

United Nations Economic Commission for Europe (UNECE)
Convention on Long-range Transboundary Air Pollution (CLRTAP)

International Co-operative Programme on Assessment and
Monitoring of Air Pollution Effects on Forests (ICP Forests)

MANUAL

on

methods and criteria for harmonized sampling, assessment,
monitoring and analysis of the effects of air pollution on forests

Part XIII

Sampling and Analysis of Litterfall

Version 2025-1

Prepared by:

ICP Forests Expert Panel on Foliage and Litterfall

(Liisa Ukonmaanaho, Rona Pitman, Annemarie Bastrup-Birk, Nathalie Breda, Pasi Rautio, Anita Nussbaumer, Anne Thimonier, Lena Wohlgemuth, Katrin Haggenmüller)

Ukonmaanaho, L., Pitman R, Bastrup-Birk A, Breda N, Rautio P, Nussbaumer A, Thimonier A, Wohlgemuth L., Haggenmüller K., 2025: Part XIII: Sampling and Analysis of Litterfall. Version 2020-2. In: UNECE ICP Forests Programme Co-ordinating Centre (ed.): Manual on methods and criteria for harmonized sampling, assessment, monitoring and analysis of the effects of air pollution on forests. Thünen Institute for Forests Ecosystems, Eberswalde, Germany, 17 p. + Annexes [www.icp-forests.net/manual].

All rights reserved. Reproduction and dissemination of material in this information product for educational or other non-commercial purposes are authorized without any prior written permission from the copyright holders provided the source is fully acknowledged. Reproduction of material in this information product for resale or other commercial purposes is prohibited without written permission of the copyright holder.

Application for such permission should be addressed to:

Programme Co-ordinating Centre of ICP Forests
Thünen Institute of Forest Ecosystems
Alfred-Möller-Str. 1, Haus 41/42
16225 Eberswalde
Germany

Email: pcc-icpforests@thuenen.de

Eberswalde, 2025

CONTENTS

1	INTRODUCTION	4
2	SCOPE AND APPLICATION	4
3	OBJECTIVES	5
4	SAMPLING REQUIREMENTS AND FIELD SYSTEMS	6
4.1	FIELD SAMPLING DESIGN.....	6
4.1.1	Number of replicates.....	6
4.1.2	Sampling scheme	7
4.2	SAMPLING EQUIPMENT	7
4.3	FREQUENCY OF SAMPLING	8
4.4	SAMPLE COLLECTION, TRANSPORT AND STORAGE – QUALITY CONTROL IN THE FIELD	8
5	LABORATORY MEASUREMENTS	9
5.1	VARIABLES TO BE ASSESSED	9
5.2	LITTER SORTING AND QUANTITY MEASUREMENT	10
5.3	QUALITY OF LITTERFALL – CHEMICAL ANALYSIS.....	11
5.4	SPECIFIC LEAF AREA MEASUREMENTS FOR LEAF AREA INDEX ESTIMATION.....	12
6	QUALITY ASSURANCE AND QUALITY CONTROL.....	12
6.1	PLAUSIBILITY LIMITS.....	13
6.2	DATA COMPLETENESS	17
6.3	DATA HANDLING, SUBMISSION PROCEDURES AND FORMS.....	17
7	REFERENCES	17
	ANNEX I: MAIN CHANGES COMPARED TO THE PREVIOUS MANUAL VERSION	18
	ANNEX II: MINOR CHANGES AFTER 2025.....	21

1 Introduction

Litterfall is a key parameter in the biogeochemical cycle linking the tree part to the water and soil part. Both the biomass of the litter and its chemical content (including heavy metals) are needed to quantify the annual return of elements and organic matter to the soil. Litter decomposition is a major pathway of nutrient fluxes and determines the organic matter input to forest soils and has a strong influence on forest productivity and soil nutrient status.

Effects of anthropogenic and natural factors, such as climate change, could influence both litterfall production and its seasonal progression. Processes like carbon cycling and carbon sequestration are closely related to stand leaf area index (LAI) and litterfall.

Changes in litterfall are responses to disturbances caused by biotic factors such as insect pests and/or environmental factors like spring frost, drought, wind, or pollution. Litterfall production is a quantitative parameter of stand vitality and gives additional information to the visual assessment of canopy condition already observed in each plot. Direct observation of abnormalities of the leaves can be performed on the collected litter (leaf size, fungi, and necrosis) for symptomatology.

Litterfall can also provide temporal and quantitative information about phenological development of the stand. The quantification of the foliage amount, flowering and fruiting patterns allows direct measurements of year-to-year variation in phenology as a reaction to short term weather patterns, long term climate, and tree vitality.

Litterfall area of leaves is also one of the components of direct estimate of LAI, the stand leaf area per ground area expressed in m^2/m^2 . LAI describes a fundamental property of the plant canopy in its interaction with the atmosphere, especially radiation, energy, momentum and gas exchange (Monteith & Unsworth, 1990). LAI plays a key role in the interception of radiation, canopy interception (rainfall and deposition), in the carbon assimilation and water evapotranspiration during the diurnal and seasonal cycles, and in the pathways and rates of biogeochemical cycling within the canopy-soil system (Bonan, 1995; Van Cleve et al., 1983, Vesterdal et al., 2008). Finally, various soil-vegetation-atmosphere models use LAI (Sellers et al., 1986; and Bonan, 1993). For evergreen species the annual litter represents the turn-over of needle/leaf area. For deciduous species, litterfall collection throughout one year and sorting among species is probably the most accurate way of measuring total leaf area produced, and of calculating the contribution of each species to the total (e.g. Breda, 2003).

