

Standard Observation SOATM_025

Forest-LAI

Version 0.4

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NOTE: THIS PROTOCOL IS STILL UNDER REVIEW.



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Review Team

The document was reviewed solely for language and style, without assessing its scientific content.

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The present protocol is based on ICOS protocol for ancillary vegetation measurements in forest on ICOS ecosystem stations (Gielen et al. 2017).

To reference the methodology, the corresponding original document should be cited:

Gielen, B., Op de Beeck, M., Michilsens, F., and Papale, D. (2017): ICOS Ecosystem Instructions for Ancillary Vegetation Measurements in Forest (Version 20211109). ICOS Ecosystem Thematic Centre.

To reference the implementation of the requirements of the ICOS protocol at eLTER sites, the eLTER Standard Observation Protocol can be cited as:

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By the end of January 2026 the further work on the protocol was handed over to and executed by the provisional eLTER Head Office and Topic Centre on Interoperability of the emerging eLTER ERIC.

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SO variable overview

Habitat:
Applies to the eLTER habitat group *Forest and other wooded land* and *Cat-1 sites* only

Variable(s):

- **Leaf area index (LAI)** Reporting unit: %

Contents

1 Introduction **5**

2 PRIME method **5**

2.1 Scope and data product 5
2.2 Method 6
2.2.1 Digital Hemispherical Photography 6
2.2.2 Linear ceptometry 7
2.3 Measurement design 7
2.3.1 Spatial design 7
2.3.2 Temporal design 7
2.3.3 Measurement 8
2.4 Maintenance 9
2.5 Calibration 9

3 Data and metadata format **9**

1 Introduction

Leaf area index (LAI) represents the ratio of the total leaf surface area to the corresponding ground area ($m^2\,m^{-2}$) (Bréda 2003). It is a key structural parameter of forest ecosystems and plays a fundamental role in regulating biogeochemical fluxes and ecosystem functioning. LAI is widely used in models of carbon, water and energy exchange because it regulates radiation interception and thereby affects photosynthesis, transpiration, and ecosystem productivity (e.g. Baldocchi et al. (2002)). It also affects canopy interception of precipitation and atmospheric deposition, thereby influencing evapotranspiration, water availability and nutrient cycling (Bréda 2003). Moreover, LAI is an important determinant of forest energy balance, through its effects on radiation absorption and heat transfer and canopy-atmosphere interactions (Margolis et al. 1995). These processes are strongly influenced by the seasonal dynamics of the canopy, as well as by effects of climate change and other limiting factors (Margolis et al. 1995).

Commonly, LAI is estimated indirectly by measuring light transmission through the forest canopy using photosynthetically active radiation (PAR) sensors or hemispherical photographs (Bréda 2003; Yan et al. 2019). It is important to distinguish LAI from related metrics. Green Area Index (GAI) not only considers leaves, but also stems and other photosynthetically active plant organs, whereas the Plant Area Index (PAI) quantifies the surface area of all aboveground standing vegetation per unit of ground area (Bréda 2003). Since many indirect optical methods measure GAI or PAI rather than LAI, appropriate corrections for stems and branches should be applied whenever possible (Bréda 2003). Since LAI,GAI and PAI strongly correlate to each other and various software packages automatically report results as LAI by default, we use LAI in this protocol, which is widely used in terms of ecosystem and flux studies. Generally, accurate estimation of LAI requires consideration of several factors, including the seasonal dynamics of foliage (phenology), solar elevation, different proportions of diffuse and direct solar radiation and the spatial distribution of foliage within the canopy. The clumping of the forest canopy can introduce substantial biases in indirect optical measurements and should be accounted for using appropriate correction methods (cf. Kucharik et al. (1999)).

In this eLTER instruction manual, we refer to the instruction manual published by ICOS (Gielen et al. 2018). Instructions documents are regularly updated. Please refer to the current versions at ICOS Ecosystem Instructions and Guidelines (icos-etc.eu)[1].

