter breast height measurement (Photo by Beverly Law).

To determine stem growth, increment cores are taken from a subset of trees. By measuring the annual growth rings, it is possible to calculate the change in stem diameter over a known period of years. Applying allometric equations to these estimates of stem radial growth leads to an estimate of biomass growth over the same period. Tree cores are also used to determine wood density and sapwood volume, which are valuable in computing wood mass and stem respiration, respectively.

The stem survey is broken down into four separate surveys:

1. Large tree survey: trees greater than 80cm DBH sampled comprehensively in the entire 1ha plot.
2. Main tree survey: trees 10-80 cm DBH sampled inside four subplots with radii of 5-17m depending on tree density.
3. Sapling survey: trees 1-10 cm DBH sampled inside four subplots with radii of 2-5m depending on tree density.
4. Stump Survey: stumps of all sizes sampled inside four subplots with radii of 10m

Because radial growth does not account for the changes in biomass that a stand experiences through tree mortality and recruitment, permanent numbered tags should be affixed to each live tree surveyed. Surveys made in future years will allow tracking of the changes in tree biomass due to mortality and recruitment.

While not directly related to the calculation of tree biomass, additional crown dimension measurements can be made on a sub-sample of trees (height to base of live crown, crown radius). These parameters are useful in characterizing canopy architecture for the calibration of remotely sensed data and the parameterization of various canopy process models that have detailed light environment characteristics.

3.3 Sampling Design

3.3.1 Tagging

Each qualifying tree stem determined to be inside the subplot shall receive an individually numbered aluminum tag. Using an aluminum nail, affix the tag to the tree at breast height facing plot center. Drive the nail angled upward and only as deep as is necessary to permanently secure the tag.

3.3.2 Large Tree Survey

Tree stems $\geq$ 80 cm DBH are sampled over the entire hectare plot. From the orange center stake, measure any large tree within a 56.4 m radius.

What counts as a large tree stem

- All living woody stems having a DBH of 80 cm or greater.
- Any dead woody stem (snag) having a DBH of 80 cm or greater provided its angle from true vertical is less than 45°.

Measurements taken in the large tree survey

- Species
- DBH recorded in mm to the nearest 1mm.
- Total height of tree measured in dm to the nearest 1 dm using laser range finder
- If tree is dead (a snag), record decay class (see Woody Detritus Survey section for definitions of decay classes).

3.3.3 Main Tree Survey

Tree stems 10-80 cm DBH are sampled in each of four circular subplots. The center of the central subplot is indicated by an orange-top stake that is used to locate the plot center; the centers of the other three subplots should be marked with white-top painted stakes. The default subplot size for the main tree survey is 10 m radius. However, in stands with especially high or low tree density, it may be necessary to adjust the radius (Stevens 1997) between 5-17 meters. In making the decision to adjust subplot size, carefully follow the guidelines below:

- Use the same subplot size for all four subplots in a hectare plot (the need to reduce the subplot radius should be assessed with the laser before beginning measurements).
- The total number of trees counted in all four subplots should be approximately 50. Note that it is preferable to over-sample than to under-sample.
- As a rule of thumb, there should not be less than 12-13 trees per subplot. However, forest gaps may necessarily leave some subplots with few trees.
- ALWAYS record the subplot radius used on the stem survey data sheet. An error here would have significant consequences to nearly all of the measurements made in the study.

What counts as a main tree stem

- All living woody stems having a DBH between 10 and 80 cm.
- Any dead woody stem (snag) having DBH between 10 and 80 cm provided its angle from true vertical is less than 45°.

Measurements taken in the main tree survey

- Species (use four-letter species codes)
- DBH recorded in mm to the nearest 1mm.
- Total height of tree measured in dm to the nearest 1 dm using laser range finder

- If tree is dead (a snag), record decay class (see Woody Detritus Survey section).

3.3.4 Sapling Survey

Woody stems 1-10 cm DBH and exceeding 2 m in height are sampled in each of four circular subplots, centered at the PVC stakes. Default and maximum subplot radius is 5 m. Adjust subplot radius for dense stands where many more than 15 saplings per subplot would be sampled, within an acceptable range of 2-5 m radius (follow radius-adjustment guidelines above).

What counts as a sapling

- All living woody stems having a DBH between 1 and 10 cm and height exceeding 2 m. Stems of multi-stemmed individuals are treated as separate records if branching occurs below 2 m height.
- Any dead woody stem (snag) having DBH between 1 and 10 cm and height exceeding 2 m, provided its angle from true vertical is less than 45^o.

Measurements taken in the sapling survey

- Species
- DBH recorded in mm to the nearest 1mm**.**
- Total height of tree measured in dm to the nearest 1 dm using laser range finder
- If tree is dead (a snag), record decay class (see Woody Detritus Survey section).

3.3.5 Stump Survey

Stumps are sampled in each of four circular subplots, centered at the subplot stakes. Default and maximum radius is 10 m (adjustable between 2 and 10 m if the number of stumps per subplot is > 25).

What counts as a stump

- All dead woody stems not reaching DBH, and with a top-diameter > 10 cm.

Measurements taken in the stump survey

- Species if known (this is often unknown)
- Top diameter from outside bark to outside bark to nearest 1cm. If full cross-section is not present due to decay or damage, estimate original top diameter.
- Record decay class.

4. Tree Increment Coring

4.1 Rationale

Tree increment cores are used to:
1. determine the annual growth in stem wood
2. establish an age class distribution for the plot
3. determine site-specific wood density for select species

Because only a subset of trees of the trees tallied in the stem survey will be cored, plot-specific regressions relating stem diameter to age and radial increment will be used to model the age and radial increment of those trees not cored**.**

4.2 Field Methods

A total of 20 trees shall be cored. The 20 trees shall be stratified by stem diameter with some trees being cored all the way to the pith and some cored only 10 years back in time (10 complete rings with early and late wood).

- Largest stem class (≥ 80 cm DBH): Collect cores from 5 trees. One tree should be cored to the pith, and the other four need only be cored for 10 years of increment (optional: core to 20 years).

- Middle stem class (10-80 cm DBH): Collect cores from 10 trees. Four trees should be cored to the pith, and the other 6 need only be cored for 10 years of increment (optional: core to 20 years).

- Sapling stem class (1-10 cm DBH): Collect cores from 5 trees. Three trees should be cored to the pith, and the other two need only be cored for 10 years of increment.

For each tree cored, record the species (using four letter species code) and DBH. Write these data directly on the core mounting stick along with the plot number.

In the event there are not 5 large trees and/or 5 saplings to core (which will often be the case), make up the difference with extra 'main trees' to get 20 cores.

Be sure to sample trees across the entire diameter distribution (within each size class; main, large, and sapling) and species composition on the plot.

If a tree selected for coring to the pith has a radius greater than the length of the increment borer, bore as deeply as possible and follow guidelines for estimating age beyond the length of core.

Mounting Cores

Increment cores are to be mounted to wooden mounting sticks with wood glue. The mounted cores should be wrapped in aluminum foil to remove them from the field without damage. Each evening, carefully remove the aluminum foil, spread additional glue over the top of the cores, and let dry. Cores mounts should be dry enough to transport without foil by the next morning. If not dry by morning, rewrap the cores for transport to the laboratory. Do not let glue dry with foil attached.

Preparation of cores for reading increment

Using a belt sander, sand the top face of the core that protrudes from the wood mounting block so that a smooth surface results for ease of reading increments with an electronic increment core reader.

4.3 Laboratory Methods

To determine the age of trees with radius greater than the length of the increment borer, use the following procedure (Field Instructions for the Inventory of Western Oregon 1995-97):

1) Subtract the length of the borer that was exposed (see above) from the total length of the increment borer
2) Extract the core, and count the rings
3) Count the number of rings in the inner 5 cm of the core
4) Divide the tree's DBH by 2
5) Subtract (2) from (5), which gives the distance that is short of reaching tree center
6) Divide this number (6) by 5, which gives the number of 5 cm length that is short by
7) Multiply this number (7) by the number of rings in inner 5 cm
8) Add this number (8) to the total number of rings in the extracted core (3), which gives the tree's estimated age
9) Note "extrapolated age" in the remarks column.

5. Foliage Sampling

5.1 Rationale

Foliage samples collected in each study plot will be used to calculate the following parameters:

1. Leaf retention time: determined for each major species present in the plot.
2. Leaf Mass per unit Area (LMA): determined for both current and previous years foliage for each major species present in the plot and scaled to the entire canopy using mean leaf retention and species composition.
3. Total foliage mass: determined by multiplying the optically determined leaf area index by forest canopy LMA.
4. Total foliage production: determined by multiplying total foliage mass (total canopy) by the fraction that is new growth (as determined from foliage samples)
5. Leaf carbon and nitrogen content: determined for both current and previous years foliage for each major species present in the plot.
6. Foliar elemental dimension: used for clumping correction of optical LAI measurements.
7. Litterfall: estimated as the total foliage mass divided by the leaf retention time.

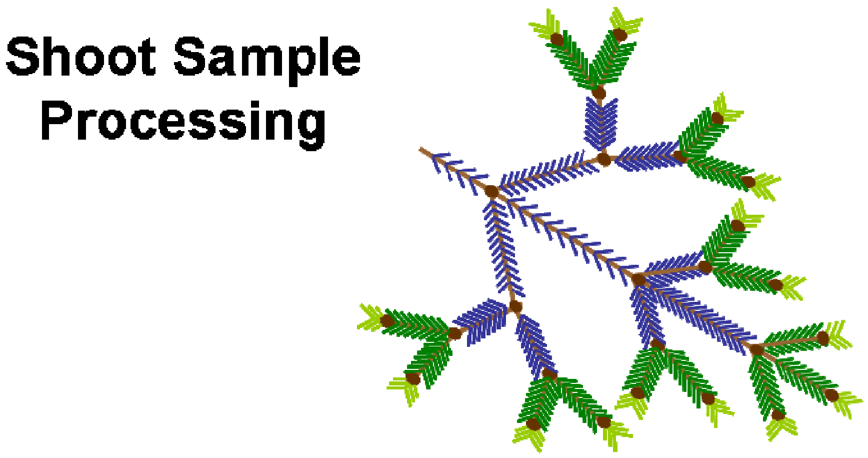
5.2 Field Methods

To maximize ability to detect and use plot-specific values, the following sample sizes are used for each plot individually. Depending on species composition, the total number of samples per plot will vary from 5-8.

Table 2. Sample size determination for each species within a plot**.**

Fraction of canopy occupied by a given species (estimated)	Number of branches harvested for a given species
76 - 100	5
51 –75	4
21 - 50	3
11 - 20	1
0 - 10	0

For conifers, a suitable foliar sample is a shoot that includes the current season's growth (fully extended) and the maximum number of years of foliage retained (e.g. 4-7 for Douglas-fir, 3-4 for ponderosa pine; Figure 2). In some cases, sparse needle retention can exist beyond nine years, making a complete sample awkwardly large. In such cases retain only the foliage having significant needle retention and note (on sample tag) the maximum needle age observed in the field. For deciduous species, a suitable foliar sample should include at least 10 leaves.



(brown line)	Twig	Discard
(brown dot)	Node (bud scar)	Count the number of years foliage is retained
(light green chevrons)	Current foliage	Discard
(dark green chevrons)	Last full year foliage	Determine total mass, average LMA, average [C], average [N], and retain archive sample
(blue chevrons)	All previous foliage	Determine total mass, average LMA, average [C], average [N], and retain archive sample

Figure 2. Sampling evergreen conifer shoots.

Foliage samples should be harvested using the following guidelines:

- Sample when foliage is completely extended and 'hardened off'
- Sample only from trees of average size for the given species in the plot.
- Sample only from the middle third (by height) of that tree's crown.
- Sample only from the east or west side of the crown (avoid north or south facing branches).
- Avoid branches facing large gaps.
- Do not use the terminal shoot, which normally only has fewer years of foliage.

In choosing branches to sample, remember that [N] and LMA (SLA) vary with height and light exposure. The goal is to choose samples that represent the *average* foliar characteristics for a given species in the plot without having to obtain a logistically infeasible sample size. In some cases, loppers or pole pruners can be used to reach suitable branches. In other cases, however it will be necessary to shoot branches down with a shotgun.

Upon collection:

1. Affix tag on branch end noting sample plot.
2. If the sample does not contain all years growth due to excessive retention time record the maximum needle retention in years on the back-side of the same tag

Place each shoot in a plastic sample bag, bending the shoot if necessary. Branch samples must be kept fresh until they can be delivered to the laboratory for analysis. Issues of concern are moisture loss that affect SLA and respiratory carbon loss that alter the dry mass and therefore the mass based [N]. To minimize these two handling concerns, samples must be kept in plastic bags and stored on ice until they can be delivered to the laboratory. At the laboratory, immediately refrigerate samples.

5.3 Laboratory Methods

Calculations

LAI computations and site level production are shown in Figures 3 and 4. In summary:

Foliage biomass (g C / m2 ground) = sum (Mean LMA for each species in plot (grams leaf / m^2 leaf) x proportion foliar C x fraction of total LAI of that species x Total LAI in plot (m^2 leaf / m^2 ground))

Foliage production (g C /m2 ground) = foliage biomass x fraction of biomass that is new foliage that year

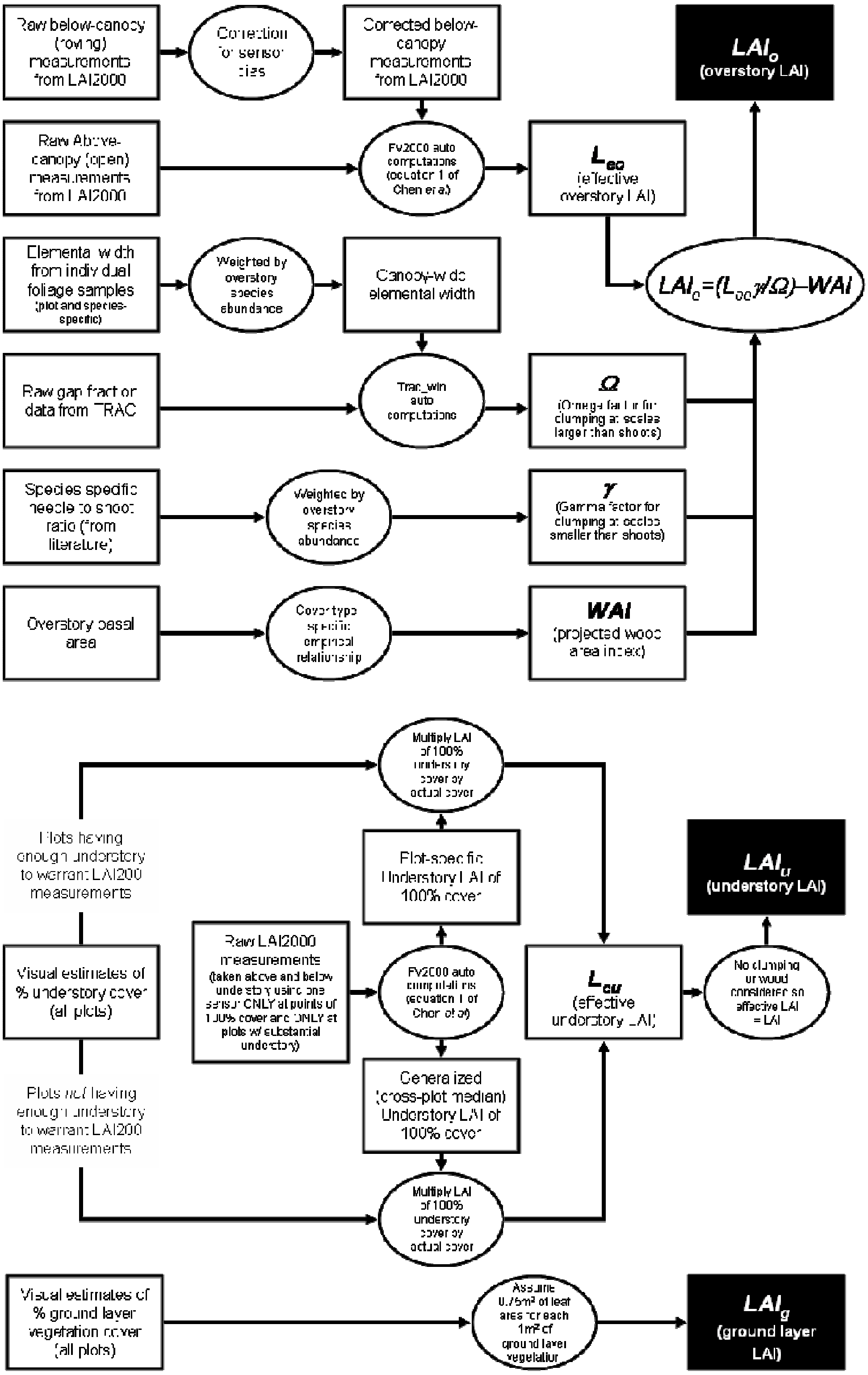


Figure 3. Computation of site-level leaf area index (LAI).