2 Scope and application

This part of the Manual aims to provide sufficient methodological advice to allow participating National Focal Centres to sample and prepare an accurate measurement of the quantity and quality of litterfall, from selected plots of the ICP Forests intensive monitoring system. Harmonization of procedures of collection and chemical analysis is essential to ensure comparability of the chemical composition of litterfall, and accurate assessment of LAI. Only data obtained by the methodologies described in this chapter will be accepted for submission into the international database of the ICP Forests programme.

An overview on the variables assessed in the litterfall survey is given in Table 1. Litterfall chemistry is optional on standard Level II plots but mandatory on Level II core plots.

Litterfall sampling is strongly recommended on Level II sites where meteorology data is available.

Table 1: Status of variables for measurements at various levels

Form	Variable	Level I	Level II	Level II core
Biomass measures				
LFD	Dry weight per m ² [g/m ²] for total litter biomass	n	o	m
LFD	Dry weight per m ² [g/m ²] for foliar litter biomass	n	o	m
LFD	Dry weight per m ² [g/m ²] for other litter biomass	n	o	m
LFA	Dry mass of 100 leaves or of 1000 needles [g]	n	o	o
LFA	Area of 100 leaves or of 1000 needles [m ²]	n	o	o
Chemical analyses				
LFC	C [g/100g]	n	o	m
LFC	N [mg/g]	n	o	m
LFC	S [mg/g]	n	o	m
LFC	P [mg/g]	n	o	m
LFC	Ca [mg/g]	n	o	m
LFC	Mg [mg/g]	n	o	m
LFC	K [mg/g]	n	o	m
LFC	Zn [µg/g]	n	o	o
LFC	Mn [µg/g]	n	o	o
LFC	Fe [µg/g]	n	o	o
LFC	Cu [µg/g]	n	o	o
LFC	Pb [µg/g]	n	o	o
LFC	B [µg/g]	n	o	o
LFC	Cd [ng/g]	n	o	o
LFC	As [ng/g]	n	o	o
LFC	Cr [µg/g]	n	o	o
LFC	Co [µg/g]	n	o	o
LFC	Hg [ng/g]	n	o	o
LFC	Ni [µg/g]	n	o	o
LFC	reference temperature	n	o	m

o: optional m: mandatory n: not assessed

3 Objectives

The main objectives of litterfall sampling and analysis are to quantify litterfall production and its chemical composition over time. This will enable:

- Quantification of litterfall amounts at any one plot, to be expressed in g/m².

- The option to assess the local seasonal variation of litterfall components at any one forest plot, and between plots of different species. (N.B. Annual totals only need to be reported)
- Accurate measurement of litterfall chemical quality, to be prepared from oven dried and **bulked annual** samples, or the weighted **means** of periodic analysis, and expressed as concentrations of specific elements.
- Measurement of specific leaf area of deciduous species on each 'core' plot of the intensive monitoring network in each year, allowing a direct assessment of LAI in [m^2/m^2] as an alternative to field-based methods (See details in Part XVII of the ICP Forests Manual on Leaf area measurements).

Evaluation of the data will then allow for

- Comparisons of litterfall quantity variation across latitudinal and longitudinal gradients by species
- Investigation of relationships with insect vectors, weather phenomena, soil changes and climate variation by inter-plot comparisons
- Greater understanding of the role of litterfall in nutrient cycling, across gradients of temperature, soil moisture and soil type, and in particular to improve knowledge of the N, P and C cycles and in heavy metal cycles.
- Accurate estimates of the effects of year-on-year variation of leaf area for use with assessments of water budgets on forest plots with differing soils across a variation of climate types. (See details in Part XVII of the ICP Forests Manual on Leaf area measurements).
- Assessment of mast years (high seed production coordinated across populations), in particular in beech and oak forest stands

4 Sampling requirements and field systems

Litterfall sorting is time-consuming and hence an expensive analysis. Within the ICP Forests monitoring system, fine sorting of the fractions is mandatory only on Level II core plots where meteorology, soil water, soil solution, and phenology are also performed (see Table 2). On standard Level II plots litterfall collection is optional. When it is carried out on Level II plots, at least a less detailed level of sorting to determine foliar and non-foliar litterfall mass is recommended. Plot data should be recorded and submitted on Form *.LFP (see ICP Forests Manual Part XVII Data handling and data submission forms).

4.1 Field sampling design

4.1.1 Number of replicates

It is recommended to sample litterfall from at least 10 collectors per plot under uniform forest canopy, but up to 20 or 30 collectors under mixed species or in larger plots with uneven topography. Leaves from deciduous trees are more susceptible to turbulent air movement than conifer needles. This effect may be mitigated either by increasing the number of litterfall traps (e.g. 10 traps for coniferous species and 20 traps for deciduous species) or by increasing the collecting area of each trap (especially for species with large leaves e.g. *Populus*).

4.1.2 Sampling scheme

As litterfall is a canopy parameter, and not a tree one, litterfall traps should be distributed all over the plot area. It is recommended that the traps are set up in a design enabling comparisons with deposition and soil water results. The traps are fixed and may be placed randomly or systematically e.g. at regular intervals and in sufficient number to represent the whole plot and not only the dominant tree species.

In case the stand where the monitoring plot is located reaches the age of final cutting, or the stand is destroyed by e.g. storm or pest infestation, monitoring activities need to be either (i) moved to a new location, or (ii) remain in the same location in regenerated stand. If the plot is moved to a new stand the same rules as establishing a new monitoring plot applies (see Manual Part II on Basic design principles for the ICP Forests monitoring networks, Ferretti et al. 2020). If the monitoring continues on the same location in an artificially or naturally regenerated stand, litterfall sampling needs to be adapted to the new situation. It is recommended to wait until the dominant species (i.e. the species that prevailed in the stand before the cutting or destruction or that is aimed to be the dominant species in the future in the forest planning for the stand) reach the average height of 1.3 meters. In case sampling is done in seedling phase it is recommended to wait until the seedlings reach the average height of 50 cm.