Recommended read: Yan et al. (2019) and Bréda (2003)

2 PRIME method

2.1 Scope and data product

Measuring LAI is relevant to assess the energy balance for Cat-1 sites

Site category	1
Raw data	Ceptometer: photosynthetically active radiation (PAR below and under canopy in $\mu\mathrm{mol\,m^{-2}\,s^{-1}}$ LAI-2000/2200: Radiation intensity in 5 zenith rings (relative/in $\mu\mathrm{mol\,m^{-2}\,s^{-1}}$) Fisheye images: Pixel values
Data products	LAI (%)

[1]Note: In the ICOS instruction manuals, GAI/PAI is used instead of LAI.

2.2 Method

Optical methods estimate LAI indirectly via radiation transmission through the forest canopy, based on the Beer-Lambert law. Widely used optical instruments include, for example, the SunScan Ceptometer, LAI-2000/LAI-2200, AccuPAR LP-80 or digital cameras with a fisheye objective and a gimbal. In this document, detailed guidelines are provided for digital hemispherical photographs (if seasonal max GAI < 6 m^2 m^{-2}) and the SunScan Ceptometer (if seasonal max GAI > 6 (m^2 m^{-2}) as following the ICOS manual (Gielen et al. 2017). More detailed guidelines for other instruments are available in the respective ICP Forest Manual (Fleck et al. 2020). Note that eLTER members can select any instruments, but the precision of LAI measurements have to be at least as accurate as those described here.

Basic assumptions for the indirect measurements using optical instruments are a random spatial distribution of the foliage and a random horizontal orientation of the leaves. However, near-natural forest ecosystems often show high spatial heterogeneity due to species diversity, different growth and senescence stages. The resulting non-random distribution of foliar elements is called the clumping effect of the canopy.

Measurements of LAI should consider the seasonal dynamics of foliage (phenology), in particular for deciduous trees, the seasonal solar elevation, the different proportions of diffuse and direct solar radiation and the clumping effect of the forest canopy. Appropriate methods for correcting clumping effects should be applied in accordance with Yan et al. (2019).

According to the instruction document by ICOS (Gielen et al. 2017), LAI of the forest canopy, which corresponds to the GAI of ICOS, is determined by means of digital hemispherical photography (DHP) if seasonal max GAI < 6 m^2 m^{-2} and by means of linear ceptometry if seasonal max GAI > 6 m^2 m^{-2}.

2.2.1 Digital Hemispherical Photography

The standard systems consist of a digital camera with a fisheye objective and a gimbal. The camera should correspond to a single lens reflex camera with at least 12.3 Mpixel (no compact camera). The compatible Fish-eye lens should provide a 180° horizontal field of view. A 4.5mm lens should be used for APS-C cameras, whereas an 8mm lens should be used for full frame cameras.

Additionally needed is a:

- Tripod or telescopic monopod with a levelling head
- Measuring tape or a measuring stick to set the tripod height
- 3D bubble level or self-levelling mount
- Compass to align the camera to True North
- Inclinometer for determining the slope in case of complex terrain
- Material required for calibration of the lens and camera

The North in this document refers to the True North, which is different from the magnetic North indicated by a standard compass. To derive the True North from the magnetic North, please follow these steps:

1. Calculate the declination between the True North and the magnetic North. Several online tools are available for this purpose (e.g. https://www.ngdc.noaa.gov/geomag-web/#declination).
2. Adjust the bezel ring of your compass according to the calculated declination to enable accurate alignment with the True North.

2.2.2 Linear ceptometry

The standard setup consists of a linear ceptometer with an external PAR sensor and a tripod. The method described in this eLTER manual refers to the SS1 SunScan Canopy Analysis System (Delta-T Devices). Further information on the required instrumentation is found in the Instructions for SS1 Canopy Analysis System for Green Area Index Measurements. More detailed guidelines for the measurements using alternative instruments are available in the respective ICP Forest Manual (Fleck et al. 2020).