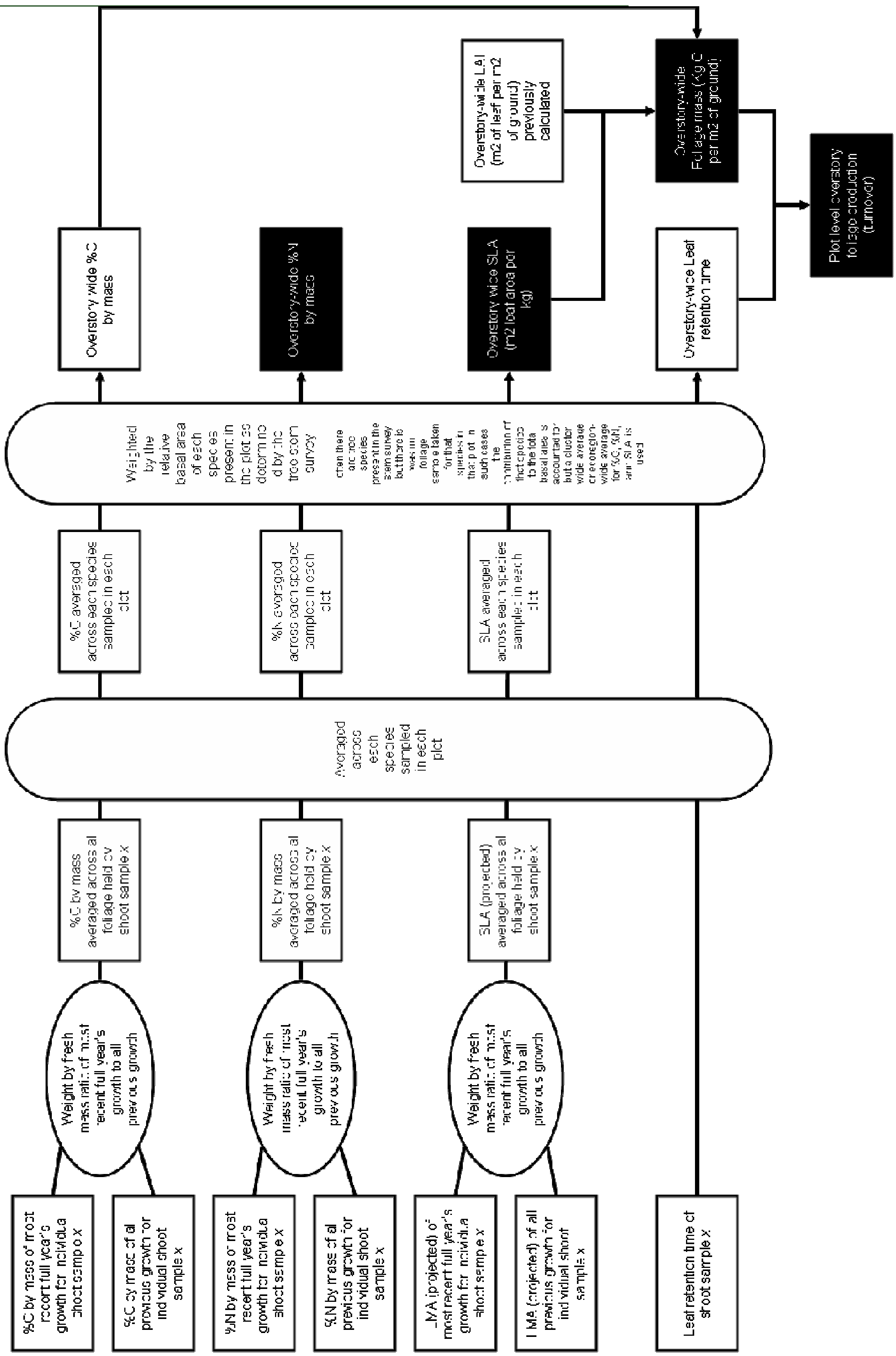


Figure 4. Foliage computations for site-level estimate of leaf area index, foliage mass and production**.**

6. Understory and Ground Cover Survey

6.1 Rationale

Understory can contribute significantly to ecosystem carbon stocks and fluxes (e.g. mosses and lichens in boreal forests), as well and site fertility e.g. (nitrogen fixers in early successional forests).

6.2 Field Methods

6.2.1 Rough approximation

For more rapid and less rigorous estimates of aboveground biomass of understory vegetation, use ocular cover estimates and allometric mass conversions. Like the tree stem survey, understory sampling is conducted in fixed area subplots distributed throughout the study plot.

Understory vegetation is sampled in each of four circular subplots measuring 5 m in radius and centered on each of the subplots used for the tree stem survey.

Understory vegetation is defined here as all living plants having a total height of less than 2 m and DBH < 1 cm. Forest understory includes shrubs, seedling trees, forbs, ferns, grasses, mosses and other cryptogams.

6.2.2 Ground cover

For each subplot, record an ocular estimate of percent ground cover for each of the following categories. These percent cover estimates must add up to 100%.

1. Litter
2. Forbs (including ferns)
3. Grass
4. Wood
5. Moss and Lichen
6. Mineral soil
7. Rock
8. Other

When estimating cover, disregard area occupied by the cross-sectional area of tree stems and stumps. That is, the 100% area is that area not occupied by stem area (See Figure 5 for guidance in making ocular estimates of percentage cover).

6.2.3 Woody shrubs and tree seedlings

- For all woody plants 0-0.5 m tall and separately for each species, record:
    1. ocular estimate of percent cover
    2. number of individuals.
    3. percent of tissue mass that appears dead, estimated to the nearest 10% (in most cases this value is less than 10% in which case nothing is recorded)
- Record the same information for all woody shrubs 0.5-1 m tall.
- Record the same information for all woody shrubs 1-2 m tall.

Note that a single species may occupy multiple height classes.

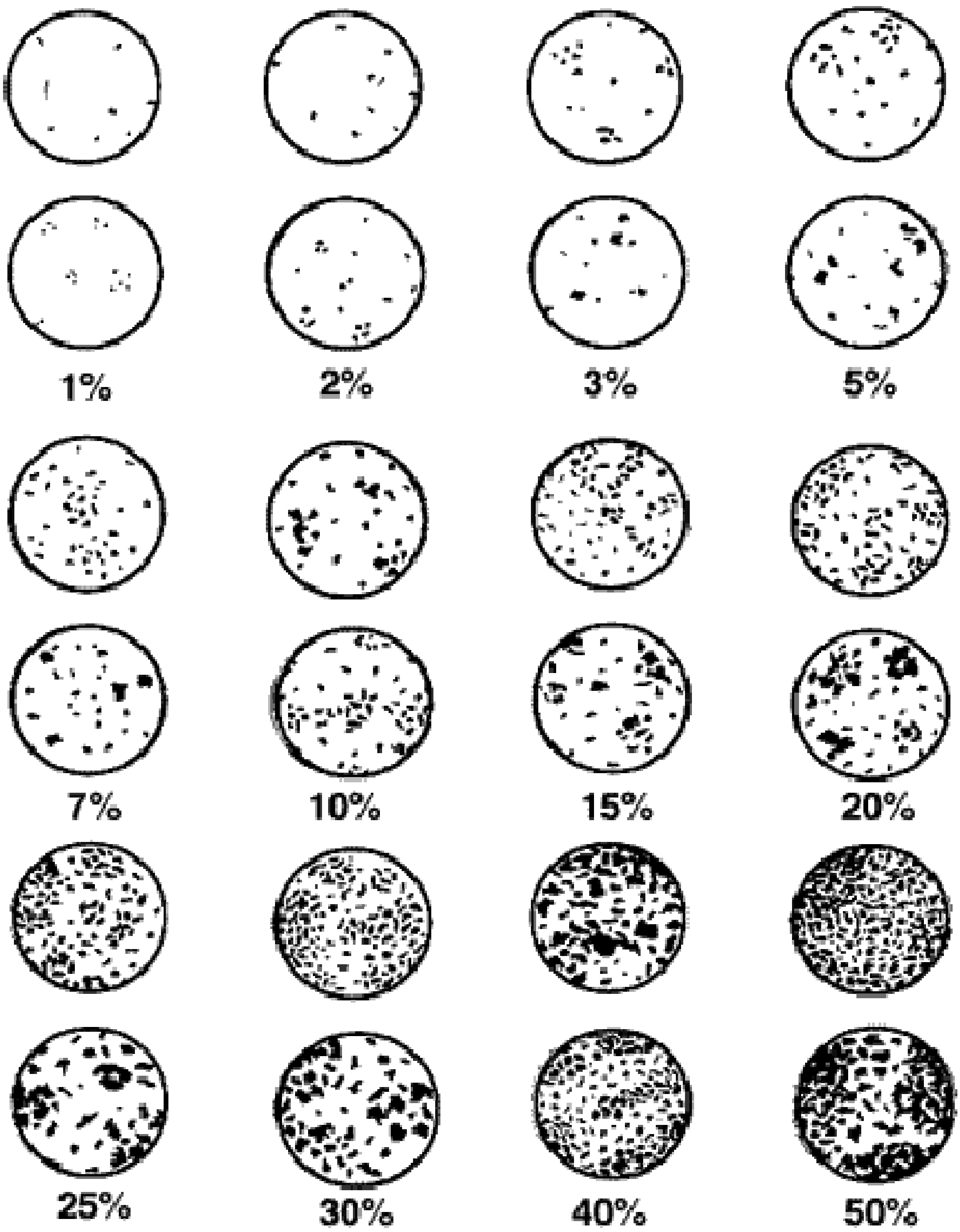


Figure 5. Examples of percent cover.

6.3 More robust estimates

6.3.1 Woody shrubs

All shrubs present in the understory subplot are to be sampled. A shrub is considered in the subplot if it is rooted within the subplot boundary. For coppice plants (e.g. vine maple), the plant is in the subplot if the center of the multi-stemmed plant is within the 2 m radius subplot. Alternately include and exclude stems too close to call.

The plant dimensions necessary to allometrically compute the biomass of shrubs varies among species but usually include stem basal diameter basal area (DBA) and some measure of crown height or volume. To determine which variables to record for a given plant, identify the species and refer to a table of allometric equations listed for your region. For example, the table below lists the measurements required for some of the more common Pacific Northwest U.S. shrubs. Enter species and measurement in understory data sheet (field data).

Table 3. Example of common names, species code, and measurement used in allometric equations (Pacific Northwest U.S.)

Vine maple (ACCI), California hazel (COCA), Salmon berry (RUSP)	Mean DBA of multiple stems and total number of stems in plant
Sword fern (POMU), Brackenfern (PTAQ), Oregon Grape (BENE)	Number of fronds (NFR) and average frond length (LAF)
Red Huckleberry (VAAL)	Mean DBA of multiple stems and total number of stems in plant
Rhododendron (RHMA)	Mean DBA of multiple stems and total number of stems in plant
Manzanita, Bitterbrush (PUTR)	Canopy volume (VCA = LxWxH in cm)

Basal diameter
Basal diameter is defined as the diameter of the stem at its lowest point before any buttressing or basal swelling occurs (see Figure 6). In this study basal diameter should be recorded to the nearest 0.1 cm.

Aboveground NPP calculations:
ANPP of woody tissue is calculated from change in biomass, using the 1-year growth increment data for previous DBH of trees. Shrub biomass and NPP

are determined from the allometric equations applied to each shrub, and scaled to site by number of shrubs per size class (Law et al. 2001c).

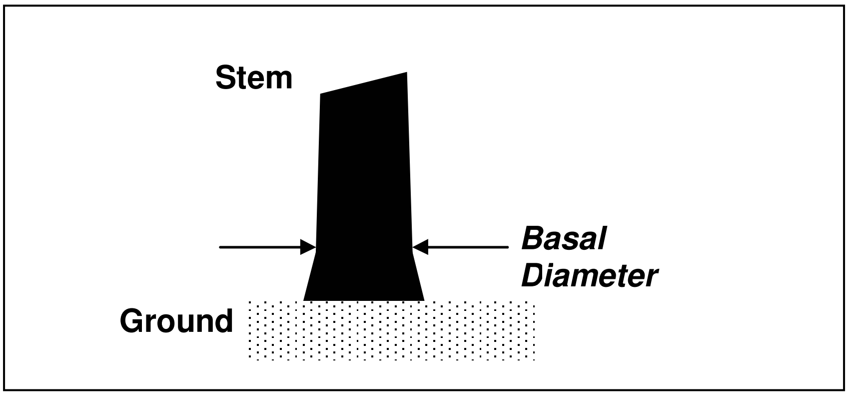


Figure 6. Position for basal diameter measurement.

Note Do not confuse basal diameter with DBH (diameter at breast height). Regardless of a plants basal diameter, if it has a DBH >=5.0 it is a tree and is not to be included in the understory survey. Conversely, if a plant has a DBH<5.0 it is to be included in the understory survey.

6.3.2 Mosses and cryptogams

On the 2.0 m subplot, record the ocular estimate of cover by mosses and lichens (identification code of MOSS on understory data sheet).

7. Litter Sampling

7.1 Rationale

Litter samples are required for determining the forest floor C&N concentration and litter carbon. Litter layer refers to the surface layer on a forest floor that contains all dead, fresh or dry, and partially decomposed plant tissues above the organic and mineral soil surface, including twigs up to 0.6 cm diameter (you must be able to tell if the litter is leaves, twigs, etc., otherwise, it is organic matter). Litter samples are to be collected with a 10 cm diameter core at four (half) of the eight soil sample locations per subplot.

7.2 Methods

1. Four samples cores are taken from each subplot, 2 m from subplot center in the 4 following directions: 0, 90, 180, and 270° (i.e. all four cardinal directions).

2. Place PVC ring on sample point. Remove any woody detritus (from surface only) larger than 0.6 cm. Cut around outside with blade, then collect all litter material down to the top of the mineral soil.

3. Samples are consolidated by subplot. Label paper bag as follows: {year}{plot}{sample type}{subplot}

4. Keep sample well-ventilated and place in drying oven upon return to the lab.

8. Soil and Root Sampling

8.1 Rationale

Soil samples are required for determining soil BD, C&N, and texture on each plot. The data are used to compute soil carbon content.

8.2 Methods

1. The soil depth should be established by augering a few examples and deciding what depth can consistently be achieved. This maximum depth should be used throughout the plot. Preferred: Sample by profile depths, 0-0.1 m, 0.1-0.2 m, 0.2-0.5 m, 0.5-1.0 m, and deeper if necessary. These are the depths used by AmeriFlux (alternative: some use soil horizons, but for global consistency, soil depth sampling in centimeters is better and less prone to mistakes).

Photo 2. Soil sampling and the auger used (Photo by Beverly Law).

2. Eight soil cores are taken from each subplot, 2 m from subplot center in the following directions: 0, 45, 90, 135, 180, 225, 270, and 315° (i.e. all four cardinal directions and the 45° intervals between them).

Note: These are the same sample points as those for litter samples. The soil samples are to be taken directly under the litter samples so that 0 cm is the top of the mineral soil. If the soil depth cannot be achieved find a place where it can.

3. Label bag with plot, subplot and achieved depth.

4. Auger core and put in labeled bag. It is important to record the plot depth to be able to compute the core volume.

5. Alternative to sampling to 1.0 m depth on all core locations: At all locations, sample to 0.0-0.1 m depth. At a subset of locations per hectare plot, collect 1 core each of 0.0-0.1 m, 0.1-0.2 m, 0.2-0.5 m, to as deep as possible up to 1.0 m. Take these cores at representative spots. Label the depths on the bag so the volume can be calculated.

9. Laboratory Procedures for Root Sampling and Soil Preparation

9.1 Methods

9.1.1 Preparation for C & N concentration

Sift soil sample through 2mm sieve and set out to air dry in tin plates or in bags. Air-drying can take days, weigh and re-weigh samples to see that they are no longer loosing moisture weight.

Air-dried samples are weighed and data is entered. A portion (~200ml) is removed and combined with others from the same subplot for an aggregate sample to send to laboratory for further analysis of C and N concentration.

A separate batch of soil may be sent to a laboratory to determine soil texture. A typical sample size needed for soil texture determination is about 50-100 grams of soil.

Organic matter and rocks bigger than 2mm are saved for bulk density measurements (below).

9.1.2 Roots

Material bigger than 2mm is put in a labeled plastic bag. Store in cooler until there is time to both wash and remove roots from the samples (letting wet samples sit around allows them to mold).

Everything bigger that 2mm should be processed in a root washer. In a root elutriator), start with 6 minutes using the largest screen size (760). Open and check that no roots/organic matter (OM) are floating on the top. Empty the screen and run again for 2-minute increments until nothing significant is coming out of the screen. Empty rocks into sieve and save for bulk density measurements (below).