4.2 Sampling equipment

The countries are free to select the type of traps for the monitoring of litterfall. Figure 1 gives examples of two litterfall trap designs.

It is recommended that the litterfall traps are not fixed too close to the ground, to ensure adequate water drainage. The opening area of the collectors must be horizontal, and if necessary, special trap fixation should be prepared for mountainous plots. A top height between 1.0 and 1.3 m should ensure that there is clearance from the ground on the up-slope side, whilst still allowing capture of leaves from shrub vegetation. Canopy leaves and other litterfall inputs can be collected in nets or litter bags which are attached to a frame of durable material, with a known catching area (minimum 0.18 m² but preferably over 0.25 m²). The total sampling area must be sufficiently large to be able to determine litter amount and quality. There may be a need to trim tall ground vegetation from just beneath the trap itself, to avoid interference with the nets/bags, which is acceptable as long as the trap position is not within the ecological survey area. For tree species with very large individual leaves e.g. *Populus*, the collecting area of individual traps must be increased (i.e. up to 0.5 m²).

It is recommended that the litter bags or collecting funnels are at least 0.5 m deep to prevent litter from blowing out of the traps. Deposition of litter into these traps due to lateral movements by wind is assumed to be minimal. The material of the mesh must not interact with the litterfall sample. Litter nets/bags of inert materials like cotton, polyethylene or nylon are suitable materials, not interfering with the major ions present in litter. However, natural materials like fine cotton stitching will decay quickly on site under sustained high temperature and moisture levels. The mesh size of the bags must be large enough to allow for easy drainage of water. It is recommended to adapt mesh size to the dimension of smallest elements, i.e. for needles from coniferous species up to 0.5 mm, but if there is interest in the finest 'frass' material (caterpillar droppings), then the texture needs to be much smaller. During the winter season in areas of heavy snowfall, traps may be lowered on to the ground to avoid breakage of the collector structures, preferably on to a plastic mesh sheet to avoid direct contact with the soil.



Mesh trap



Solid funnel with bag

Figure 1: Potential collector design

4.3 Frequency of sampling

It is recommended that litterfall is collected at least monthly and even bi-weekly in periods of heavy fall, which may be co-incident with heavy rainfall. This is to avoid pre-collection decomposition in the traps and chemical leaching of the material during rain episodes. It is particularly vital to obtaining true weights of the fine flower and bud components in spring, which very quickly become compressed and unidentifiable. The samples may be pooled to periodic or annual totals – the litterfall year for reporting purposes should run from spring to spring i.e. beginning of April (year 1) to the end of March (year 2). In regions with snow in the winter or which are remote, it may be impossible to collect samples at regular intervals. Litterfall may then be collected once before the winter period and once after snowmelt, as frost will limit both drainage and litter decomposition. Total values for this period should then be subdivided proportionally to the months passed since the last collection.

4.4 Sample collection, transport and storage – quality control in the field

The collection bags must be carefully labelled with site number, trap number and date before removing them from the site. It is recommended that a record sheet is taken to the field at each bag change to record any unusual conditions or missing samples, and that this should be sent in each time with the bags and be stored in suitable files in the analysing laboratory. If collection is made from fixed nets by hand then powder-free vinyl gloves should be worn to lessen sample contamination ahead of chemical analysis. Alternatively, suspended bags may be replaced at each visit, and possibly cleaned and re-used.

Ideally all samples should be transferred immediately to the laboratory, preferably in cool boxes, or, if necessary, temporarily stored at 4°C, but not frozen.

5 Laboratory measurements

5.1 Variables to be assessed

The variables of interest concern quantity (mass measurements) and chemical quality of litter, and the possibility to measure specific leaf area (SLA) values from the foliar fraction. In standard Level II plots the litterfall survey is optional, but at least litterfall quantity is recommended, along with measures of dry mass (Table 1), but in the Level II designate 'core' plots chemical analysis is requested of finer fractions (see section 5.3, Table 2).

A procedural flow diagram to facilitate assessment of all these variables is given in Figure 2.

Reception

Litter samples should be checked and counted into the lab on arrival, using non-contaminating gloves, and the paper work filed. This is a vital part of the quality control of samples from the field to the laboratory.

If the samples are damp, this may be an opportunity to measure leaf area for pines, which are particularly difficult when dry, as the longer needles tend to warp and twist. Incoming samples should then be kept damp, but cooled, and processed as soon as possible so that decay does not start. In all cases, samples are easier to sort when dried, and could be left covered for several days in a warm, dry place to air dry – alternatively they may be oven dried at temperatures below 70°C for at least 24 hours. However, if mercury (Hg) or arsenic (As) will be analysed, lower temperature is recommended (+40 °C). Any insect life in the bags should be noted, and identified if in large numbers.