2.3 Measurement design

2.3.1 Spatial design

LAI measurements are conducted at four continuous circular plots (CP)[2] with a surface of 2,000 m^2 and a fixed radius of 25.2 m. In case of plantations, the use of a rectangular shape of CPs should be discussed. The CPs are located in a cross-like scheme around the Eddy-Covariance (EC) flux tower, which is mandatory for Cat-1 sites focussing on Atmosphere (Figure 1). Generally, the center of CPs are located at 35 m distance (X) to the EC flux tower and the minimum distance between two CP centers equals to 55 m (Figure 1). In case of heterogeneous site conditions, e.g. a predominant wind direction, the sampling design should be adapted to maximize representativeness of the site. Distances from the EC flux tower to CP centers can vary from 30 m (Y1) to maximum 100 m (Y2) (Figure 1). The desing should ensure that CPs do not overlap.

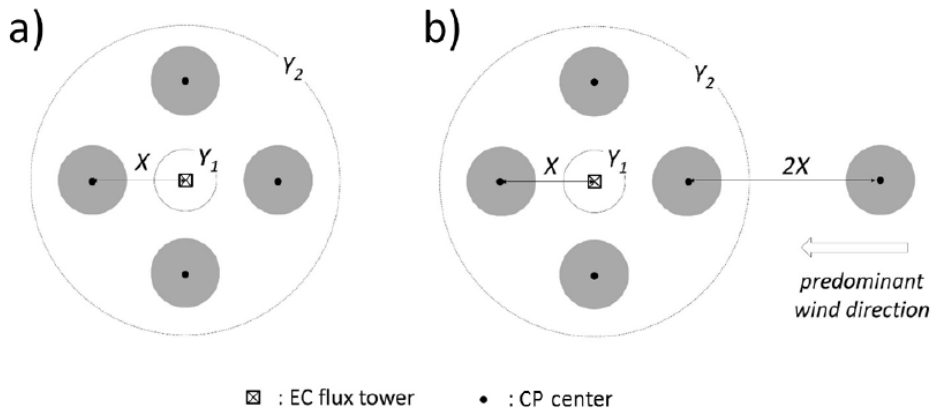


Figure 1: Cross-like scheme of continuous plots (CP) around the Eddy Covariance (EC) flux tower in forested sites (a). Optionally, a fifth CP is selected in the predominant wind direction (b) (figure modified after Papale and Nicolini (2016))

2.3.2 Temporal design

LAI should be measured throughout the growing season to consider the interannual variation of the leaf area. Measurements are conducted at least six times per year for both deciduous and coniferous forests: two times during the period of leaf development, once at the peak GAI, two times between the peak GAI and senescence and a final measurement during the dormant season. Additional sampling dates should be included immediately before and after thinning operations and after disturbance events such as storms, insect attacks etc. (Gielen et al. 2017). Apart from disturbances, LAI values change relatively slowly due to stand growth. Hence, LAI should be measured at least every 3 years on all standard Cat-1 sites (Fleck et al. 2020).

[2]This section describes the data collection in standard circular plots. In case of rectangular CPs, please see details in the ICOS manual (Gielen et al. 2017)

2.3.3 Measurement

Ceptometer measurements Measurements are preferably done in stable light conditions, i.e. under a uniformly blue or grey sky. If measuring in unstable conditions, restrict measurements to the brief periods of stable light conditions. It is recommended to consistently measure in the same light conditions throughout the growing season. Measurements should not be conducted when above-canopy PAR is below 200 $\mu\mathrm{mol}\,\mathrm{m}^{-2}\,\mathrm{s}^{-1}$, under precipitation, at temperatures outside the ceptometer's range of operation (e.g. below 0 °C). Try to avoid measurements at solar zenith angles $> 60°$.