Root + OM samples are taken to clean laboratory for removing roots from the washed material. Separate roots into fine alive, fine dead, medium and coarse. Pick out all other organic matter and weigh together. Label manila envelopes {year}{plot}{subplot}{core no.} to prepare for drying oven:

Fine alive: < 2 mm
Fine dead: <2 mm
Medium: 2- 10 mm
Coarse: > 10 mm
All other debris

Dry roots in oven at 72^{o}C for 2 to 3 days. Then check to see that root and OM samples are dry. If so, weigh and record data in grams. Place in labeled boxes for long-term archive.

9.1.3 Bulk Density

Rock samples are consolidated by subplot and their volume is measured by water displacement in the column.

Bulk density (g cm^{-3}) is defined as the mass of rock-free mineral soil per volume earth:

BD = (mass of bench-dry soil that passed through a 2mm screen)/(total volume of core sample minus the volume of the stones that did not pass through the 2mm screen)

9.1.4 Soil Carbon Content Calculations

The amount of organic carbon found in a soil can be calculated using values for the depth (cm) of the soil layer of interest, the soil bulk density (g/cm3) and the soil carbon content (%) (Equation 1). Using Equation 1, a 20 cm layer of soil having a bulk density of 1.5 g/cm^3 and a carbon content of 1.2% contains 3.6 Kg C/m^2 (36 Tonnes of C/ha).
Organic Carbon (Kg C/m^2 ground) = Depth (cm) x Bulk density (g/cm3) x Carbon content (%) x 10^{-1} (conversion factor)

10. Woody Detritus Survey

10.1 Rationale

Coarse and fine woody detritus (CWD, FWD) contain a significant amount of carbon and nutrients in a forest ecosystem. The material decomposes and can be a substantial component of heterotrophic respiration (Rh) and thus net ecosystem production (NEP=NPP - Rh). In quantifying NEP, it is important to include the amount and turnover of carbon in this component.

10.2 Methods

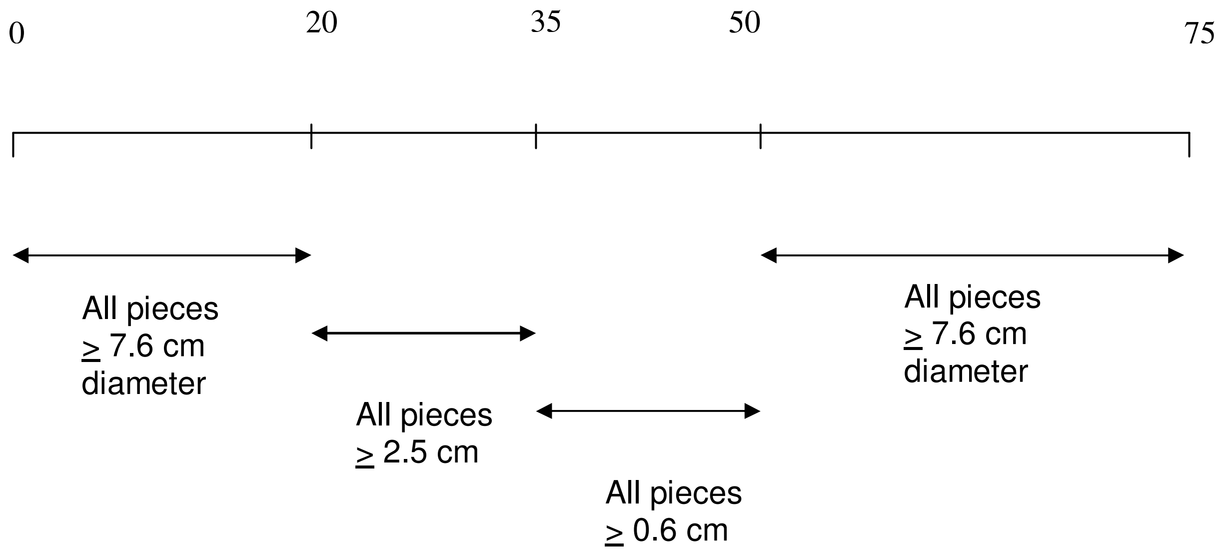
- The planar intersect technique involves counting intersections of woody pieces with vertical sampling planes that resemble guillotines dropped through the downed debris (Harmon & Sexton 1996).
- A survey tape is run out from plot center for 75 meters in each of the NW, NE, SW, and SE directions. Woody detritus intersecting the transect plane is recorded up to a height of 2 meters above the forest floor.
- The % slope of the survey tape is recorded for each transect. For example, a transect laid out diagonally down and across a slope will have a gentler slope than the actual hillside. A perfectly sidehilling tape would have a slope of zero.
- CWD (woody pieces 7.6 cm in diameter and larger) is recorded along the entire 75-meter transect. Record for each qualifying piece its species, true diameter at line intercept and decay class (1-5; see class definitions below).
- FWD (pieces less than 7.6 cm in diameter) is sampled along sub-sections of each transect, starting at meter 50 and working inward. Particles with diameters of 0.60 to 2.54 cm are sampled along 15 m of transect and particles with diameters between 2.54 and 7.63 cm are sampled along 30 m of transect. Note that these sub-sections begin at meter 50 and work inward towards plot center. Use a red "in or out " gauge to assign a size class to each piece.
    - For FWD, simply tally the number of "hits" for each size class:
        1. 0.6 – 2.5 cm
        2. 2.5 – 7.6 cm

- What counts as woody detritus?
    - Any downed, dead woody material (twigs, branches, or stems of trees and shrubs) that has fallen and lies within 2 m of the ground.

Leaning snags that form an angle of > 45° from true vertical also count.

- The transect tape must intersect the central axis of the piece for it to be counted. This means that if the tape only clips a corner at the end of a log, it does not count.
- Any piece can be recorded multiple times if the tape intersects it more than once (e.g., a curved piece, or at both the branch and the bole of a fallen tree).
- Count wood slivers, bark and irregular chunks; visually mold these pieces into cylinders for determining size class.
- Count *uprooted* stumps and roots not encased in soil. Do not count undisturbed stumps or roots still in contact with soil.
- The piece must be in or above the litter layer to count; it does not count if its central axis is buried in soil at the point of intersection.
- Dead branches and stems still attached to standing trees or shrubs do not count.

Schematic of wood detritus transect:



10.2.1 Decay classification

1 – Freshly dead pieces which contain most of their fine branches, possibly foliage, and all their barks. The wood is solid and there has been very little decay.

2 – Logs that have lost almost all of the fine branches. The bark is mostly intact but has begun to loosen, and the wood has been colonized by decay

organisms. There has not been much loss of strength or material. Good firewood materials.

3 – Usually losing the bark and beginning to loose portions of sapwood. The log will have no remaining branches, but is still strong and easily support itself. Branch stubs are rigid and are not easily wiggled or torn free.

4 – Logs have lost the ability to support themselves but still have a round to elliptical shape rising above the general forest floor. Branch stubs can be easily torn free. There is some remaining rigidity in that a kick will wiggle the log for several meters in either direction. This is the oldest class that can stand as a short snag.

5 – Form the ill-defined hummocks that appear to be part of the forest floor. They are made up of reddish brown crumbly materials that can be easily grabbed out in handfuls. When kicked they do not hold together enough to wiggle any more than the rest of the forest floor. Can be easily overlooked.

10.2.2 Coarse Woody Detritus Calculations

The volume of logs per unit area (m^3 m^{-2}), *V*, from line intercepts is calculated by:

$$V = 9.869 * \sum\left(\frac{d^2}{8L}\right)$$

where *d* is the piece diameter (m), and *L* the transect length (m) (Warren and Olson 1964, Van Wagner 1968).

11. Plot Photographs

11.1 Rationale

Photographs should be taken during the site visit to archive for future reference on the vegetation and soil characteristics at the time of sampling.

11.2 Methods

On each plot take six digital photos, one each from subplots 2, 3, and 4 pointing inward toward subplot 1, and three from subplot 1 pointing 60°, 180°, and 300°, respectively (Figure 7). Take photo using the default zoom level (the zoom that the camera is set to when turned on), from "eye" height, and point level to the ground. Contain in each photo an unobstructed view of "whiteboard" sign denoting the plot number and photo location/direction.

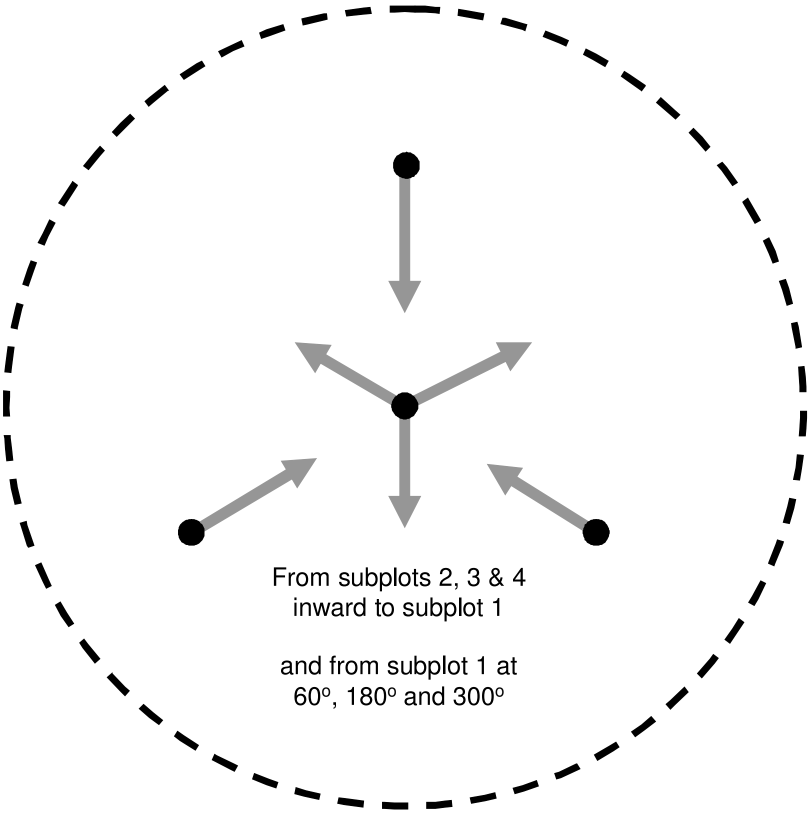


Figure 7. Plot photographs.

12. LAI Measurements (with LAI-2000)

12.1 Rationale

Leaf area index (LAI) is a unitless measure of canopy leaf area. Generally LAI is expressed in terms of square meters of leaf (half surface area) per square meter of ground. LAI is used to estimate live foliage biomass (foliage biomass = LMA x LAI) and foliage production (biomass x fraction new foliage). It is also used to develop remote sensing algorithms for estimating LAI, and to validate remotely sensed LAI, which will be used in an ecosystem process model to estimate NEP and NPP.

12.2 Methods

12.2.1 Variables to be measured

Gap fraction, gap size distribution, plant area index (PAI), clumping index, leaf area index (LAI), and crown closure.
The LAI is defined as one half the total green leaf area per unit ground surface area (Chen and Black, 1992). On sloping surfaces, the LAI should be projected to the normal to the slope. The basic equation for obtaining the true LAI from optical measurements is (Chen, 1996):

$$L = (1-\alpha) L_e \gamma_E / \Omega_E \qquad (1)$$

where L denotes LAI, α is the woody-to-total plant area ratio; Le is the effective LAI; γE is the needle-to-shoot area ratio; and ΩE is the foliage element clumping index. A foliage element refers to a conifer shoot or a broad leaf. If no correction is made using this woody-to-plant area ratio, i.e., alpha=0, the plant area index (PAI), including both green leaves and non-green materials, is obtained from Eq. (1). The effective LAI is the starting point for optical measurements of LAI, as optical instruments normally acquire the canopy gap fraction data through measuring radiation transmission. From the gap fraction, the effective LAI can be calculated under the assumption of a random spatial distribution of leaves. As the distribution is often not random, the effective LAI generally differs considerably from the true LAI. It is therefore necessary to make corrections with respect to the leaf spatial distribution pattern. In conifer stands, needles are grouped first in shoots, which are often dense and allow little penetration by light. Shoots of conifer needles are therefore treated as foliage elements and a correction for this leaf grouping effect is made using the needle-to-shoot area ratio. For broad leaf stands, individual leaves are considered as the element, and no such correction is necessary, i.e., $\gamma E=1$. Foliage elements are usually further grouped into canopy structures at large scales such as branches and tree crowns. This clumping at scales larger than the shoot is quantified using the element-clumping index, which can be derived from optical measurements of canopy gap size distribution. The clumping index was found to vary with zenith angle (Chen, 1996; Law et al. 2001). The recommended range of solar zenith angle for making TRAC measurements is 35° to 60°, which is representative of the mean clumping conditions. Fisheye photographs can be used to study the angular variability of clumping index. In optical gap size or gap fraction measurements, all objects above ground including leaves and woody materials affect LAI measurements. Since we are interested in green leaves only, these effects need to be removed by incorporating a woody-to-total plant area ratio. LAI-2000 and fisheye photography can also produce gap fraction near the vertical direction, i.e., in the first annulus from 0º to 15º zenith for LAI-2000 or similarly derived from photographs. This gap fraction can be approximately taken as the crown closure.

12.2.2 Measurement Protocols

LAI measurement protocols are developed to obtain the necessary variables given at the right hand side of Equation (1). The following strategies should be followed in LAI measurements at all locations:

(1) Measure L_e, using LAI-2000 at all sites if possible, otherwise L_e is measured at a few solar zenith angles using TRAC. A $\sin\theta$ weighting scheme should be used to obtain the stand average when TRAC data were acquired at more than one zenith angle.

(2) Measure the element clumping index Ω_E using TRAC at all forest sites.

(3) Measure the needle-to-shoot area ratio where possible. Since it is highly labor-intensive to acquire this number, the suggested values below can be used as the default values. When this variable is measured, it is recommended that you use the volume displacement method for measuring needle area outlined in the Appendix of Chen et al. (1997) and the multi-angle projecting method for measuring shoot area described in Chen (1996).

(4) Measure the element width where possible, otherwise the suggested values below can be used. The width is taken as the square root of half the largest projected leaf area for broad leaves. For conifer shoots close to cylindrical or spherical shapes, it can be approximated as the square root of the product of shoot length and diameter. Detailed theories and methods for handling the projection of foliage elements on the ground surface at various solar zenith angles and azimuth

angles relative to the transect direction are given in Chen and Cihlar (1995a) and the TRAC manual (Leblanc et al., 2002a). The width can also be approximately found from measured gap size distributions by TRAC or photographs using the P-approach described in Chen and Cihlar (1995).

(5) Estimate the woody-to-total area ratio where possible, otherwise the suggested values below are used for the major forest types.

12.2.3 Variables to be estimated

Generally, the needle-to-shoot area ratio is larger at sites with better growing conditions even for the same species (Chen et al., 2006), and the woody-to-plant area ratio increases with forest age. However, as the differences among species are large, the following values for the needle-to-shoot area ratio and woody-to-plant area ratio are suggested for values forest species based on existing literature (Chen, 1996; Chen et al., 2006; Gower et al., 1999; Law et al., 2001a, 2001b):

Needle-to-shoot area ratio:

- Black spruce (*Picea mariana*): 1.30-1.60;
- Jack pine (*Pinus Banksiana*): 1.20-1.40;
- Red pine (*Pinus resinosa)*: 2.08,
- Scots pine (*Pinus sylvestris*): 1.75;
- White Pine *(Pinus strobes):* 1.90
- Balsam Fir *(Abies balsamea):* 1.70
- Douglas Fir (*Pseudotsuga menziesii*): 1.60-1.70
- Ponderosa pine (*Pinus ponderosa*): 1.25 -1.29

Woody to total area ratio:

- Black spruce (*Picea mariana*): 0.12-0.17;
- Jack pine (young) (*Pinus Banksiana*): 0.03-0.05;
- Jack pine (old) (*Pinus Banksiana*): 0.11-0.34;
- Red pine (*Pinus resinosa)*: 0.07,
- Douglas Fir (*Pseudotsuga menziesii*): 0.08
- Aspen (*Populous tremuloides*): 0.21-0.22
- Oak-hickory: 0.11
- Sitka spruce: 0.23
- Ponderosa pine (*Pinus ponderosa*): 0.19 – 0.39

Element width (mm):

- Black spruce (*Picea mariana*): 30 ;

- Jack pine (*Pinus Banksiana*): 50;
- Red pine (*Pinus resinosa)*: 130,
- Scots pine (*Pinus sylvestris*): 70 ;
- Douglas Fir (*Pseudotsuga menziesii*): 50
- Aspen (*Populous tremuloides*) : 50
- Ponderosa pine (*Pinus ponderosa*): 370

12.3 Final temporal and spatial scale

Seasonal or annual measurements at the stand/tower site level

12.4 Spatial characteristics

12.4.1 Number of samples needed

LAI measurements are made at 35 points in each plot as shown in Figure 8.