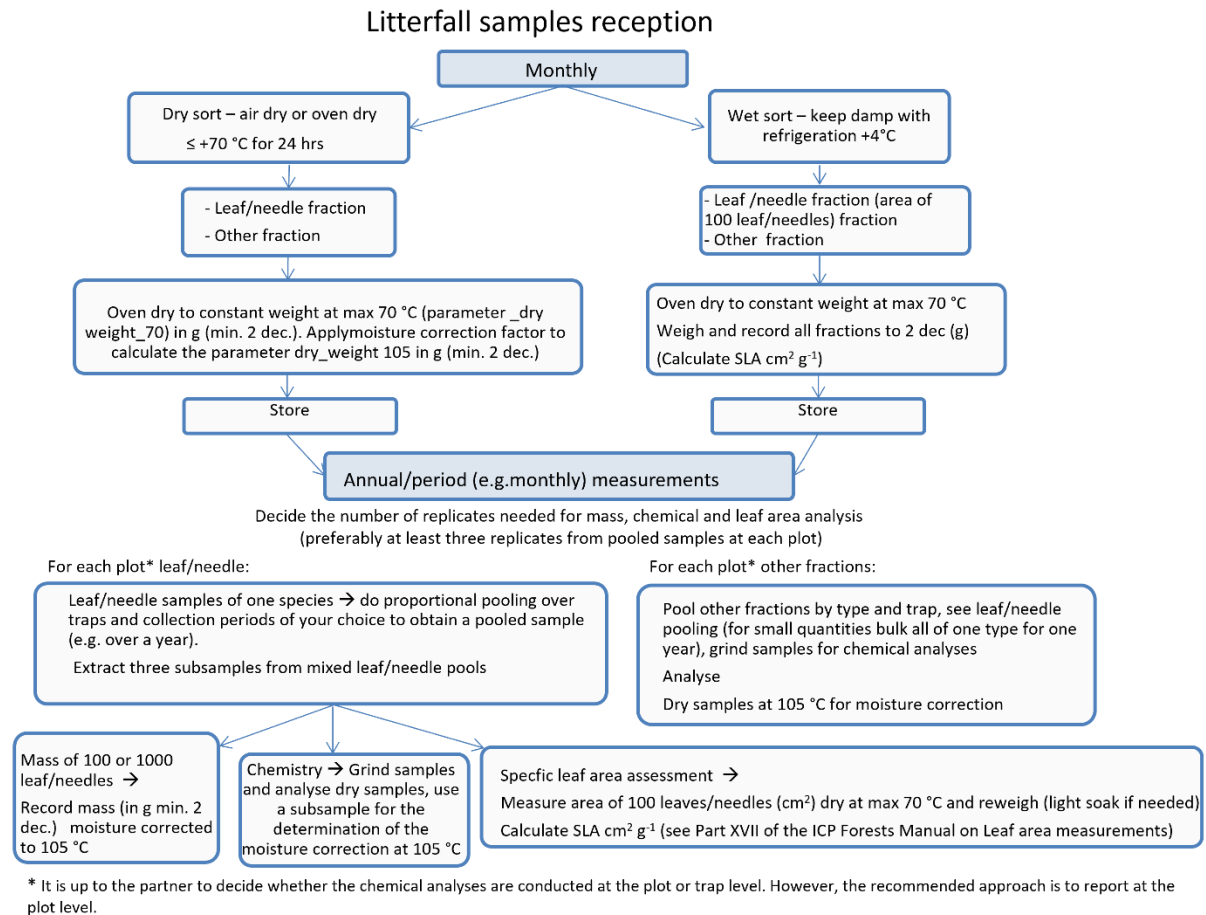


Figure 2: Procedural flow diagram for pre-treatment of litter samples

5.2 Litter sorting and quantity measurement

All litter sorting into fractions should be made wearing non-contaminatory gloves (i.e., no gloves with talc powder), both for personal safety and to avoid contamination risk of sample. If the samples are dusty, a light weight face mask should also be worn during lab work. Paper bags can be used to contain the various fractions during oven drying at temperatures at maximum 70°C.

Any litter collected from Level II plots should be sorted into at least foliar and non-foliar fractions for reporting purposes. If the plot has been designated as Level II core plot, then litter should be further separated into the fractions shown in Table 2. The reported biomass values of sorted fractions per collection period should always sum up to total litter biomass.

It is assumed that large branches >2 cm diameter, not often captured within the litter traps, will be recorded as part of the deadwood estimates of the plot, as taken during ecological surveys. The various fractions should be dried separately at maximum 70°C until constant weight is achieved (at least 24 hrs for fine fractions and leaves, but longer for substantial woody debris), and weighed to 2 decimal places (g). Litterfall dry mass/m² (either from individual collection periods or aggregated/annual totals) will be reported in the form *.LFD along with respective collection start and end dates. Information on litterfall dry mass from individual collection periods can be quite valuable particularly in fall for e.g. phenological analysis.

Table 2: Fractionation of litterfall

https://icp-forests.org/documentation/Dictionaries/d_litter_sample.html

Fractions of Litterfall	Level II	Level II core plot
Total litter biomass g/m ² (all tree species)	o	m
Foliar litter total (all tree species)	o	m
Foliar litter (main tree species)	o	m
Foliar litter (secondary tree species)	o	m
Non foliar litter (all tree species), i.e. total litter sample minus foliage. Together with foliar litter of the respective collection period, this non foliar litter fraction should sum up to total litterfall.	o	m
Rest of litterfall sample. Together with the other submitted fractions of the respective collection period, this rest should sum up to total litterfall.	o	o
Flowering total	o	o
Flowering (main tree species)	o	o
Flowering (secondary tree species)	o	o
Fruits and seeds total (all tree species)	o	m
Fruits and seeds (main tree species)	o	m
Seeds only (main tree species)	o	o
Capsules and cones including green cones (main tree species). Capsules and cones can be either empty or still contain seeds that are tightly attached.	o	o
Fruits and seeds (secondary tree species)	o	m
Seeds only (secondary tree species)	o	o
Capsules and cones including green cones (secondary tree species). Capsules and cones can be either empty or still contain seeds that are tightly attached.	o	o
Bud scales	o	o
Wood fraction (Twigs /branches D< 2cm/bark)	o	o
Fines, frass, insects [#]	o	o
Leftover biomass, that is not a part of the tree itself (e.g. lichen, moss etc)	o	o

o = optional, m = mandatory

m* mandatory only for main tree species = *Fagus sylvatica*

[#]If the organism involved can be identified, the scientific name must be reported using codes of 7 letters. Codes for common damaging species are listed in the database dictionary *d_cause_sc_name*: https://icp-forests.org/documentation/Dictionaries/d_cause_sc_name.html