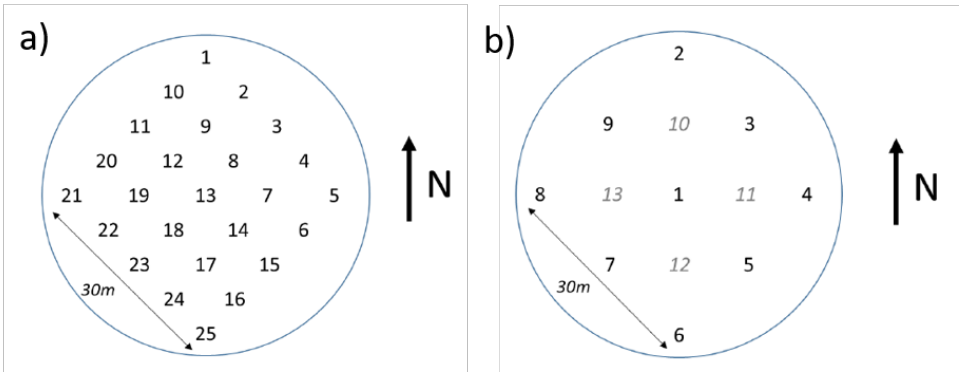


Figure 2: Measurement design for a) ceptometer measurements and b) Digital Hemispherical Photography inside the continuous plots (CP) modified after Gielen et al. (2017)

Measurements are carried out at 25 locations in each circular CP (Figure 2a). For a standard circular CP, a grid of 25 points must be used with 7.5 m between points and with the middle point (ID = 13) coinciding with the centre of the CP (Figure 1). The four corners of the square have to be at equal distance from the centre of the plot, with the upper one facing true North. To avoid interference from stems and trees on the measurements, we advise moving the measurement point away from a tree using the 10° rule that implies that a sampling point should be at a minimum distance of 5.7 times the diameter of the tree. During the first measurement campaign, permanently mark the sampling location using a wooden/metal stick with a clearly labelled tag following the scheme in Figure 2a (Gielen et al. 2017).

At each location, below-canopy PAR (PARb) is measured with the ceptometer probe. Above-canopy PAR is measured either with ceptometer's PAR sensor or simultaneously with the external PAR sensor installed in a nearby clearing or on the EC tower. A detailed explanation of the measurements can be found in the instruction documents of the corresponding ceptometer instruments.

Digital Hemispherical Photography Measurements are ideally done under diffuse light conditions on entirely overcast days with a uniform cloud cover. Pictures should only be taken in the absence of direct sunlight to avoid a wrong classification of the pixels. In exceptional cases, pictures can be taken before sunrise and after sunset, when the sun is hidden behind the horizon and the vegetation is not directly sunlit. Avoid measurements during rain, heavy wind, foggy conditions and snow (Gielen et al. 2017).

A systematic measuring grid of nine points has to be installed within each CP (Figure 2b). For a standard circular CP, a grid of nine points must be used with 15 m between points and with the middle point (ID = 1) coinciding with the centre of the CP (cf. Figure 2). The four corners of the square have to be at equal distance from the center of the plot, with the upper one facing True North. In case of a high standard error of GAI within the plot (>5% of the mean), four additional measurement points may be added. To avoid interference from stems and trees on the measurements

we advise moving the measurement point away from a tree using the 10° rule that implies that a sampling point should be at a minimum distance of 5.7 times the diameter of the tree.

The minimum distance between the lens and a leaf has to be 10 times the length of the leaf. Thus in case a leaf has a length of 10 cm, the minimum distance to the lens has to be 100 cm. During the first measurement campaign, permanently mark the sampling location with a wooden/metal stick with a clearly labelled tag following the scheme in Figure 2b (Gielen et al. 2017). Measure the mean slope and slope direction of the CP, considering the entire area of the CP.

For detailed explanations of the measurement at each point in the CPs please see p.17 in Gielen et al. (2017).

2.4 Maintenance

Please check the required maintenance in the user manuals of the respective instruments.

2.5 Calibration

The external PAR sensor requires a calibration every few years. Please check your instrument's user manual. Please calibrate your hemispherical camera according to Gielen et al. (2017) Appendix A.

3 Data and metadata format

Reporting is conducted in accordance with the rules and conventions specified in Peterseil and Geiger (2020)[3] regarding file naming, file formats, and metadata scope.

[3]Document is currently under revision

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