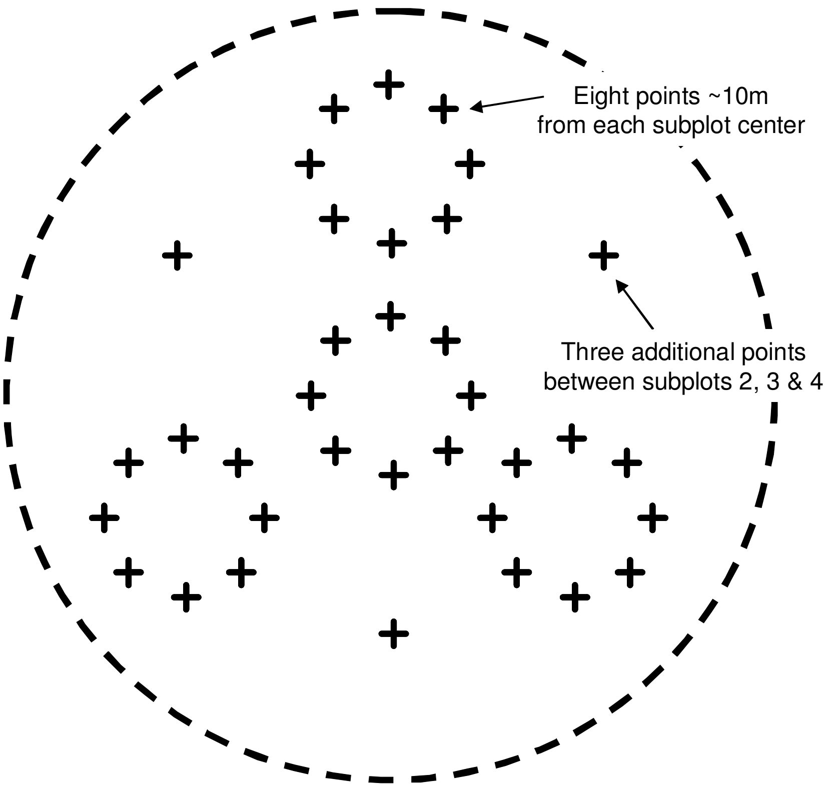


Figure 8. LAI2000 measurement points.

Alternatively, if measurements are to represent the footprint of a forest flux tower, the strategy is to obtain the mean LAI of the footprint area of the tower. Three transects in the mean wind direction of the tower is the best. A transect should be at least 300 m long to characterize the footprint variability. In this case, a permanent marker is placed every 10 m on the forest floor. The markers along the transects are the locations for distance marker for TRAC and for LAI-2000 or fisheye photographs. See the next section for TRAC measurements in the 1 ha plot.

12.4.2 Lighting Conditions

LAI-2000 measurements must be made under uniformly overcast or diffuse lighting conditions. While cloudy days may occur occasionally, it is likely that the best time to find the appropriate conditions is immediately pre-dawn and immediately post-sunset. As a general rule, if you can see shadows on the ground or sunlit foliage in the canopy the sky conditions are NOT met. Examples of such inappropriate conditions are: just after the sun dips below the horizon – the sun may still be lighting foliage high up in the canopy; when an overcast sky's cloud layer is very thin – although clouds are covering the sun you may still be able to see shadows on the ground.

Stop logging before sky conditions are so dark that you cannot distinguish individual needles or leaves in the canopy. Another way to tell if lighting conditions are too dark is to place your hand over the sensor while looking at the datalogger screen. If the light levels on screen respond to your hand covering the sensor, you still have enough light. If the light levels on screen do not respond much, it is too dark. Both of these methods are judgment calls; so if you are unsure about your lighting conditions, stop taking measurements.

12.4.3 Above Canopy Sensor Location

The above canopy sensor should be placed in a clearing that is large enough for unrestricted view. If the clearing is greater than 3 times the height of the tallest surrounding vegetation the clearing is of acceptable size. Place the 45-degree mask on the sensor and place the above sensor at one end of the clearing pointing towards the open space. As an alternative to estimating the diameter of the clearing, one can inspect the angle of view to the top of the surrounding vegetation. The lowest the LAI-2000 sensors can 'see' is 26 degrees off the horizon. Use a clinometer to determine if all of the surrounding vegetation within the sensor view is at least 26 degrees off the horizon.

12.4.4 Placement of Above Canopy Sensor within the Opening

On sloped plots, make below canopy measurements along the contours of the slope. Since the above canopy sensor must point in the same direction as the below canopy sensor, place the above canopy sensor in the opening so that it points along the contour of the slope you will be taking measurements on. In other words, the sensor should point perpendicular to the direction of the face of the slope.

12.4.5 Field Measurements (with units already configured)

Above Canopy Unit

1. Mount above canopy wand on tripod in opening. Use unit A as this one is already set up to be the slave unit, otherwise you must reconfigure.
2. Connect Wand to X-port on matching logger box.
3. Turn Unit on using ON button
4. Set start time to a few minutes after present and stop time to several hours later. To do this, use FCT 11. Use ENTER button to advance past other parameters until you are prompted for start and end time.
5. Press LOG button
6. Answer prompt 1 and 2, which should prompt for “PLOT” and ”COMMENTS” respectively.
7. Watch time until measurements count down. Unit will beep when it begins to take measurements.
8. After taking roving measurements return to slave and turn it off using FCT 09.

Below Canopy Unit

1. Connect Wand B to X-port on matching logger box. Use unit B as this one is already set up to be the roving unit, otherwise you must reconfigure.
2. Turn Unit on using ON button
3. Press LOG button
4. Answer prompt 1 and 2, which should prompt for “PLOT” and ”CANOPY LAYER” respectively.
5. Use button on wand to take as many measurements as desired in each plot and canopy layer.
6. When switching between plots or canopy layers simply hit LOG and re-answer prompts 1 and 2. This will start a new file.
7. When done taking all measurements turn unit off using FCT 09.

Data are now stored in the boxes as sequentially numbered files ready for download to PC using *FV2000* for windows.

Configuring Units for simple measurements (if not already configured)

Above Canopy Unit

1. FCT 01 to confirm serial number of wand and calibration factors for all 5 rings.
2. FCT 04 to set resolution to HIGH
3. FCT 05 to set/synchronize clock
4. FCT 11 to set operation mode. Choose "REMOTE ABOVE X" and "INTERVAL"=15
5. FCT 12 to set prompts. Set first prompt to "CLUSTER". Set second prompt to "COMMENTS".

Below Canopy Unit

1. FCT 01 to confirm serial number of wand and calibration factors for all 5 rings.
2. FCT 04 to set resolution to HIGH
3. FCT 05 to set/synchronize clock
4. FCT 11 to set operation mode. Choose "REMOTE BELOW X" and "AVERAGE"=0
5. FCT 12 to set prompts. Set first prompt to "PLOT". Set second prompt to "CANOPY LAYER".

Configuration for download (both units)

1. FCT 31:
    - BAUD =4800
    - DATA BITS =8
    - PARITY= none
    - XON/XOFF= NO
2. FCT 33:
    - FORMAT =Standard
    - PTINT OBS =Yes

Once these configurations are set, they remain the same between uses and until changed. Check only for piece of mind.

12.4.6 Data Logging

After instrument calibration, note the time you've set the above sensor to begin logging. Travel to the site of interest and wait until the designated logging time has passed (the time set in step 12 of calibration). When the above sensor has begun logging, move to each logging point (every 20 meters), hold the instrument level at 2m or above understory vegetation and log one measurement by pressing the button on the sensor wand, then log a measurement while holding the instrument level at ground level while crouching behind the sensor mask. The unit will emit two beeps when logging a measurement. The second beep indicates the measurement is finished; wait for the second beep before moving to the next measurement point. When logging, it is important to hold the instrument so the sensor mask is facing in the same direction as the above sensor.

12.5 Corn and Soybeans

12.5.1 Population Determination

Accurate determination of plant population for each sampling location is critical for precision in both biomass and LAI calculations.

Corn

The numbers of plants in nine 8-meter by 2 row sections (row spacing of 30 inches) are counted at approximately the V4 growth stage. Plant population for corn [plants per hectare] is calculated:

$$PP_c = \frac{plantnum}{109.7\ m^2} \times 10,000$$

Where *plantnum* is the sum of all the plants counted in the nine areas.

Soybeans

Procedures for population counts of soybeans are similar to that in corn except only 2-meter by 2 row sections (row spacing of 30 inches) are counted at the V2 stage.

$$PP_s = \frac{plantnum}{27.43\ m^2} \times 10,000$$

Additional Specifics:

- Volunteer corn and soybean plants are considered weeds and are not counted
- Areas with atypical stands are not used. Examples include areas where plants were driven over by equipment, isolated rodent damage, planter errors, pivot wheel tracks, etc.
- Areas that were alleys or walkways the previous year were avoided.

12.5.2 Field Sampling Procedures

Plant samples should be taken when air temperatures are as cool as reasonable possible to reduce plant desiccation.

Sampling Location

Fifteen dry matter sampling areas, each 1-meter in length, are pre-marked in the six center rows of planter pass 2 of the sampling location at about the V2 stage. Sample areas are at least one row away from the planter "guess row." Areas are also at least three meters from the nearest sampling area in the same row or 1 meter away in the adjacent row. Sampling begins from the areas nearest the alley and progresses toward the center of the plot. Typically 10 to 12 samplings are conducted during the growing season so several extra sample areas are available in case of poor stands or other atypical plant problems.

Sampling Frequency

Plots are generally sampled every 7 to 10 days. One sampling should be timed to correspond to maximum leaf area index which usually occurs at tasseling. Additional samplings are useful just after the start of rapid growth, between V6 and V11. A sampling just prior to the start of rapid leaf senescence is helpful for identifying the rapid decline in green leaf area.

Corn

The harvest area is identified and, before each plant is harvested, the plant height is taken. The plant is cut off at as close to ground level as possible, any brace roots removed, and the plant cut into segments and placed in a fine mesh bag. All dead leaves still attached to the plant are placed in the bag as well. The plant material is placed in a cooler with ice-packs, and moist towels as quickly as possible to prevent water loss. Once all samples are taken they are moved to an air conditioned laboratory for dissection and measurement.

Soybeans

Steps and precautions for soybeans are similar except that the number of plants in the 1-meter harvest section is recorded. Plants are not bagged individually, but as a group, unlike corn.

12.5.3 Laboratory Procedures for Determining Leaf Area Index

Corn

All steps need to be carried out as quickly as possible so that plant material is exposed to room temperature for as short of a time as possible. Plants are separated into:

- green leaves (GL) – all green leaf material from the collar to the leaf tip
- dead leaves (DL) – material consisting of greater than 50% necrotic (or entirely yellow) leaf
- stalk (S) – includes the stem, leaf sheaths, immature or undeveloped ears and unfurled leaves
- reproductive (R) – includes tassel, husk, ear shank, cob, kernels and silks

Fresh weights are taken on each part and the green leaves are run through a Licor LI-3100 leaf area meter and the area recorded in cm^2 *(plant area)*. Green leaf area index (LAI) is calculated by:

$$LAI_{green} = \frac{plant\ \ area}{10{,}000} \times \frac{PP_c}{10{,}000}$$

Plant parts are dried at 105°C. Because dead leaves can not accurately be run through a leaf area meter, dead leaf area index is estimated using the specific leaf area of the green leaves. Specific leaf area of green leaves [g per cm^2] is calculated as:

$$SLA_{green} = \frac{DW_{green}}{plant\ area}$$

Where DW_{green} is the dry weight of the green leaves. Dead LAI is then calculated as:

$$LAI_{dead} = \left[\frac{\left(DW_{dead} / SLA_{green} \right)}{10{,}000} \right] \times \frac{PP_c}{10{,}000}$$

Where DW_{dead} is the dry weight of the dead leaves. Total LAI would then be:

$$LAI_{Total} = LAI_{green} + LAI_{dead}$$

Soybeans

Steps for soybeans are essentially the same as for corn. Plants are separated into:

- green leaves (GL) – all green leaf material from the point trifoliate leaflets attach to the petiole
- dead leaves (DL) – material consisting of greater than 50% necrotic (or entirely yellow) leaf
- stem (S) – includes the stem and petioles
- reproductive (R) – blossoms, pods and seeds

Since data are not kept on an individual plant basis, the total weights and leaf areas are divided by the number of plants in the sample. Calculations are then done the same as in corn.

13. TRAC Measurements

13.1 Rationale

The TRAC instrument is used to obtain a clumping index for the stand (clumping at scales larger than the shoot) (Chen and Cihlar 1995, Chen et al. 1997, Law et al. 2001a, 2001b). This clumping index is used to correct LAI-2000 measurements, which tend to underestimate LAI.

13.2 Methods

TRAC measurements will be made along 24 10m transects in each plot as shown in Figure 9.

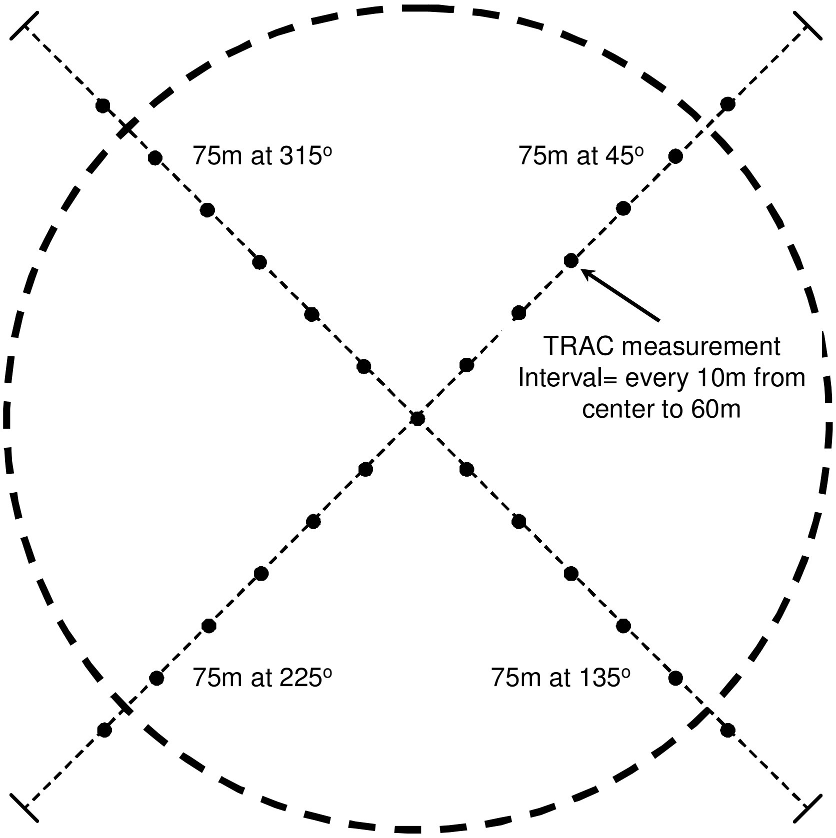


Figure 9. Woody detritus transects and TRAC transect nodes.

13.2.1 Sun Angle

Measurements should be taken when the solar zenith angle is near 60° (see list of ideal TRAC measurement times in SOLAR CALENDAR section).

13.2.2 TRAC Setup

Immediately before measurements are taken the TRAC must be setup for measurements. This will reset the clock and clear the memory for new data.

1. Attach the TRAC to port COM1 on the computer with the 9-pin adaptor cable supplied with the instrument. Plug the other end of the cable into the instrument (telephone-style cord adaptor) and power the TRAC on. The TRAC will beep twice when turned on and then proceed to make a repeated clicking sound. This is normal. If the TRAC beeps three times on power up, turn the instrument off and replace the 9-volt battery.
2. Start the TRACOM-X program from the start menu (Start → Programs → Ccrs → Trac → TRACOM-X).
3. Press the SETUP button on the screen. When prompted to clear TRAC memory press YES. The TRAC will beep twice. Make sure the TRAC beeps twice, this is your cue that it is properly set up.
4. A predetermined filename will appear in the FILE NAME field. Leave this name for now. You can change it when you download the data.
5. The TRAC is now ready for measurements. Unplug the cable from the instrument and insert the placeholder cord into the phone port (this prevents dirt and debris from getting into the port).

13.2.3 Data Logging

Position the black plastic diffusion strip on the TRAC in order to block the direct sun. Hold the TRAC in a comfortable position that allows you to watch the bubble level and your timer. Press the control button for 0.5 seconds to enter datalogging mode. The TRAC will emit a single beep and the frequency of clicking will change, indicating that the instrument has entered datalogging mode. Walk the transect at approximately 1 meter per 3 seconds moving at a steady pace and keeping the TRAC level. It is better to err on the side of slow walking. If you must speed up a little or stop momentarily (less than a second) that is okay, but resume your pace as soon as possible.

When you reach each 10 m-distance marker, press the control button momentarily (for less than 0.5 seconds) to insert a distance marker in the data stream. The TRAC does not indicate if you have successfully inserted a distance marker; this is not a problem just assume a marker has been inserted. If you accidentally stop the TRAC from logging by holding the button too long (the TRAC will beep and the frequency of clicking will change), restart logging mode by holding the button down and continue along the transect. When you reach the end of the transect, insert a final distance marker and then hold the control button for 0.5 seconds to exit datalogging mode. The TRAC will beep and the frequency of clicking will change. Move to your next transect and start logging as before. Walk the second transect entering distance markers by pressing the button momentarily.