Add the insect's name to column *other_obs*

If annual samples are reported, litter material can be combined at plot level at the end of the year and thoroughly mixed. Separate samples of 100 leaves or 1000 needles should be taken from the combined sample, weighed, and the weight reported (see Fig. 2) (minimum requirement). Additionally, at least two or more samples should be taken from the total annual litter mass, which must be at least separated into leaf/needle litter and other litter, for chemical analysis (see 5.3). If results are reported for a shorter period, litter samples should be combined at plot level for the respective period equivalently to the annual guidelines (see above). If specific litter materials, such as flowers, bud scales, etc., occur only in small quantities but have been separated, it is recommended that they will be pooled on an annual basis.

5.3 Quality of litterfall – chemical analysis

The chemical analysis of litter is similar to that of sampled foliage within the ICP Forests foliage survey. For techniques and analytical methods in more detail see Part XII of the ICP Forests Manual on Sampling and Analysis of Needles and Leaves. Analysis will be made on an annual sample of the various fractions or alternatively from shorter periods, The annual reporting period can be either the calendar year or April–March (see 4.3).

For chemical analysis the litterfall samples are dried to constant weight in an oven at maximum 70°C, and samples are ground to a homogeneous powder in a suitable mill. However, if mercury (Hg) or arsenic (As) will be analysed, lower drying temperature is recommended (+40°C). For large twig fractions and tough seed cases and cones, this may mean a two-stage pre-treatment to achieve chipped material of a suitable size for laboratory grinding. All chemical element concentrations and biomass of litterfall should be reported moisture corrected from dry ground material mass by drying subsamples to 105°C. Reporting biomass and concentrations in reference to other drying temperatures but 105°C is not recommended but possible, in case you were e.g. not able to determine a moisture correction factor for actual drying temperature to 105°C. In this case, the reference temperature for submitted nutrient concentrations can be reported in the column *reference temperature* in form LFC, while biomass dried at 70°C is reported in column *dry_weight_70* in form LFD. For Quality control recommendations see section 6.

Reporting on annual chemistry of element concentrations should be made on Form *.LFC

5.4 Specific Leaf area measurements for Leaf Area Index estimation

The litterfall based method is an optional approach for leaf area index (LAI) estimation which has been frequently used in the past for broadleaf stands (Breda, 2003; Thimonier et al., 2010). The most suitable definition of LAI is half the total green leaf area (one-sided area for broad leaves) in the plant canopy per unit ground area (Chen and Black, 1992). While the leaf area subtended by deciduous trees for each year (cumulative LAI, LAIcum) can be computed from total leaf litter dry biomass of that species in that year (April-March) per m², the maximum LAI (LAI_{max}) that occurs in the course of a year is assessed from litterfall dry weight only between August and March, assuming that maximum foliation of the canopy is achieved end of July. In both cases, the litterfall of that period needs to be multiplied by a ratio to convert dry weight to leaf area. This ratio of leaf area (A): dry mass (m) is named Specific Leaf Area and its alternative expression is as LMA (leaf mass per area):

$$\text{SLA} = A/m \text{ (cm}^2 \text{ per g)} \qquad \text{LMA} = m/A \text{ (g per cm}^2\text{)}$$

Canopy leaf area (LAI) is the composite measure from all tree and tall shrub species in the plot and can only be obtained from litterfall if foliar SLA is determined for each of the component species. SLA can be measured leaf by leaf, as may be needed in photosynthesis or porometry research, or in bulk as an annual value smoothing out the variations of the individuals. However, this requires suitable laboratory equipment for accurate leaf area measurement, such as the Delta-T scanner or the Li-cor CI-203 laser area machine.

SLA should be made on a dry weight basis, to give better standardisation between sites. It has to be determined for each main canopy species from a random subsample of litter leaves (at least 100 leaves from different traps). Preferentially, several replicates from one year's leaf litter total should be analyzed to obtain a measure of the variability of the material from the site accruing through the year.

See detailed information and methodology in Part XVII of the ICP Forests Manual on Leaf Area Measurements.

6 Quality Assurance and Quality Control

The quality of the litterfall analytical data is controlled by regular Interlaboratory comparison ring tests of plant material by the Forest Foliar Co-ordinating Centre. It is anticipated that there will be increasing need for these tests on non-foliar litter material, in order to establish the limits

of expected and acceptable variation, as and when such material is available in sufficient quantity and homogeneity. All countries wishing to report litterfall chemistry should regularly take part in laboratory inter-comparisons.

Guidelines for QA/QC procedures in the laboratory are given in the Manual part XVI on laboratory QA/QC. Documentary proof of the QA/QC adopted in each laboratory should be submitted, together with the annual results, to the European-level data centre.

6.1 Plausibility limits

Tables 3a-d summarise the current suggested plausibility limits based on the reported chemical composition of litterfall samples. It is anticipated that these limits will be revised as increasing numbers of litterfall results become available in the central database, and the full range in chemical composition of the different fractions of litterfall is established. Plausibility limits were determined as the 5th and 95th percentile for all cases, in which >100 chemical measurements per species, fraction and nutrient were available in the ICP Forests database respectively (last update March 2025).

Table 3a: Plausible range of element concentrations based on 5th and 95th percentile of respective measured values in the ICP Forests Litterfall Database in the a) foliar, b) flower, c) seeds, and d) twigs-litter **of different species**.