13.2.4 Preliminary Data Analysis

To be certain you have collected enough good data, follow the data transfer and data analysis guidelines below to analyze the data preliminarily IN THE FIELD. The lower threshold for an acceptable amount of data is 200 meters (20, 10m transect sections). In order to determine if you have reached this threshold:

1. Transfer the data from the TRAC to the computer (see Data Transfer below).
2. Run TRAC-WIN program (see Data Analysis below).
3. Select the Read TRAC file and browse to the file you wish to use.
4. The right side of the program window will show all of the measurement segments (measurements between distance markers) for your transect(s). Segments with 16 readings indicate time periods when the instrument was in standby mode. If walking at the proper pace (1 meter every 3 seconds), segments should have about 1000 readings. A little variation (~100 readings) is fine, more readings will give more precision, and fewer will give less precision.
5. Count the number of transect segments that have greater than 850 readings. These are considered acceptable transect segments.
6. If the number of acceptable transect segments is 20 or greater, stop taking measurements.

7. If the number of acceptable transect segments is less than 20, RESET THE TRAC AND RE-RUN ALL THREE TRANSECTS

13.2.5 Data Transfer

It is best to transfer the data to a computer soon after the data is collected to prevent data loss, and determine if the measurements need to be repeated.

1. Connect the TRAC to the same computer used in the Setup procedure.
2. If the instrument is not on (if TRAC power has been interrupted), turn it on and enter logging mode for a few second, then stop logging. If the instrument was not shut off between the end of measurements and this step, it is not necessary to enter logging mode.
3. Press the TRANSFER button in TRACOM-X.
4. Enter the filename you wish to use in the popup window and press OK.
5. A green light will appear next to the TRANSFER button and the TRAC will beep once. You will see the time marks and data run by in the program window. When the download has finished, the light will go out and the TRAC will beep again.
6. Disconnect the TRAC and turn it off, or SETUP for another set of measurements.
7. The downloaded file is placed on the desktop of the computer. Move the file to the appropriate location.

Caution If you do not SETUP the instrument between measurements, new data will be appended to the old data. After collecting 45 minutes of data, the datalogger will begin to 'wrap around' and overwrite the data at the beginning.

13.2.6 Data analysis

The TRAC comes with a data analysis program to calculate gap fraction and LAI. The file that is downloaded from the TRAC is read directly into this program. The program is self-explanatory, but below is a step-by-step walk through.

TRAC-WIN:

1. Start up the TRAC-WIN program (Start → Programs → Ccrs → Trac → TRAC for Windows).
2. Select the Read TRAC file and browse to the file you wish to use. The program will automatically give the output file the same name as the input file, unless you specify otherwise. The ouput file will have a .lai extension and will contain most of the important data you need from the TRAC measurements.
3. The right side of the program window will show all of the measurement segments (measurements between distance markers) for your transect(s). Segments with 16 readings indicate time periods when the instrument was in standby mode. If walking at the proper pace (1 meter every 3 seconds), segments should have about 1000 readings. A little variation is fine, more readings will give more precision, and

fewer will give less precision. Measurements with fewer than 850 readings should not be used.

4. *Note:* Pressing the Time button will allow you to look at the time stamps for each segment rather than the number of measurements.
5. *Note:* By selecting one segment (clicking in the check box next to the segment) and pressing the PPFD PLOT button you can look at a graphical representation of the data.
6. Select the segments you wish to use for your analysis.
7. Enter the Mean Element Width (in mm) for the plot. *Note: the mean element width is described in the TRAC manual FAQ.*
8. Select Spacing Between Markers and enter the value (in m) for the plot. According to the protocol this should be 10m.
9. On the right side of the screen, select the check boxes next to the blocks of data you wish to use.
10. Select the Compute Mean button at the bottom of the screen.
11. In this window, select the 'use mean as above value' box. Press the OK button. This will use the mean PPFD value for the plot as the 'Above or Outside PPFD measurement.
12. *Note: 'Above or Outside PPFD measurement' and 'Needle-to-Shoot ratio' are not part of the gap fraction or OMEGAe calculation, so these values don't really matter. The only reason for entering the mean value for PPFD (step 7) is that the program won't run without a value here.*
13. Hit the 'Process' button at the bottom of the screen. The gap fraction and OMEGAe will appear at the bottom of the screen. A .lai file is created for the data which contains all of the information listed in the Windows Trac program, this file can be referenced for future use.

Batteries

If, upon power up, the TRAC beep three times (as opposed to the normal two) it is time to replace the 9-volt battery. One nine volt battery is supposed to last about 40 hours, but keep some batteries on hand just in case.

The 3-volt lithium battery should be replaced once a year.

14. Phenology

14.1 Rationale

Seasonal measurements of phenology can be used to understand changes in seasonal process over years, and to help diagnose flux measurements. In any given year, plant phenological activities determine when terrestrial ecosystem carbon uptake changes rapidly in spring and autumn, how fast this transition can occur, and how long the ecosystem stays as a sink. For example, emergence and leaf out and senescence dates are important for quantifying growing season length for modeling ecosystem processes, and for diagnosing observed fluxes. Thus, phenology and terrestrial carbon cycles are intimately linked.

Phenophases cover most phases of a plant's above-ground reproductive life cycle, from emergence to leaf out and flowering to fruiting to senescence and leaf fall. Each of these life history stages has ecological and botanical significance. For example, flowering is critical for plant-pollinator interactions, and fruit ripening is important for plant dispersal and as food for many wildlife species. It is important to understand the relationships among these stages in individual plants and species, and how these relationships may be changing with climate.

14.2 Methods

Two levels of methodology are described below: basic, which is intended for all levels of observers; and quantitative, which is intended for generally trained ecologists. These were modified from draft protocols of the USA National Phenology Network (http://www.usanpn.org) and the European Phenology Network (http://www.dow.wau.nl/msa/epn/standardisation.asp).

Phenophases are based on the general BBCH scale used by the European Phenology Network, modified to accommodate target species. Ideally, there should be a small number of individuals evaluated per species for a given phenophase. The time commitment at each site should less than 1 hour for observations, 3 times per week (for a sampling interval of 3 days maximum, spanning at least 5 days from the 1st to the 3rd observation), with less than 15 minutes of data for each observation day. Observations can be conducted around the time of the relevant phenophases, and time commitments can be reduced in the off-season (e.g. between full leaf expansion and senescence).

14.2.1 General guidelines

1. Submit record for each observation day, not just when phenophase is reached.

2. Record observations on each individual observed. A recommended sample size is 3-10 for each species. If it is not possible to observe individuals, observers should report the average phenology among the individuals observed

14.2.2 Definitions

Emergence above ground: Any part of the plant visible above the soil. Appropriate for herbaceous species and seedlings of woody species.

Leaf out, on woody plants: Report when leaves are completely unfolded from the bud. The leaves should be completely open and the leaf stem or leaf base must be visible (you might need to bend the new leaf backwards to see those).

Photo 3 - Leaf-out of woody plant (Douglas-fir), measured as 51-90% in March 2002 (Photo by Beverly Law).

Flowering: Must be able to see the stamens among the unfolded petals. For a single herbaceous plant, one open flower or inflorescence (wind pollinated species and other species with many tiny flowers) is sufficient. For trees, large shrubs, or patches of herbs, make sure there are blooms on at least three places on the tree, shrub, or patch. In wind-pollinated plants, look for the presence of powdery, yellow pollen from their cones or catkins (cone-like flower clusters), or visible anthers.

Fruit ripening (Ripe): Fruit ready to disperse from plant (Species-specific characters).

Fruit dispersal: Report as fruits or seeds disappear from the plant, dropping naturally or being eaten by wildlife.

Leaf color (woody plants): Consider color turned on a single leaf if more than 50% of the leaf is not green.

Leaf fall (woody plants): Leaves are no longer present if they have fallen or if they have dried and turned brown (e.g., oaks and beech).

Senescence (herbaceous plants): Report proportion of plant that is green, as it browns/yellows and dries up during senescence at the end of its growing season.

14.2.3 Basic level of observations (most general, all levels of observers)

Record date and each of the following phenophases:

- Emergence above ground: yes or no
- Leaf out (woody plants): 0-5% (not yet leafed out); 6-50%; 51-90%; 91-100% (fully leafed out)
- Flowering: yes or no
- Fruit ripening: 0-5% fruits ripe, 6-50%, 51-90%, 91-100%
- Fruit and seed dispersal: all ripe fruit/seeds still present; some (not all) present; none present
- Leaf color (woody plants): 0-5% turned; 6-50%, 51-90%, 91-100%
- Leaf fall (woody plants): 100-91% leaves on tree; 90-51%; 50-6%; 5-0%
- Senescence (herbaceous plants): plant 100-91% green; 90-51%, 50-6%, 5-0%

14.2.4 Quantitative observations

- Sample size: minimum of 5 individuals (genets)/species

- Frequency: every 3 days during growing season (Remote sites may need to observe less frequently.)
- Emergence above ground: height above ground
- Leaf out (woody plants): number of leaves per branch fully open (recommend examining 3-10 representative marked branches—same branches during each observation day); length of leaves on marked branches
- Flowering: number of flowers or inflorescences per individual plant (on trees and large shrubs, estimate by examining 3-10 representative marked branches—same branches during each observation day); note sex of each flower
- Fruit ripening: number of unripe fruits; number of ripe fruits
- Fruit and seed dispersal: number or proportion (e.g., tiny fruits and seeds) of fruits or seeds dispersed
- Leaf color (woody plants): number of leaves turned per branch (examine 3-10 representative marked branches—same branches during each observation day)
- Leaf fall (woody plants): number of leaves per branch (examining 3-10 representative marked branches—same branches during each observation day)
- Senescence (herbaceous plants): percent of plant green
- Comments: submit appropriate comments (e.g., health of plant, herbivory, other disturbance, etc.)

15. Biological Data Submission Guidelines

One of the fundamental requirements of being a participant in the AmeriFlux network is to submit data to the central AmeriFlux data repository located at the Carbon Dioxide Information Analysis Center (CDIAC). Investigators are expected to provide biological data to CDIAC following the guidance below within a reasonable timeframe.

Photo 4 - AmeriFlux: the eddy covariance flux tower in Oregon (*Metolius ponderosa* pine forest)- (Photo by Beverly Law).

Biological data are submitted in four Excel spreadsheets. The spreadsheets are used to handle the richness and variation in the data and to address the importance of capturing comments and metadata describing the data and data collection practices. Templates are provided on the AmeriFlux web site at http://public.ornl.gov/ameriflux. Please adhere to the guidance below.

This document explains each of the biological spreadsheets. For a cross reference listing of which spreadsheet contains a specific biological variable, see the appendix.

Not all biological data are submitted in one of the biological spreadsheets. Automated or regularly sampled data are submitted in the same format as the flux meteorology and micrometeorology data. That format is described on the AmeriFlux web site at http://public.ornl.gov/ameriflux/data-guidelines.shtml.

- Soil CO_2 efflux (Rs) may be measured periodically (e.g. LI6400) or automatically (e.g. LI8100, or home-made system with LI820 or LI6262 gas analyzer). This document describes how the periodic Rs and the accompanying Ts measurements are submitted.
- Leaf area index (LAI) may be measured periodically (e.g. with LAI-2000, AcuPAR, or hemispherical photos) or automatically (e.g. above- and below-canopy quantum sensors). This document describes how the periodic LAI measurements are submitted.

- Sapflow (SAPFLOW) is always measured automatically by the Granier method or heat pulse method and reported on hourly intervals.
- Soil water content (SWC) may be measured periodically (e.g. Techtronix TDR) or automatically (e.g. CS615). This document describes how the periodic SWC measurements are submitted.

Note that the flux-met format and the biological format use the same names for the same variables. For example, "Rs" is used for both.

Raw files from specific instruments are also submitted to CDIAC. The format for these submissions is still TBD. The variables and instruments are:

- LAI. Raw files from an LAI-2000 should be submitted to the CDIAC and must include timestamps. The format for this is currently TBD.
- ACi. Raw data files from the LI6400 should be submitted to the CDIAC and must include timestamps. The file format and how different curve data can be combined is also TBD.
- PSN_LT. Raw photosynthetic light response curve data from the LI6400 combined from multiple samples and dates. The file format is TBD.

15.1 Content and Format of Biological Spreadsheets

The biological spreadsheets are organized columns; this differs from the flux-met templates which are organized in rows. When multiple measurements of the same variable are made, the data are reported in consecutive columns. Multiple measurements of a variable are reported whenever that variable is measured at different time in a year, across different species, or at different depths, An "<n>" in the variable name indicates whether multiple measurements can be submitted.
An example of this is LAI. A single LAI measurement includes entries in the LAI<n>, LAI<n>_DATE< LAI<n>_CLUMP, LAI<n>_TECHNIQUE, and LAI<n>_COMMENT rows. The first measurement is reported in the fourth column (first empty cells) of the submission spreadsheet. The second measurement is reported in the fifth column (next empty cells) and so on.
Each spreadsheet contains a brief header followed by one or more data columns. The header includes information identifying the site, investigator, and submission date. A missing data value is indicated by a value of -9999.
It is important to report the measurement date of many of the requested variables. Separate variable names are provided where dates are sought. The site disturbance data are reported in DD/MM/YYYY format; all other variables are reported in DOY/ YYYY format. For historical site disturbance data where the exact day or even year may be unknown, the day (if possible) and year can be approximated; the DIST_DATE_QUAL is used to

indicate the approximation. For all other data, the exact measurement day and/or hour should be reported.

Line	Row Text	Contents
1	Sitename:	Site name. The site name should be consistent with the one on the AmeriFlux web site. Note that the site name cannot contain any commas.
2	Email:	E-mail contact for questions. The e-mail contact need not be the principal investigator, nor is the e-mail contact expected to be able to answer questions on all subject matters. The e-mail contact can forward questions as appropriate to ensure that questions can be resolved
3	Created:	File creation date
4		Variable name, description, and (optional) units column identifiers.

Data must be submitted in standard units. The units for each variable are documented in the tables below and in the spreadsheet templates.

15.2 Site Biological Ancillary Data Spreadsheet

The site ancillary biological data spreadsheet contains rarely changing site characteristics. This spreadsheet is organized in four columns: variable name, description, units, and entered data.

Variable Name	Description
LAND_OWN	Land ownership type. Land ownership code. The list of codes is below. Public Private
LAND_OWNER	Land owner. If public, name agency (Forest Service, Bureau of Land Management, etc.). If private, name owner if available.
SITE_DESC	Site description including published references describing the site.
VEG_TYPE	Vegetation type. Vegetation type is reported using IGBP designations. The list of IGBP designations is below: DBF: Deciduous Broadleaf Forests Lands dominated by woody vegetation with a percent cover >60% and height exceeding 2 meters. Consists of broadleaf tree communities with an annual cycle of leaf-on and leaf-off periods.

DNF: Deciduous Needleleaf Forests
Lands dominated by woody vegetation with a percent cover >60% and height exceeding 2 meters. Consists of seasonal needleleaf tree communities with an annual cycle of leaf-on and leaf-off periods.

EBF: Evergreen Broadleaf Forests
Lands dominated by woody vegetation with a percent cover >60% and height exceeding 2 meters. Almost all trees and shrubs remain green year round. Canopy is never without green foliage.

ENF: Evergreen Needleleaf Forests
Lands dominated by woody vegetation with a percent cover >60% and height exceeding 2 meters. Almost all trees remain green all year. Canopy is never without green foliage.

MF: Mixed Forests
Lands dominated by trees with a percent cover >60% and height exceeding 2 meters. Consists of tree communities with interspersed mixtures or mosaics of the other four forest types. None of the forest types exceeds 60% of landscape.

CSH: Closed Shrublands
Lands with woody vegetation less than 2 meters tall and with shrub canopy cover >60%. The shrub foliage can be either evergreen or deciduous.

OSH: Open Shrublands
Lands with woody vegetation less than 2 meters tall and with shrub canopy cover between 10-60%. The shrub foliage can be either evergreen or deciduous.

WSA: Woody Savannas
Lands with herbaceous and other understory systems, and with forest canopy cover between 30-60%. The forest cover height exceeds 2 meters.

SAV: Savannas
Lands with herbaceous and other understory systems, and with forest canopy cover between 10-30%. The forest cover height exceeds 2 meters.

GRA: Grasslands
Lands with herbaceous types of cover. Tree and shrub cover is less than 10%. Permanent wetlands lands with a permanent mixture of water and herbaceous or woody vegetation. The vegetation can be present in either salt, brackish, or fresh water.

CRO: Croplands
Lands covered with temporary crops followed by harvest and a bare soil period (e.g., single and multiple cropping systems). Note that perennial woody crops will be classified as the appropriate forest or shrub land cover type.

URB: Urban and Built-Up Lands
Land covered by buildings and other man-made structures.

WET: Permanent Wetlands
Lands with a permanent mosaic of water and herbaceous or woody vegetation. The vegetation can be present in either salt, brackish, or fresh water.

SNO: Snow and Ice
Lands under snow/ice cover for most of the year.

BSV: Barren or Sparsely Vegetated Lands
Lands with exposed soil, sand or rocks and has less than 10% vegetated cover during any time of year.

15.3 Site Disturbance Data Spreadsheet

The site disturbance data spreadsheet contains rarely changing site characteristics. This spreadsheet is organized in three or more columns: variable name, description, and entered data. Each new disturbance is entered into a new column.

Variable Name	Description
DIST<n>	Site disturbance history code. List multiple disturbances as far back in time as possible. The DIST, DIST_QUAL, DIST_DATE, DIST_DATE_QUAL, and DIST_COMMENT for each reported disturbance/site history event are entered into consecutive columns. The list of disturbance codes is below. Note that for agricultural crops, management variables (e.g. fertilizer application amount) are listed in the DIST_QUAL field separately.
	grassland/grazed
	grassland/ungrazed
	harvest (DIST<n>_QUAL indicates if left on the field and is either on field or removed
	thinning (DIST<n>_QUAL indicate the % of thinning)
	FWD removal (If not by underburning)
	Underburn
	Planted
	fertilized (DIST<n>_QUAL contains dates of application, amounts, (Kg N ha^{-1}), fertilizer type and method of application. Add the following.

fertilizer type
fertilizer method

The type of fertilizer (e.g. dry granule, urea ammonium nitrate or manure) is important. How the fertilizer is applied (e.g. broadcast, coulter injection knife, sprayer) is also important.

Irrigated (include data and amounts of irrigation)

natural regeneration

natural regeneration filled (i.e., natural regeneration, supplemented with planted trees)

wildfire (DIST<n>_QUAL indicates the wildfire severity and is one of high, moderate or low)

crop type and species - In case of cultivated crops, the cultivar should be listed. The information should be listed in order of importance: common name, genus and species, and then cultivar. Examples:
-Maize (*Zea mays L.*) Pioneer 33P67
-Soybean (*Glycine max* [L.] Merr.) Asgrow 2703

Tillage (DIST<n>_QUAL indicates the type of tillage, e.g., conventional, no-till, strip-till, ridge-till) and depth. Add the following:
- tillage type
- tillage depth

crop residue management (DIST<n>_QUAL indicates the % left on field)

windthrow (DIST<n>_QUAL indicates the % left on field)

insects and pathogens

woody encroachment

DIST<n>_QUAL	Site disturbance code qualifier. Qualifier for DIST<n> disturbance code. This qualifier is disturbance code specific as explained in the list of codes for DIST<n>.
DIST<n>_DATE	Date of site disturbance (MM/DD/YYYY). If approximate, the date can be qualified by "approx" in the DIST<n>_DATE_QUAL field.
DIST<n>_DATE_QUAL	Date of site disturbance qualifier. Qualifier for DIST<n>_DATE. The qualifier is either "approx" or blank.
DIST<n>_COMMENT	Disturbance comments. Additional descriptive text about the site disturbance other than that contained in the DIST<n>_QUAL or DIST<n>_DATE_QUAL qualifiers.

15.4 Biological Data Spreadsheet

The biological data spreadsheet is used to submit periodically sampled biological variables. These variables may be annual averages, annually sampled, or sampled multiple times during the year. This spreadsheet is organized in four or more columns: variable name, description, units, and entered data. Each repeated sample is entered into the next consecutive column.

Variable Name	Units/ FORMAT	Description
ASA		Mean stand age. In years.
ASA_DATE	YYYY	Mean stand age measurement year. Year ASA was measured.
MSA		Maximum stand age. In years, calculated as the mean age of the oldest 10% of trees.
MSA_DATE	YYYY	Maximum stand age measurement year. Year MSA was measured.
SPP_O<n>		Overstory dominant species. Species codes must be the standardized codes in the Natural Resource Conservation Service (NRCS) PLANTS database January 2000 version (http://plants.usda.gov). Identification to species only is expected. However, if subspecies information is known, enter the appropriate NRCS code. If a plant cannot be identified confidently, assign a NRCS PLANTS genus or unknown code appropriate to the species. The SPP_O and SPP_O_PERC for each significant overstory species present in the reporting area are entered into consecutive columns.
SPP_O<n>_PERC	%	Overstory dominant species percent. Percent of overstory (tree stems) that SPP_O<n> represents. The reported SPP_O<n>_PERC values should sum to no more than 100% and at least 50%.
SPP_U<n>		Understory dominant species. Species codes must be the standardized codes in the Natural Resource Conservation Service (NRCS) PLANTS database January 2000 version (http://plants.usda.gov). Identification to species only is expected.

		However, if subspecies information is known, enter the appropriate NRCS code. If a plant cannot be identified confidently, assign a NRCS PLANTS genus or unknown code appropriate to the species. The SPP_U and SPP_U_PERC for each significant understory species present in the reporting area are entered into consecutive columns.
SPP_U<n>_PERC	%	Understory dominant species percent. Percent of understory that SPP_U<n> represents. The reported SPP_U<n>_PERC values should sum to no more than 100% and at least 50%.
SPP_DATE	DOY/ YYYY	Dominant species measurement date. Date SPP_O<n> and SPP_U<n> were measured.
SPP_COMMENT		Dominant species comments. Additional comments regarding the species composition entries including inventory method, N-fixers, etc.
LAI<n>	m^2/m^2	Leaf Area Index. Averaged over the tower footprint. Calculated as m^2 half-surface area leaf per m^2 ground. Report green leaf LAI and not total leaf LAI. If measured multiple times during a year, the LAI, LAI_DATE, LAI_CLUMP, LAI_TECHNIQUE, and LAI_COMMENT for each measurement are entered into consecutive columns.
LAI<n>_DATE	DOY/ YYYY	Leaf Area Index measurement date. Date LAI<n> was measured.
LAI<n>_CLUMP		Foliage element clumping index. Used to correct LAI-2000 optical data estimate of LAI<n>. Needle clumping within shoot for conifers. See Chen and Law protocols for LAI measurements and estimation, where clumping indices are provided for a few species (on AmeriFlux web site).
LAI<n>_TECHNIQUE		Leaf Area Index measurement technique. Sampling or measurement technique used for LAI<n>. The list of entries for the LAI measurement techniques is below. Direct LAI-2000 ACUPAR

		hemispherical photo litter fall Other
LAI<n>_COMMENT		Leaf Area Index comments. Descriptive text on LAI<n> measurement. May include number of samples, corrections applied (wood interception, foliage clumping [Y/N], clumping at scales larger than shoot [Y/N]) as well as comments on total LAI results, wood and reproductive part components, etc.
HEIGHTC	M	Mean canopy height. Mean canopy height, expressed in meters.
HEIGHTC_DATE	DOY/ YYYY	Mean canopy height measurement date. Date HEIGHTC was measured.
AG_BIOMASS_TF	gC/m^2 (ground)	Aboveground biomass of tree foliage. Annual value; dry weight of live foliage. Grassland, crops and tundra sites do not report this variable.
AG_BIOMASS_TW	gC/m^2 (ground)	Aboveground live biomass of tree wood. Annual value; dry weight of live stems and branches. Grassland, crops and tundra sites do not report this variable.
AG_BIOMASS_TT	gC/m^2 (ground)	Aboveground live biomass trees total. Annual value; dry weight live foliage, stems, and branches. Grassland, crops and tundra sites do not report this variable. Sites are encouraged to report both AG_BIOMASS_TF and AG_BIOMASS_TW; in this case, AG_BIOMASS_TT will be computed by the CDIAC. If AG_BIOMASS_TF and AG_BIOMASS_TW cannot be separated, the site should report the combined AG_BIOMASS_TT value.
AG_BIOMASS_SF	gC/m^2 (ground)	Aboveground biomass of shrub foliage. Annual value; dry weight of live foliage.
AG_BIOMASS_SW	gC/m^2 (ground)	Aboveground biomass of shrub wood. Annual value; dry weight of stems and branches.
AG_BIOMASS_ST	gC/m^2 (ground)	Aboveground biomass of shrubs total. Annual value; dry weight of foliage, stems, and branches. Sites are encouraged to report both AG_BIOMASS_SF and AG_BIOMASS_SW; in this case, AG_BIOMASS_ST will be

		computed by the CDIAC. If AG_BIOMASS_SF and AG_BIOMASS_SW cannot be separated, the site should report the combined AG_BIOMASS_ST value.
AG_BIOMASS_NWT	gC/m^2 (ground)	Aboveground biomass of non-woody plants. Annual value; dry weight of plants including plants and forbs. Grassland sites report the total above ground biomass. Forest sites report any non-woody plants.
AG_BIOMASS_CF<n>	gC/m^2 (ground)	Aboveground biomass of crops foliage. Annual value; dry weight of foliage. If measured multiple times during a year, the AG_BIOMASS CF, AG_BIOMASS_CH, and AG_BIOMASS_DATE for each measurement are entered into consecutive columns.
AG_BIOMASS_CH<n>	gC/m^2 (ground)	Aboveground biomass of crops harvest. Annual value; dry weight of harvest materials such as fruit. If measured multiple times during a year, the AG_BIOMASS CF, AG_BIOMASS_CH, and AG_BIOMASS_DATE for each measurement are entered into consecutive columns.
AG_BIOMASS_CT<n>	gC/m^2 (ground)	Aboveground biomass of crops total. Annual value; includes live foliage and harvest materials. Sites are encouraged to report both AG_BIOMASS_CF and AG_BIOMASS_CH; in this case, AG_BIOMASS_CT will be computed by the CDIAC. If AG_BIOMASS_CF and AG_BIOMASS_CH cannot be separated, the site should report the combined AG_BIOMASS_CT value. If measured multiple times during a year, the AG_BIOMASS CT and AG_BIOMASS_DATE for each measurement are entered into consecutive columns.
AG_BIOMASS<n>_DATE	DOY/ YYYY	Aboveground biomass measurement date. Date above ground live biomass (AG_BIOMASS_*) was measured.
LIT_MASS<n>	gC/m^2 (ground)	Litter mass. Dry weight including litter and twigs < 1 cm diameter. If measured multiple times during a year, the LIT_MASS, LIT_MASS_DATE and LIT_MASS_COMMENT for each measurement are entered into consecutive columns.

LIT_MASS<n>_DATE	DOY/YYYY	Litter mass measurement date. Date LIT_MASS<n> was measured.
LIT_MASS<n>_COMMENT		Litter mass comments. Descriptive text on litter mass measurement.
CROP_RESID	gC/m^2 (ground)	Crop residue. Annual value; dead mass dry weight.
CROP_RESID_DATE	DOY/ YYYY	Crop residue measurement date. Date CROP_RESID was measured.
CWD	gC/m^2 (ground)	Coarse woody debris. Includes debris with diameter > 10 cm.
CWD_DATE	DOY/ YYYY	Coarse woody debris measurement date. Date CWD was measured.
FWD	gC/m^2 (ground)	Fine woody debris. Includes debris with diameter 1 cm – 10 cm.
FWC_DATE	DOY/ YYYY	Fine woody debris measurement date. Date FWD was measured.
ST_MASS	gC/m^2 (ground)	Stump mass. Dry weight; estimated from mean stump diameter and species-specific allometric equations.
SNAG	gC/m^2 (ground)	Mass of standing dead trees. Annual value; dry weight.
SNAG_DATE	DOY/ YYYY	Mass of standing dead trees measurement date. Date SNAG was measured.
CR_BIOMASS	gC/m^2 (ground)	Coarse root biomass (live). Annual value; calculated from allometric equations.
CR_BIOMASS_DEPTH	M	Coarse root biomass (live) measurement depth. Depth to which coarse root biomass was sampled.
FR_BIOMASS	gC/m^2 (ground)	Fine root biomass (live). Annual value. Sampled at 0-0.1m, 0.1-0.2m, 0.2-0.5m, 0.5-1.0 meter depth and aggregated.
FR_BIOMASS_DEPTH	m	Fine root biomass (live) measurement depth. Depth to which fine root biomass was sampled.
RT_BIOMASS	gC/m^2 (ground)	Total root biomass. Annual value; includes coarse and fine root mass. Sites are encouraged to report both CR_BIOMASS and FR_BIOMASS; in this case, RT_BIOMASS will be computed by the CDIAC. If CR_BIOMASS and FR_BIOMASS cannot be separated, the site should report the combined RT_BIOMASS value.
RT_BIOMASS_DEPTH	m	Total root biomass measurement depth.

		Depth to which total (course and fine) root biomass was sampled.
R_BIOMASS_DATE	DOY/ YYYY	Biomass measurement date. Date below ground biomass (CR_BIOMASS and FR_BIOMASS, or RT_BIOMASS) was measured.
WOOD_INCR<n>	mm	Wood radial increment. Provide multiple years (past 20-30 yrs), not an average of years. The WOOD_INCR and WOOD_INCR_DATE for each reported annual wood increment are entered into consecutive columns.
WOOD_INCR<n>_YEAR	YYYY	Wood radial increment measurement date. Year of WOOD_INCR<n>.
AG_PROD_TF	gC/m^2 (ground)/y	Aboveground production of tree foliage. Annual value; includes overstory foliage only. Grassland, crops, and tundra sites do not report this variable.
AG_PROD_TW	gC/m^2 (ground)/y	Aboveground production of tree wood. Annual value; includes overstory stems and branches. Grassland, crops, and tundra sites do not report this variable.
AG_PROD_TT	gC/m^2 (ground)/y	Aboveground production of tree total. Annual value; includes overstory foliage, stems, and branches. Grassland, crops, and tundra sites do not report this variable. Sites are encouraged to report both AG_PROD_TF and AG_PROD_TW; in this case, AG_PROD_TT will be computed by the CDIAC. If AG_PROD_TF and AG_PROD_TW cannot be separated, the site should report the combined AG_PROD_TT value.
AG_PROD_SF	gC/m^2 (ground)/y	Aboveground production of shrub foliage. Annual value; includes foliage only.
AG_PROD_SW	gC/m^2 (ground)/y	Annual aboveground production of shrub wood. Annual value; includes stems and branches.
AG_PROD_ST	gC/m^2 (ground)/y	Aboveground production of shrub total. Annual value; includes shrub foliage, stems, and branches. Sites are encouraged to report both AG_PROD_SF and AG_PROD_SW; in this case, AG_PROD_ST will be computed by the CDIAC. If AG_PROD_SF and AG_PROD_SW cannot be separated, the site should report the combined AG_PROD_ST value.

AG_PROD_NWT	gC/m^2 (ground)/y	Aboveground production of non-woody plants. Annual value; dry weight of plants including plants and forbs. Grassland sites report the total above ground biomass. Forest sites report any non-woody plants.
AG_PROD_CF	gC/m^2 (ground)/y	Aboveground production of crops foliage. Annual value; includes live foliage only.
AG_PROD_CH	gC/m^2 (ground)/y	Aboveground production of crops harvest. Annual value; includes agricultural crops harvest materials such as fruit.
AG_PROD_CT	gC/m^2 (ground)/y	Annual aboveground production of crops total. Annual value; includes foliage and harvest materials. Sites are encouraged to report both AG_PROD_CF and AG_PROD_CH; in this case, AG_PROD_CT will be computed by the CDIAC. If AG_PROD_CF and AG_PROD_CH cannot be separated, the site should report the combined AG_PROD_CT value.
AG_PROD_DATE	DOY/ YYYY	Aboveground production measurement date. Date above ground production (AG_PROD_*) was measured.
CR_PROD	gC/m^2 (ground)/y	Coarse root production. Annual value; includes coarse root production only.
FR_PROD	gC/m^2 (ground)/y	Fine root production. Annual value; includes fine root production only.
FR_PROD_DEPTH	M	Fine root production measurement depth. Depth to which fine root production was sampled.
RT_PROD	gC/m^2 (ground)/y	Total root production. Annual value; includes coarse and fine root mass. Sites are encouraged to report both CR_PROD and FR_PROD; in this case, RT_PROD will be computed by the CDIAC. If CR_PROD and FR_PROD cannot be separated, the site should report the combined RT_PROD value.
RT_PROD_DEPTH	M	Total root production measurement depth. Depth to which total (course and fine) root production was sampled.
R_PROD_DATE	DOY/ YYYY	Root production measurement date. Date below ground production (CR_PROD and FR_PROD, or RT_PROD) was measured.
NEP	gC/m^2 (ground)/y	Net ecosystem production. Computed from biological measurements.
NEP_YEAR	YYYY	Net ecosystem year. If NEP is a mean

		over e.g. five years (1995-2000), 1998 is the central year so NEP_YEAR=1998.
NEP_DUR		Net ecosystem duration. Number of years NEP represents.
LIT_PROD	gC/m^2 (ground)/y	Litterfall. Annual value. Sampled periodically through the year, dried and weighed and summed over year. Leaf litter and twigs < 1cm diameter.
LMA<n>	gC/m^2 (leaf)	Leaf mass per unit leaf area. For each significant species (SPP_O or SPP_U) present in the reporting area, the LMA, LMA_DATE, and LMA_SPP are entered into consecutive columns. In forests, LMA should represent the canopy mean for a given species.
LMA<n>_DATE	DOY/ YYYY	Leaf mass per unit leaf area measurement date. Date LMA<n> was measured.
LMA_SPP<n>		Leaf mass per unit leaf area species. Species with LMA<n>. LMA_SPP<n> uses the same NRCS species codes as SPP_O<n> and SPP_U<n>.
FOL_N<n>	gN/100g foliar mass	Foliage nitrogen concentration. For each significant species (SPP_O or SPP_U) present in the reporting area, the FOL_N, FOL_N_DATE, and FOL_N_SPP are entered into consecutive columns. In forests, FOL_N should represent the canopy mean for a given species.
FOL_N<n>_DATE	DOY/ YYYY	Foliage nitrogen concentration measurement date. Date samples for FOL_N<n> concentration determination were collected.
FOL_N_SPP<n>		Foliage nitrogen concentration species. Species with FOL_N<n>. FOL_N_SPP<n> uses the same NRCS species codes as SPP_O<n> and SPP_U<n>.
FOL_C<n>	gC/100g foliar mass	Foliage carbon concentration. For each significant species (SPP_O or SPP_U) present in the reporting area, the FOL_C, FOL_C_DATE, and FOL_C_SPP are entered into consecutive columns. In forests, FOL_C should represent the canopy mean for a given species.
FOL_C<n>_DATE	DOY/ YYYY	Foliage carbon concentration measurement date. Date samples for FOL_C<n> concentration determination were collected.