Tree species code name	Limit	C g/100g	N mg/g	S mg/g	P mg/g	Ca mg/g	Mg mg/g	K mg/g	Zn µg/g	Mn µg/g	Fe µg/g	Cu µg/g	Pb µg/g	B µg/g	Cd ng/g	As ng/g	Cr µg/g	Co µg/g	Ni µg/g
FOLIAR (11)																			
20 <i>Fagus sylvatica</i>	5th	46.4	7.9	0.7	0.3	4.2	0.6	1.6	20.8	900	91	3.8	0.4	13.3	45.6	40	0.4	0.1	0.9
	95th	53.3	24.3	1.6	1.6	18.7	2.6	7.3	49.6	3400	338	12.1	5.1	42.0	233	289	3.0	0.4	6.3
118 <i>Picea abies</i>	5th	48.3	6.2	0.6	0.4	2.6	0.3	1.1	14.3	287	28.3	1.4	0.3	7.1	30	n.d.	0.2	0.06	1.0
	95th	53.2	14.7	1.2	1.3	14.3	1.4	3.6	87.0	2200	402	6.5	13.6	31.7	176	n.d.	5.2	1.8	6
134 <i>Pinus sylvestris</i>	5th	49.0	4.6	0.4	0.3	3.2	0.4	0.8	25	205	54	1.5	0.4	8.3	78	50	0.3	0.1	0.5
	95th	55.3	16.7	1.3	1.3	11.1	2.0	4.5	73	2639	304	10.0	2.0	46.4	250	347	1.7	1.2	9.7
10 <i>Betula pendula</i>	5th	52.0	7.0	0.5	0.7	4.6	0.6	0.8	74	384	52	4.0	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	1.5
	95th	56.0	23.0	1.7	2.9	13.7	3.5	7.6	237	1960	334	8.7	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	8
44 <i>Quercus frainetto</i>	5th	43.4	7.0	0.8	0.4	10.1	1.7	1.0	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	95th	56.0	15.5	1.5	1.2	18.8	2.2	7.1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
51 <i>Quercus robur</i>	5th	39.8	6.4	0.6	0.4	4.2	1.1	2.0	11.1	161	84	1.2	0.3	n.d.	31	n.d.	n.d.	n.d.	n.d.
	95th	53.2	27.2	3.9	2.7	25.0	3.5	15.3	44.0	3126	300	23.7	54	n.d.	155	n.d.	n.d.	n.d.	n.d.
48 <i>Quercus petraea</i>	5th	43.9	7.0	0.6	0.3	4.3	1.0	1.3	13.1	273	72.4	3.8	0.3	15.5	20	n.d.	n.d.	0.1	1.3
	95th	53.0	27.4	1.9	1.9	15.4	3.3	9.1	45	4879	454	23.2	49.0	123	158	n.d.	n.d.	0.8	11.5

Table 3b: Plausible range of element concentrations based on 5th and 95th percentile of respective measured values in the ICP Forests Litterfall Database in the a) foliar, **b) flower**, c) seeds, and d) twigs-litter **of *Fagus sylvatica***.

Tree species code name	Limit	C g/100g	N mg/g	S mg/g	P mg/g	Ca mg/g	Mg mg/g	K mg/g	Zn µg/g	Mn µg/g	Fe µg/g	Cu µg/g
FLOWERS (13)												
20 <i>Fagus sylvatica</i>	5th	48.9	4.4	0.3	0.4	2.6	0.6	1.4	7.9	86	48.6	4.8
	95th	54.7	32.7	2.4	2.8	7.7	2.0	11.7	49.2	1385	568	19.7

Table 3c: Plausible range of element concentrations based on 5th and 95th percentile of respective measured values in the ICP Forests Litterfall Database in the a) foliar, b) flower, **c) seeds**, and d) twigs-litter **of different species**.

Tree species code name	Limit	C g/100g	N mg/g	S mg/g	P mg/g	Ca mg/g	Mg mg/g	K mg/g	Zn µg/g	Mn µg/g	Fe µg/g	Cu µg/g	Pb µg/g	B µg/g	Cd ng/g	Cr µg/g	Co µg/g	Ni µg/g
SEEDS (14)																		
20 <i>Fagus</i>	5th	46.1	3.2	0.3	0.2	1.5	0.3	1.5	5.2	21.4	29.1	3.6	0.1	4.9	30	0.1	0.03	1.2
<i>sylvatica</i>	95th	57.4	30	1.8	3.0	7.4	2.0	8.5	31.7	1797	202	17	4.7	25.0	281	2.6	0.2	10.0
118 <i>Picea abies</i>	5th	50.0	3.4	0.3	0.3	0.2	0.4	1.1	13.4	36.4	18.6	2.3	0.1	2.8	38.0	n.d.	n.d.	1.1
	95th	56.1	20.1	1.5	1.7	6.1	1.1	6.0	59.2	430	386	10.0	11.1	13.0	361	n.d.	n.d.	4.5
134 <i>Pinus</i>	5th	47.6	2.0	0.2	0.1	0.3	0.2	0.6	8.3	15.6	10.6	1.9	0.1	3.0	41.6	n.d.	n.d.	1.0
<i>sylvestris</i>	95th	55.2	26.7	3.2	6.5	2.3	3.0	6.6	112	567	328	20.1	1.6	20.5	439	n.d.	n.d.	3.6
51 <i>Quercus</i>	5th	44.3	5.2	0.4	0.4	1.3	0.4	2.1	6.0	30.0	13.7	3.6	0.1	n.d.	2.9	n.d.	n.d.	n.d.
<i>robur</i>	95th	53.0	15.1	1.5	1.6	8.0	1.7	11.9	25.6	835	296	16.9	42.9	n.d.	171	n.d.	n.d.	n.d.
48 <i>Quercus</i>	5th	44.0	6.0	0.4	0.3	1.1	0.4	0.8	6.0	63.2	11.0	4.0	0.1	n.d.	3.0	n.d.	n.d.	n.d.
<i>petraea</i>	95th	51.1	14.4	1.4	1.2	13.1	1.8	9.8	28.4	1552	129	23.2	71.6	n.d.	683	n.d.	n.d.	n.d.