FOL_C_SPP<n>		Foliage carbon concentration species. Species with FOL_C<n>. FOL_C_SPP<n> uses the same NRCS species codes as SPP_O<n> and SPP_U<n>.
WOOD_N<n>	gN/100g dry weight	Woody tissue nitrogen concentration. For each significant species (SPP_O or SPP_U) present in the reporting area, the WOOD_N, WOOD_N_DATE, and WOOD_N_SPP are entered into consecutive columns. In forests, WOOD_N should represent the canopy mean for a given species.
WOOD_N<n>_DATE	DOY/ YYYY	Woody tissue nitrogen concentration measurement date. Date samples for WOOD_N<n> concentration determination were collected.
WOOD_N_SPP<n>		Woody tissue nitrogen concentration species. Species with WOOD_N<n>. WOOD_N_SPP<n> uses the same NRCS species codes as SPP_O<n> and SPP_U<n>.
WOOD_C<n>	gC/100g dry weight	Woody tissue carbon concentration. For each significant species (SPP_O or SPP_U) present in the reporting area, the WOOD_C, WOOD_C_DATE, and WOOD_C_SPP are entered into consecutive columns. In forests, WOOD_C should represent the canopy mean for a given species.
WOOD_C<n>_DATE	DOY/ YYYY	Woody tissue carbon concentration measurement date. Date samples for WOOD_N<n> concentration determination were collected.
WOOD_C_SPP<n>		Foliage carbon concentration species. Species with WOOD_C<n>. WOOD_C_SPP<n> uses the same NRCS species codes as SPP_O<n> and SPP_U<n>.
LIT_N	gN/100g litter	Litter nitrogen concentration.
LIT_N_DATE	DOY/ YYYY	Litter nitrogen concentration measurement date. Date samples for LIT_N concentration determination were collected.
LIT _C	gC/100g litter	Litter carbon concentration.
LIT_C_DATE	DOY/ YYYY	Litter carbon concentration measurement

		date. Date samples for LIT_C concentration determination were collected.
ROOT_N<n>	gN/100g	Root nitrogen concentration. If measured multiple times during a year, the ROOT_N and ROOT_N_DATE for each measurement are entered into consecutive columns.
ROOT_N<n>_DATE	DOY/ YYYY	Root nitrogen concentration measurement date. Date samples for ROOT_N<n> concentration determination were collected.
ROOT_C<n>	gC/100g	Root carbon concentration. If measured multiple times during a year, the ROOT_C and ROOT_C_DATE for each measurement are entered into consecutive columns.
ROOT_C<n>_DATE	DOY/ YYYY	Root carbon concentration measurement date. Date samples for ROOT_C<n> concentration determination were collected.
SOIL_BD	g/cm^3	Soil bulk density. Measured at 0-0.1m, 0.1-0.2m, 0.2-0.5m, 0.5-1.0m.
SOIL_BD_PROFILE_MIN	M	Soil bulk density profile minimum depth. Minimum depth of the SOIL_BD profile. For 0-0.1m, enter 0, for 0.1-0.2m, enter 0.1, for 0.2-0.5m, enter 0.2, for 0.5-1.0m, enter 0.5.
SOIL_BD_PROFILE_MAX	M	Soil bulk density profile maximum depth. Maximum depth of the SOIL_BD profile. For 0-0.1m, enter 0, for 0.1-0.2m, enter 0.1, for 0.2-0.5m, enter 0.2, for 0.5-1.0m, enter 0.5.
SOIL_BD_DATE	DOY/ YYYY	Soil bulk density measurement date. Date SOIL_BD was measured.
SOIL_C	kg/m^2	Soil carbon content. Preferably measured at 0-0.1m, 0.1-0.2m, 0.2-0.5m, 0.5-1.0m.
SOIL_C_PROFILE_MIN	M	Soil carbon content profile minimum depth. Minimum depth of the SOIL_C profile. For 0-0.1m, enter 0, for 0.1-0.2m, enter 0.1, for 0.2-0.5m, enter 0.2, for 0.5-1.0m, enter 0.5.
SOIL_C_PROFILE_MAX	M	Soil carbon content profile maximum depth. Maximum depth of the SOIL_C profile. For 0-0.1m, enter 0, for 0.1-0.2m, enter 0.1, for 0.2-0.5m, enter 0.2, for

		0.5-1.0m, enter 0.5.
SOIL_C_DATE	DOY/ YYYY	Soil carbon content measurement date. Date SOIL_C was measured.
SOIL_N	kg/m^2	Soil nitrogen content. Preferably measured at 0-0.1m, 0.1-0.2m, 0.2-0.5m, 0.5-1.0m.
SOIL_N_PROFILE_MIN	M	Soil nitrogen content profile minimum depth. Minimum depth of the SOIL_N profile. For 0-0.1m, enter 0, for 0.1-0.2m, enter 0.1, for 0.2-0.5m, enter 0.2, for 0.5-1.0m, enter 0.5.
SOIL_N_PROFILE_MAX	M	Soil nitrogen content profile maximum depth. Maximum depth of the SOIL_N profile. For 0-0.1m, enter 0, for 0.1-0.2m, enter 0.1, for 0.2-0.5m, enter 0.2, for 0.5-1.0m, enter 0.5.
SOIL_N_DATE	DOY/ YYYY	Soil nitrogen content measurement date. Date SOIL_N was measured.
SOIL_PH	kg/m^2	Soil PH. Total soil PH as CaCl2. Preferably measured at 0-0.1m, 0.1-0.2m, 0.2-0.5m, 0.5-1.0m.
SOIL_PH_PROFILE_MIN	M	Soil PH profile minimum depth. Minimum depth of the SOIL_BD profile. For 0-0.1m, enter 0, for 0.1-0.2m, enter 0.1, for 0.2-0.5m, enter 0.2, for 0.5-1.0m, enter 0.5.
SOIL_PH_PROFILE_MAX	M	Soil PH profile maximum depth. Minimum depth of the SOIL_BD profile. For 0-0.1m, enter 0, for 0.1-0.2m, enter 0.1, for 0.2-0.5m, enter 0.2, for 0.5-1.0m, enter 0.5.
SOIL_PH_DATE	DOY/ YYYY	Soil PH measurement date. Date SOIL_PH was measured.
SAND_PERC	%	Sand content. Percent by mass.
SILT_PERC	%	Silt content. Percent by mass.
CLAY_PERC	%	Clay content. Percent by mass.
SOIL_DEPTH	M	Soil depth. Depth to bedrock; limit to root penetration.
SOIL_WATER_CAP	mm	Soil water holding capacity.
SOIL_WATER_CAP_DEPTH	M	Soil water holding capacity measurement depth. Depth at which SOIL_WATER_CAP was measured.
SWC<n>	m^3/m^3	Soil water content. Manual measurement based on time-domain measurement methods sensitive to dielectric

		permittivity. The profile should have several entries. For each measurement depth, the SWC and SWC_DEPTH are entered into consecutive columns.
SWC<n>_DEPTH	Cm	Soil water content measurement depth. Depth at which SWC<n> was measured.
SWC<n>_DATE	DOY/ YYYY	Soil water content measurement date. Date soil water content profile (SWC<n>) was measured.
Rs<n>_MEAN	umol/m^2 (ground)/s	Site-specific mean soil CO_2 efflux. Plot/site level means should be reported hourly. The Rs_MEAN, Rs_HOUR, Rs_DATE, and Ts of each successive measurement are entered into consecutive columns.
Rs<n>_HOUR	HHHH	Site-specific mean soil CO_2 efflux measurement hour. Hour site-specific mean soil CO_2 and soil temperature (Rs<n>_MEAN, Ts<n>) were measured. Similar to the convention for flux-met data reporting, the first measurement of the day occurs at 0000; the last at 2330.
Rs_DATE	DOY/ YYYY	Site-specific mean soil CO_2 efflux measurement date. Date site-specific mean soil CO_2 and soil temperature (Rs<n>_MEAN, Ts<n>) were measured.
Ts<n>	deg C	Soil temperature. Site-specific mean soil T as measured next to the soil respiration collars preferably at 8 cm depth.
BUDBK<n>_DATE	DOY/ YYYY	Budbreak date. Date budbreak or first opening of leaves was observed. For each significant species (SPP_O or SPP_U) present in the reporting area, the BUDBK_DATE and BUDBK_SPP are entered into consecutive columns. For crops or grasses, use COT_DATE rather than BUDBK_DATE.
BUDBK_SPP<n>		Budbreak species. Species with BUDBRK<n>. BUDBRK_SPP<n> uses the same NRCS species codes as SPP_O<n> and SPP_U<n>.
COT<n>_DATE	DOY/ YYYY	Cotyledons date. Date first cotyledons present. For each significant species (SPP_O or SPP_U) present in the reporting area, the COT_DATE and COT_SPP are entered into consecutive columns.
COT_SPP<n>		Cotyledons species. Species with

		COT<n>. COT_SPP<n> uses the same NRCS species codes as SPP_O<n> and SPP_U<n>.
FLOWER<n>_DATE	DOY/ YYYY	Flowering date. Date on which the first flowers have opened completely in at least three places on individual plants. For each significant species (SPP_O or SPP_U) present in the reporting area, the FLOWER_DATE and FLOWER_SPP are entered into consecutive columns.
FLOWER_SPP<n>		Flowering species. Species with FLOWER<n>. FLOWER_SPP<n> uses the same NRCS species codes as SPP_O<n> and SPP_U<n>.
LEAFFULL<n>_DATE	DOY/ YYYY	Maximum leaf expansion date. Date of maximum leaf expansion. For each significant species (SPP_O or SPP_U) present in the reporting area, the LEAFFULL_DATE and LEAFFULL_SPP are entered into consecutive columns.
LEAFFULL_SPP<n>		Maximum leaf expansion species. Species with LEAFFULL<n>. LEAFFULL_SPP<n> uses the same NRCS species codes as SPP_O<n> and SPP_U<n>.
LEAFSEN<n>_DATE	DOY/ YYYY	Date of leaf senescence (when approximately 50% of the leaves of individual plants observed, including leaves that have fallen to the ground, have taken on the colors of autumn). For each significant species (SPP_O or SPP_U) present in the reporting area, the LEAFSEN_DATE and LEAFSEN_SPP are entered into consecutive columns.
LEAFSEN_SPP<n>		Leaf senescence species. Species with LEAFSEN<n>. LEAFSEN_SPP<n> uses the same NRCS species codes as SPP_O<n> and SPP_U<n>.
LEAFOFF<n>_DATE	DOY/ YYYY	Date of total leaf-off (in conifers and some deciduous trees, most brown needles/leaves have fallen). For each significant species (SPP_O or SPP_U) present in the reporting area, the LEAFOFF_DATE and LEAFOFF_SPP are entered into consecutive columns.
LEAFOFF_SPP<n>		Total leaf-off species. Species with LEAFOFF<n>. LEAFOFF_SPP<n> uses the same NRCS species codes as SPP_O<n> and SPP_U<n>.

15.5 Site Metadata Biological Data Spreadsheet

The site metadata biological data spreadsheet contains rarely changing descriptive text documenting the biological variable measurement practices and annotations. This spreadsheet is organized in three columns: variable name, description, and entered text.

Variable Name	Description
SPP_O_METHOD	Overstory dominant species measurement methodology. Descriptive text documenting SPP_O<n> measurement methodology. Reported whenever the methodology changes.
SPP_U_METHOD	Understory dominant species measurement methodology. Descriptive text documenting SPP_U<n> measurement methodology. Reported whenever the methodology changes.
AG_BIOMASS_TF_METHOD	Aboveground biomass of tree foliage measurement method. Descriptive text including algorithm and other attributes such as number and area of plots used to obtain AG_BIOMASS_TF.
AG_BIOMASS_TW_METHOD	Aboveground biomass of tree wood measurement method. Descriptive text including algorithm and other attributes such as number and area of plots used to obtain AG_BIOMASS_TT.
AG_BIOMASS_TT_METHOD	Aboveground biomass of tree total measurement method. Descriptive text including algorithm and other attributes such as number and area of plots used to obtain AG_BIOMASS_TF.
AG_BIOMASS_SF_METHOD	Aboveground biomass of shrub foliage measurement method. Descriptive text including algorithm and other attributes such as number and area of plots used to obtain AG_BIOMASS_SF.
AG_BIOMASS_SW_METHOD	Aboveground biomass of shrub wood measurement method. Descriptive text including algorithm and other attributes such as number and area of plots used to obtain AG_BIOMASS_SW.
AG_BIOMASS_ST_METHOD	Aboveground biomass of shrub total measurement method. Descriptive text including algorithm and other attributes such as number and area of plots used to obtain AG_BIOMASS_ST.
AG_BIOMASS_NWT_METHOD	Aboveground biomass of non-woody plants measurement method. Descriptive text including algorithm and other attributes such as number and area of plots used to obtain AG_BIOMASS_NWT.

AG_BIOMASS_CF_METHOD	Aboveground biomass of crops foliage measurement method. Descriptive text including algorithm and other attributes such as number and area of plots used to obtain AG_BIOMASS_CF.
AG_BIOMASS_CH_METHOD	Aboveground biomass of crops harvest measurement method. Descriptive text including algorithm and other attributes such as number and area of plots used to obtain AG_BIOMASS_CH.
AG_BIOMASS_CT_METHOD	Aboveground biomass of crops total measurement method. Descriptive text including algorithm and other attributes such as number and area of plots used to obtain AG_BIOMASS_CT.
CR_BIOMASS_METHOD	Belowground coarse root biomass measurement method. Descriptive text including coring or allometric method; if allometric, include algorithm and other attributes such as number and area of plots used to obtain CR_BIOMASS.
FR_BIOMASS_METHOD	Belowground fine root biomass measurement method. Descriptive text including coring or allometric method; if allometric, include algorithm and other attributes such as number and area of plots used to obtain FR_BIOMASS.
RT_BIOMASS_METHOD	Belowground total root biomass measurement method. Descriptive text including coring or allometric method; if allometric, include algorithm and other attributes such as number and area of plots used to obtain RG_BIOMASS.
AG_PROD_TF_METHOD	Aboveground production of tree foliage measurement method. Descriptive text including algorithm and other attributes such as number and area of plots used to obtain AG_PROD_TF.
AG_PROD_TW_METHOD	Aboveground production of tree wood measurement method. Descriptive text including algorithm and other attributes such as number and area of plots used to obtain AG_PROD_TW.
AG_PROD_TT_METHOD	Aboveground production of tree total measurement method. Descriptive text including algorithm and other attributes such as number and area of plots used to obtain AG_PROD_TT.
AG_PROD_SF_METHOD	Aboveground production of shrub foliage measurement method. Descriptive text including algorithm and other attributes such as number and area of plots used to obtain AG_PROD_SF.
AG_PROD_SW_METHOD	Aboveground production of shrub wood measurement method. Descriptive text including algorithm and other attributes such as number and area of plots used to obtain AG_PROD_SW.