Table 3d: Plausible range of element concentrations based on 5th and 95th percentile of respective measured values in the ICP Forests Litterfall Database in the a) foliar, b) flower, c) seeds, and d) twigs-litter of different species.

Tree species code name	Limit	C g/100g	N mg/g	S mg/g	P mg/g	Ca mg/g	Mg mg/g	K mg/g	Zn µg/g	Mn µg/g	Fe µg/g	Cu µg/g	Pb µg/g	B µg/g	Cd ng/g
TWIGS (16)															
20 <i>Fagus sylvatica</i>	5th	49.0	6.0	0.5	0.3	3.1	0.3	0.7	25.5	145	48.3	4.7	0.8	12.0	103
	95th	55.3	12.1	1.0	0.9	12.4	2.4	3.3	85.9	1886	428	22.6	15.0	157	427
118 <i>Picea abies</i>	5th	50.1	7.5	0.6	0.4	2.9	0.3	0.9	32.4	113	155	5.3	1.6	n.d.	93.7
	95th	57.9	14.5	1.4	1.0	10.6	1.0	3.7	120	1536	839	12.0	21.4	n.d.	604
134 <i>Pinus sylvestris</i>	5th	47.6	2.0	0.2	0.1	0.3	0.2	0.6	8.3	15.6	10.6	1.9	0.1	3.0	41.6
	95th	55.2	26.7	3.2	6.5	2.3	3.0	6.6	112	567	328	20.1	1.6	20.5	439
51 <i>Quercus robur</i>	5th	31.7	6.1	0.1	0.4	4.5	0.5	0.6	0.5	9.7	3.7	0.7	0.1	n.d.	151
	95th	51.2	22.9	2.0	1.1	38.9	2.7	8.7	60.7	518	236	41.2	62.6	n.d.	435
48 <i>Quercus petraea</i>	5th	42.8	5.2	0.3	0.3	3.6	0.4	0.7	19.8	226	52.0	4.1	0.5	n.d.	21.8
	95th	53.0	14.9	1.2	0.8	15.5	2.2	5.1	127	2398	299	46.1	54.7	n.d.	364

6.2 Data completeness

Table 1 outlines for all the chemical variables the conditions under which they are mandatory or optional to report. When a country/federal state decides to report optional variables, they should be fulfilling the data quality requirements outlined in the methodology.

6.3 Data handling, submission procedures and forms

Forms for data submission lab quality information and explanatory items are found in Manual Part XVII - Data handling and data submission forms in this Manual (and electronically on the ICP Forests web page, at www.icp-forests.net/manual). The quality information from the labs has to be sent together with the relevant data submission forms to the data centre using form LF.LQA.

7 References

- Bonan G.B. 1993. Importance of leaf area index and forest type when estimating photosynthesis in boreal forests. *Remote Sensing of Environment* 43, 303-314.
- Bonan G.B. 1995. Land-atmosphere interactions for climate system models: coupling biophysical, biogeochemical, and ecosystem dynamical processes. *Remote Sensing of Environment* 51, 57-73.
- Bréda N. 2003. Ground-based measurements of leaf area index: a review of methods, instruments and current controversies. *Journal of Experimental Botany* 54, 2403-2417.
- Chen J. M., Black T. A. 1992. Defining leaf area index of plant canopies with branch architecture. *Agricultural and Forest Meteorology* 57, 1-12.
- Monteith J. L., Unsworth M. H. 1990. *Principles of Environmental Physics*. 2nd ed. Edward Arnold. 291 pp.
- Sellers P.J., Mintz Y., Sud Y. C., Dalcher A. 1986: A simple biosphere model (SiB) for use with general circulation models. *Journal of Atmospheric Science* 43, 505-531.
- Staelens J., Nachtergale L., Luyssaert S., Lust N. 2003. A model of wind-influenced leaf litterfall in a mixed hardwood forest. *Can. J. For. Res.* 33, 201-209.
- Thimonier A, Sedivy I, Schleppe P. 2010. Estimating leaf area index in different types of mature forest stands in Switzerland: a comparison of methods. *Eur. J Forest Res.* 129: 543-562.
- Van Cleve K., Oliver L., Schlenker R., Viereck L.A., dryness C.T., 1983. Productivity and nutrient cycling in taiga forest ecosystems. *Canadian Journal of Forest research* 13, 747-766.
- Vesterdal L, Schmidt IK, Calleson I, Nilsson LO, Gundersen P. 2008 Carbon and nitrogen in forest floor and mineral soil under six common European tree species. *Forest Ecology and Management* 255, 35-48.