AG_PROD_ST_METHOD	Aboveground production of shrub total measurement method. Descriptive text including algorithm and other attributes such as number and area of plots used to obtain AG_PROD_ST.
AG_PROD_NWT_METHOD	Aboveground production of non-woody vegetation (total) measurement method. Descriptive text including algorithm and other attributes such as number and area of plots used to obtain AG_PROD_NWT.
AG_PROD_CF_METHOD	Aboveground production of crops foliage measurement method. Descriptive text including algorithm and other attributes such as number and area of plots used to obtain AG_PROD_CF.
AG_PROD_CH_METHOD	Aboveground production of crops harvest measurement method. Descriptive text including algorithm and other attributes such as number and area of plots used to obtain AG_PROD_CH.
AG_PROD_CT_METHOD	Aboveground production of crops total measurement method. Descriptive text including algorithm and other attributes such as number and area of plots used to obtain AG_PROD_CT.
CR_PROD_METHOD	Coarse root production measurement method. Descriptive text including algorithm and other attributes such as number and area of plots used to obtain CR_PROD.
FR_PROD_METHOD	Fine root production measurement method. Descriptive text including algorithm and other attributes such as number and area of plots used to obtain FR_PROD.
RT_PROD_METHOD	Total root production measurement method. Descriptive text including technique (e.g., minirhizotron, periodic sampling) and algorithm, and other attributes such as number and area of plots used to obtain RT_PROD.
NEP_METHOD	Net ecosystem production method. Specific text indicating the net ecosystem production method. NPPRh (for NPP minus Rh, where Rh is determined from xx fraction of annual soil respiration plus decomposition of CWD and FWD) dCdt (for change in biomass and soil carbon over xx years)
Rs_METHOD	Soil CO_2 efflux measurement method. Descriptive text including the methods, instruments (e.g., LI8100) and number of sample locations used to obtain RS_MEAN.
SAPFLOW_METHOD	Sapflow measurement method. Descriptive text indicating the sap flow method (e.g., Granier, heat pulse), instruments (e.g., Dynamax, homemade), probe length (e.g., 1, 2, 3, or 10 cm length), probe installation (stem diameter at point of probe installation in cm and

sapwood thickness in cm) and corrections applied (e.g., according to Clearwater et al. 1999). Identify the tree and shrub species sampled and provide the number of trees or shrubs measured and used to produce the mean for the site.

16. Appendix: List of Biological Variables by Type

This appendix lists the biological variable by type such as Plot Condition or Productivity. The contents can be used to determine the appropriate spreadsheet for reporting the variable.

Chemistry of Soil, Forest Floor, and Live Foliage

Variable Name	Description	Reporting Type
CLAY_PERC	Clay content	Biological Data
FOL_C_SPP<n>	Foliage carbon concentration species	Biological Data
FOL_C<n>	Foliage carbon concentration	Biological Data
FOL_C<n>_DATE	Foliage carbon concentration measurement date	Biological Data
FOL_N_SPP<n>	Foliage nitrogen concentration species	Biological Data
FOL_N<n>	Foliage nitrogen concentration	Biological Data
FOL_N<n>_DATE	Foliage nitrogen concentration measurement date	Biological Data
LIT _C	Litter carbon concentration	Biological Data
LIT_C_DATE	Litter carbon concentration measurement date	Biological Data
LIT_N	Litter nitrogen concentration	Biological Data
LIT_N_DATE	Litter nitrogen concentration measurement date	Biological Data
LMA_SPP<n>	Leaf mass per unit leaf area species	Biological Data
LMA<n>	Leaf mass per unit leaf area	Biological Data
LMA<n>_DATE	Leaf mass per unit leaf area measurement date	Biological Data
ROOT_C<n>	Root carbon concentration	Biological Data
ROOT_C<n>_DATE	Root carbon concentration measurement date	Biological Data
ROOT_N<n>	Root nitrogen concentration	Biological Data
ROOT_N<n>_DATE	Root nitrogen concentration measurement date	Biological Data

SAND_PERC	Sand content	Biological Data
SILT_PERC	Silt content	Biological Data
SOIL_BD	Soil bulk density	Biological Data
SOIL_BD_DATE	Soil bulk density measurement date	Biological Data
SOIL_BD_PROFILE_MAX	Soil bulk density profile maximum depth	Biological Data
SOIL_BD_PROFILE_MIN	Soil bulk density profile minimum depth	Biological Data
SOIL_C	Soil carbon content	Biological Data
SOIL_C_DATE	Soil carbon content measurement date	Biological Data
SOIL_C_PROFILE_MAX	Soil carbon content profile maximum depth	Biological Data
SOIL_C_PROFILE_MIN	Soil carbon content profile minimum depth	Biological Data
SOIL_DEPTH	Soil depth	Biological Data
SOIL_N	Soil nitrogen content	Biological Data
SOIL_N_DATE	Soil nitrogen content measurement date	Biological Data
SOIL_N_PROFILE_MAX	Soil nitrogen content profile maximum depth	Biological Data
SOIL_N_PROFILE_MIN	Soil nitrogen content profile minimum depth	Biological Data
SOIL_PH	Soil PH	Biological Data
SOIL_PH_DATE	Soil PH measurement date	Biological Data
SOIL_PH_PROFILE_MAX	Soil PH profile maximum depth.	Biological Data
SOIL_PH_PROFILE_MIN	Soil PH profile minimum depth.	Biological Data
SOIL_WATER_CAP	Soil water holding capacity	Biological Data
SOIL_WATER_CAP_DEPTH	Soil water holding capacity measurement depth	Biological Data
WOOD_C_SPP<n>	Foliage carbon concentration species	Biological Data
WOOD_C<n>	Woody tissue carbon concentration	Biological Data
WOOD_C<n>_DATE	Woody tissue carbon concentration measurement date	Biological Data
WOOD_N_SPP<n>	Woody tissue nitrogen concentration species	Biological Data

WOOD_N<n>	Woody tissue nitrogen concentration	Biological Data
WOOD_N<n>_DATE	Woody tissue nitrogen concentration measurement date	Biological Data

Phenology

Variable Name	**Description**	**Reporting Type**
BUDBK_SPP<n>	Budbreak species	Biological Data
BUDBK<n>_DATE	Budbreak date	Biological Data
COT<n>_DATE	Cotyledons date	Biological Data
COT_SPP<n>	Cotyledons species	Biological Data
FLOWER<n>_DATE	Flowering date	Biological Data
FLOWER_SPP<n>	Flowering species	Biological Data
LEAFFULL<n>_DATE	Maximum leaf expansion date	Biological Data
LEAFFULL_SPP<n>	Maximum leaf expansion species	Biological Data
LEAFSEN<n>_DATE	Date of leaf senescence	Biological Data
LEAFSEN_SPP<n>	Leaf senescence species	Biological Data
LEAFOFF<n>_DATE	Total leaf-off date	Biological Data
LEAFOFF_SPP<n>	Total leaf-off species	Biological Data

Plot Condition

Variable Name	**Description**	**Reporting Type**
ASA	Mean stand age	Biological Data
ASA_DATE	Mean stand age measurement year	Biological Data
DIST<n>	Site disturbance history code	Site Disturbance Data
DIST<n>_COMMENT	Disturbance comments	Site Disturbance Data
DIST<n>_DATE	Date of site disturbance	Site Disturbance Data
DIST<n>_DATE_QUAL	Date of site disturbance qualifier	Site Disturbance Data
DIST<n>_QUAL	Site disturbance code qualifier	Site Disturbance Data
LAND_OWN	Land ownership type	Site Biological Ancillary Data
LAND_OWNER	Land owner	Site Biological Ancillary Data

MSA	Maximum stand age	Biological Data
MSA_DATE	Maximum stand age measurement year	Biological Data
SITE_DESC	Site description	Site Biological Ancillary Data

Productivity

Variable Name	**Description**	**Reporting Type**
AG_PROD_CF	Aboveground production of crops foliage	Biological Data
AG_PROD_CF_METHOD	Aboveground production of crops foliage measurement method	Site Metadata Biological Data
AG_PROD_CH	Aboveground production of crops harvest	Biological Data
AG_PROD_CH_METHOD	Aboveground production of crops harvest measurement method	Site Metadata Biological Data
AG_PROD_CT	Annual aboveground production of crops total	Biological Data
AG_PROD_CT_METHOD	Aboveground production of crops total measurement method	Site Metadata Biological Data
AG_PROD_DATE	Aboveground production measurement date	Biological Data
AG_PROD_NWT_METHOD	Aboveground production of non-woody(total) measurement method	Site Metadata Biological Data
AG_PROD_NWT	Aboveground production of non-woody plants	Biological Data
AG_PROD_SF	Aboveground production of shrub foliage	Biological Data
AG_PROD_SF_METHOD	Aboveground production of shrub foliage measurement method	Site Metadata Biological Data
AG_PROD_ST	Aboveground production of shrub total	Biological Data
AG_PROD_ST_METHOD	Aboveground production of shrub total measurement method	Site Metadata Biological Data
AG_PROD_SW	Annual aboveground production of shrub wood	Biological Data
AG_PROD_SW_METHOD	Aboveground production of shrub wood measurement method	Site Metadata Biological Data
AG_PROD_TF	Aboveground production of tree foliage	Biological Data
AG_PROD_TF_METHOD	Aboveground production of tree	Site Metadata

	foliage measurement method	Biological Data
AG_PROD_TT	Aboveground production of tree total	Biological Data
AG_PROD_TT_METHOD	Aboveground production of tree total measurement method	Site Metadata Biological Data
AG_PROD_TW	Aboveground production of tree wood	Biological Data
AG_PROD_TW_METHOD	Aboveground production of tree wood measurement method	Site Metadata Biological Data
CR_PROD	Coarse root production	Biological Data
CR_PROD_METHOD	Coarse root production measurement method	Site Metadata Biological Data
FR_PROD	Fine root production	Biological Data
FR_PROD_DEPTH	Fine root production measurement depth	Biological Data
FR_PROD_METHOD	Fine root production measurement method	Site Metadata Biological Data
LIT_PROD	Litterfall	Biological Data
NEP	Net ecosystem production	Biological Data
NEP_DUR	Net ecosystem duration	Biological Data
NEP_METHOD	Net ecosystem production method	Site Metadata Biological Data
NEP_YEAR	Net ecosystem year	Biological Data
R_PROD_DATE	Root production measurement date	Biological Data
RT_PROD	Total root production	Biological Data
RT_PROD_DEPTH	Total root production measurement depth	Biological Data
RT_PROD_METHOD	Total root production measurement method	Site Metadata Biological Data
WOOD_INCR<n>	Wood radial increment	Biological Data
WOOD_INCR<n>_YEAR	Wood radial increment measurement date	Biological Data

Soil Respiration

Variable Name	**Description**	**Reporting Type**
Rs		RawFiles
Rs_DATE	Site-specific mean soil CO_2 efflux measurement date	Biological Data
Rs_METHOD	Soil CO_2 efflux measurement	Site Metadata

	method	Biological Data
Rs<n>_HOUR	Site-specific mean soil CO_2 efflux measurement hour	Biological Data
Rs<n>_MEAN	Site-specific mean soil CO_2 efflux	Biological Data
SWC<n>	Soil water content	Biological Data
SWC<n>_DATE	Soil water content measurement date	Biological Data
SWC<n>_DEPTH	Soil water content measurement depth	Biological Data
Ts<n>	Soil temperature	Biological Data

Tree Physiology

Variable Name	**Description**	**Reporting Type**
ACi		RawFiles
PSN_LT		RawFiles
SAPFLOW	Sapflow	Flux-Met
SAPFLOW_METHOD	Sapflow measurement method	Site Metadata Biological Data

Vegetation Condition

Variable Name	**Description**	**Reporting Type**
AG_BIOMASS_CF_METHOD	Aboveground biomass of crops foliage measurement method	Site Metadata Biological Data
AG_BIOMASS_CF<n>	Aboveground biomass of crops foliage	Biological Data
AG_BIOMASS_CH_METHOD	Aboveground biomass of crops harvest measurement method	Site Metadata Biological Data
AG_BIOMASS_CH<n>	Aboveground biomass of crops harvest	Biological Data
AG_BIOMASS_CT_METHOD	Aboveground biomass of crops total measurement method	Site Metadata Biological Data
AG_BIOMASS_CT<n>	Aboveground biomass of crops total	Biological Data
AG_BIOMASS_NWT	Aboveground biomass of non-woody plants	Biological Data
AG_BIOMASS_NWT_METHOD	Aboveground biomass of non-woody plants measurement method	Site Metadata Biological Data
AG_BIOMASS_SF	Aboveground biomass of shrub foliage	Biological Data
AG_BIOMASS_SF_METHOD	Aboveground biomass of shrub foliage measurement method	Site Metadata Biological Data

AG_BIOMASS_ST	Aboveground biomass of shrubs total	Biological Data
AG_BIOMASS_ST_METHOD	Aboveground biomass of shrub total measurement method	Site Metadata Biological Data
AG_BIOMASS_SW	Aboveground biomass of shrub wood	Biological Data
AG_BIOMASS_SW_METHOD	Aboveground biomass of shrub wood measurement method	Site Metadata Biological Data
AG_BIOMASS_TF	Aboveground biomass of tree foliage	Biological Data
AG_BIOMASS_TF_METHOD	Aboveground biomass of tree foliage measurement method	Site Metadata Biological Data
AG_BIOMASS_TT	Aboveground biomass trees total	Biological Data
AG_BIOMASS_TT_METHOD	Aboveground biomass of tree total measurement method	Site Metadata Biological Data
AG_BIOMASS_TW	Aboveground biomass of tree wood	Biological Data
AG_BIOMASS_TW_METHOD	Aboveground biomass of tree wood measurement method	Site Metadata Biological Data
AG_BIOMASS<n>_DATE	Aboveground biomass measurement date	Biological Data
CR_BIOMASS	Coarse root biomass	Biological Data
CR_BIOMASS_DEPTH	Coarse root biomass measurement depth	Biological Data
CR_BIOMASS_METHOD	Belowground coarse root biomass measurement method	Site Metadata Biological Data
CROP_RESID	Crop residue	Biological Data
CROP_RESID_DATE	Crop residue measurement date	Biological Data
CWD	Coarse woody debris	Biological Data
CWD_DATE	Coarse woody debris measurement date	Biological Data
FR_BIOMASS	Fine root biomass	Biological Data
FR_BIOMASS_DEPTH	Fine root biomass measurement depth	Biological Data
FR_BIOMASS_METHOD	Belowground fine root biomass measurement method	Site Metadata Biological Data
FWC_DATE	Fine woody debris measurement date	Biological Data
FWD	Fine woody debris	Biological Data
HEIGHTC	Mean canopy height	Biological Data

HEIGHTC_DATE	Mean canopy height measurement date	Biological Data
LAI Raw Files		RawFiles
LAI<n>	Leaf Area Index	Biological Data
LAI<n>_CLUMP	Foliage element clumping index	Biological Data
LAI<n>_COMMENT	Leaf Area Index comments	Biological Data
LAI<n>_DATE	Leaf Area Index measurement date	Biological Data
LAI<n>_TECHNIQUE	Leaf Area Index measurement technique	Biological Data
LIT_MASS<n>	Litter mass	Biological Data
LIT_MASS<n>_COMMENT	Litter mass comments	Biological Data
LIT_MASS<n>_DATE	Litter mass measurement date	Biological Data
R_BIOMASS_DATE	Biomass measurement date	Biological Data
RT_BIOMASS	Total root biomass	Biological Data
RT_BIOMASS_DEPTH	Total root biomass measurement depth	Biological Data
RT_BIOMASS_METHOD	Belowground total root biomass measurement method	Site Metadata Biological Data
SNAG	Mass of standing dead trees	Biological Data
SNAG_DATE	Mass of standing dead trees measurement date	Biological Data
SPP_COMMENT	Dominant species comments	Biological Data
SPP_DATE	Dominant species measurement date	Biological Data
SPP_O_METHOD	Overstory dominant species measurement methodology	Site Metadata Biological Data
SPP_O<n>	Overstory dominant species	Biological Data
SPP_O<n>_PERC	Overstory dominant species percent	Biological Data
SPP_U_METHOD	Understory dominant species measurement methodology	Site Metadata Biological Data
SPP_U<n>	Understory dominant species	Biological Data
SPP_U<n>_PERC	Understory dominant species percent	Biological Data
ST_MASS	Stump mass	Biological Data
VEG_TYPE	Vegetation type	Site Biological Ancillary Data

17. Abbreviations

BD – Bulk density
C & N – Carbon and nitrogen, respectively
CWD – Coarse woody detritus
DBA – Diameter basal area
DBH – Diameter at breast height (1.37 m)
FWD – Fine woody detritus
FIA – Forest Inventory and Analysis
Ht – Height
LAI – Leaf area index (m^2 half surface area per m^2 ground)
LMA – Leaf mass per unit area (g cm^{-2})
NEP – Net Ecosystem Productivity (NEP = NPP – Rh)
NPP – Net primary production
Ra – Autotrophic respiration
Rh – Heterotrophic respiration
Rs – Soil CO_2 efflux
Ta – Air temperature (°C)
Ts – Soil temperature (°C)
TDR – Time Domain Reflectometry

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