Annex I: Main changes compared to the previous Manual version

Page	Item	Version 2020	Change	Motivation for change
5	Table 1 Status of variables for measurements	.LFM	.LFM--> LFA, LFM -->LFA, .LFM--> LFC	New reporting tables/ forms within the ICP F database
5	Table 1 Status of variables for measurements		added variable "reference temperature"	More information was added about the reference temperature of reported chemical values. Reference temperature is important for calculation of litterfall nutrient fluxes.
6	3 Objectives	added item to motivation of litterfall measurements	Added item to motivation of litterfall measurements: Assessment of most years (high seed production coordinated across populations), in particular in beech and oak forest stands	Most year research is an emergly vibrant field, for which the ICP F litterfall database can provide valuable contributions particularly with regard to the "fruits and seeds" fraction of beech
10	Figure 2 Procedural flow diagram		updated figure	More precise description of LF treatment procedure, some grammar mistakes corrected
10	5.2 Litter sorting and quantity	All litter sorting into fractions should be made wearing non-contaminatory gloves,	All litter sorting into fractions should be made wearing non-contaminatory gloves (i.e., no gloves with talc powder),	More precise which kind of gloves should be avoided
10	5.2 Litter sorting and quantity		Added sentence: The reported biomass values of sorted fractions per collection period should always sum up to total litter biomass.	This might be clear to most partners, but maybe not all partners and was therefore explicitly mentioned in the manual in order to avoid problems of sample completeness in the database.
11	Table 2 Fractionation of litterfall		Updated table for new fractions ("Rest of litterfall after sorted fraction" and "Fruits and seeds (main species)", "Fruits and seeds (secondary species)"). These new fractions prevented data submission of some partners who approached the PCC about it. Furthermore, the definition of some fractions was refined, because they were unclear/ambiguous in the past: "Seeds only" and "Capsules and cones including green cones. Capsules and cones can be either empty or still contain seeds that are tightly attached"	New/updated fraction definitions were asked for by partners who had problems either while sorting litterfall or submitting measured fractions.

<p>11</p>	<p>5.2 Litter sorting and quantity measurement</p>	<p>It is assumed that large branches >2 cm diameter, not often captured within the litter traps, will be recorded as part of the deadwood estimates of the plot, as taken during ecological surveys. The various fractions should be dried separately at maximum 70°C until constant weight is achieved (at least 24 hrs for fine fractions and leaves, but longer for substantial woody debris), and weighed to 2 decimal places (g). Annual totals will be reported on Form *.LFM, but there is also the facility to report mass/m2 with other time periods as both start and end date are to be recorded in form *.LFM. Storage may then be made until the annual total of material is accumulated (see flow chart Figure 2.). The monthly mass of the various fractions can then be totalised from April to March to achieve annual litterfall mass at the plot in g/m2, and submitted to the data centre on form *.LFM. Stored material may then be pooled at the end of the year, well mixed and subsamples taken for assessment of the weight of 100 leaves or 1000 needles (minimum requirement). Two further subsamples of the annual total can then be taken for chemical analysis (5.3). In the case of foliar material from the main canopy species, it is recommended that a series of replicates should be prepared from the pooled total to allow some assessment of both the chemical variability of the material, although only the mean is required for reporting purposes. However, litter material present in only small quantities at the end of the year, such as flowers (or bud scales), may be pooled across all the traps and chemically analysed as one total sample</p>	<p>"It is assumed that large branches >2 cm diameter, not often captured within the litter traps, will be recorded as part of the deadwood estimates of the plot, as taken during ecological surveys. The various fractions should be dried separately at maximum 70°C until constant weight is achieved (at least 24 hrs for fine fractions and leaves, but longer for substantial woody debris), and weighed to 2 decimal places (g). Litterfall dry mass/m2 (either from individual collection periods or aggregated/annual totals) will be reported in the form *.LFD along with respective collection start and end dates. Information on litterfall dry mass from individual collection periods can be quite valuable particularly in fall for e.g. phenological analysis.</p>	<p>Corrected references to the table, clarified text (too much remains from foliar manuals)</p>
<p>12</p>	<p>5.3 Quality of litterfall – chemical analysis</p>	<p>The chemical analysis of litter is similar to that of foliar component. For techniques and analytical methods in more detail see Part XII of the ICP Forests Manual on Sampling and Analysis of Needles and Leaves. Analysis will be made on an annual sample of the various fractions, determined by pooling the monthly collection through the year (April – March) or mean of periodic samples (see 4.3).</p>	<p>The chemical analysis of litter is similar to that of sampled foliage within the ICP Forests foliage survey. For techniques and analytical methods in more detail see Part XII of the ICP Forests Manual on Sampling and Analysis of Needles and Leaves. Analysis will be made on an annual sample of the various fractions or alternatively from shorter periods, The annual reporting period can be either the calendar year or April–March (see 4.3).</p>	<p>Text is clearer now with respect to length of pooling periods</p>

12	5.3 Quality of litterfall – chemical analysis		All chemical element concentrations and biomass of litterfall should be reported moisture corrected from dry ground material mass by drying subsamples to 105°C. Reporting biomass and concentrations in reference to other drying temperatures but 105°C is not recommended but possible, in case you were e.g. not able to determine a moisture correction factor for actual drying temperature to 105°C. In this case, the reference temperature for submitted nutrient concentrations can be reported in the column reference temperature in form LFC, while biomass dried at 70°C is reported in column dry_weight_70 in form LFD.	More information was added about the reference temperature of reported chemical values. Reference temperature is important for calculation of litterfall nutrient fluxes.
16	5.4 Specific Leaf area measurement	SLA can be made both fresh weight and on a dry weight basis, but the latter gives better standardisation between sites.	SLA should be made on a dry weight basis, to give better standardisation between sites.	In the LAI manual, there is no mention that SLA should be measured on both a fresh and dry weight basis. SLA is defined by dry weight.
18	Tables 3a-d Plausibility limits	plausible values	updated plausible values	Updated reference values are now based on 5th and 95th percentile of current LF database. This was necessary, because the former min/max approach rendered some implausible values particularly for N. Reference values were only calculated for chemical measurement series of > 100 values.

Annex II: Minor changes after 2025

Date	Minor change to latest published version in 2025	Affected sections of this document