Part XIII: Sampling and Analysis of Litterfall

Liisa Ukonmaanaho, Rona Pitman, Annemarie Bastrup-Birk, Nathalie Bréda, Pasi Rautio

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 2020-1

Prepared by:

ICP Forests Expert Panel on Foliage and Litterfall

(Liisa Ukonmaanaho, Rona Pitman, Annemarie Bastrup-Birk, Nathalie Breda, Pasi Rautio)

Ukonmaanaho, L., Pitman R, Bastrup-Birk A, Breda N, Rautio P, 2020: Part XIII: Sampling and Analysis of Litterfall. Version 2020-1. 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, 18 p. + Annex [http://www.icp-forests.org/manual.htm].

ISBN: 978-3-86576-162-0

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, 2020

CONTENTS

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 m2 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				
LFM	Dry weight per m^2 [kg/m^2] for total litter biomass	n	o	m
LFM	Dry weight per m^2 [kg/m^2] for foliar litter biomass	n	o	m
LFM	Dry weight per m^2 [kg/m^2] for other litter biomass	n	o	m
LFM	Dry mass of 100 leaves or of 1000 needles [g]	n	o	o
LFM	Area of 100 leaves or of 1000 needles [m^2]	n	o	o
Chemical analyses				
LFM	C [g/100g]	n	o	m
LFM	N [mg/g]	n	o	m
LFM	S [mg/g]	n	o	m
LFM	P [mg/g]	n	o	m
LFM	Ca [mg/g]	n	o	m
LFM	Mg [mg/g]	n	o	m
LFM	K [mg/g]	n	o	m
LFM	Zn [µg/g]	n	o	o
LFM	Mn [µg/g]	n	o	o
LFM	Fe [µg/g]	n	o	o
LFM	Cu [µg/g]	n	o	o
LFM	Pb [µg/g]	n	o	o
LFM	B [µg/g]	n	o	o
LFM	Cd [ng/g]	n	o	o
LFM	As [ng/g]	n	o	o
LFM	Cr [µg/g]	n	o	o
LFM	Co [µg/g]	n	o	o
LFM	Hg [ng/g]	n	o	o
LFM	Ni [µg/g]	n	o	o

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 kg m^{-2}.

- 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 **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).

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 situating 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 m^2 but preferably over 0.25 m^2). 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 m^2).

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 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.

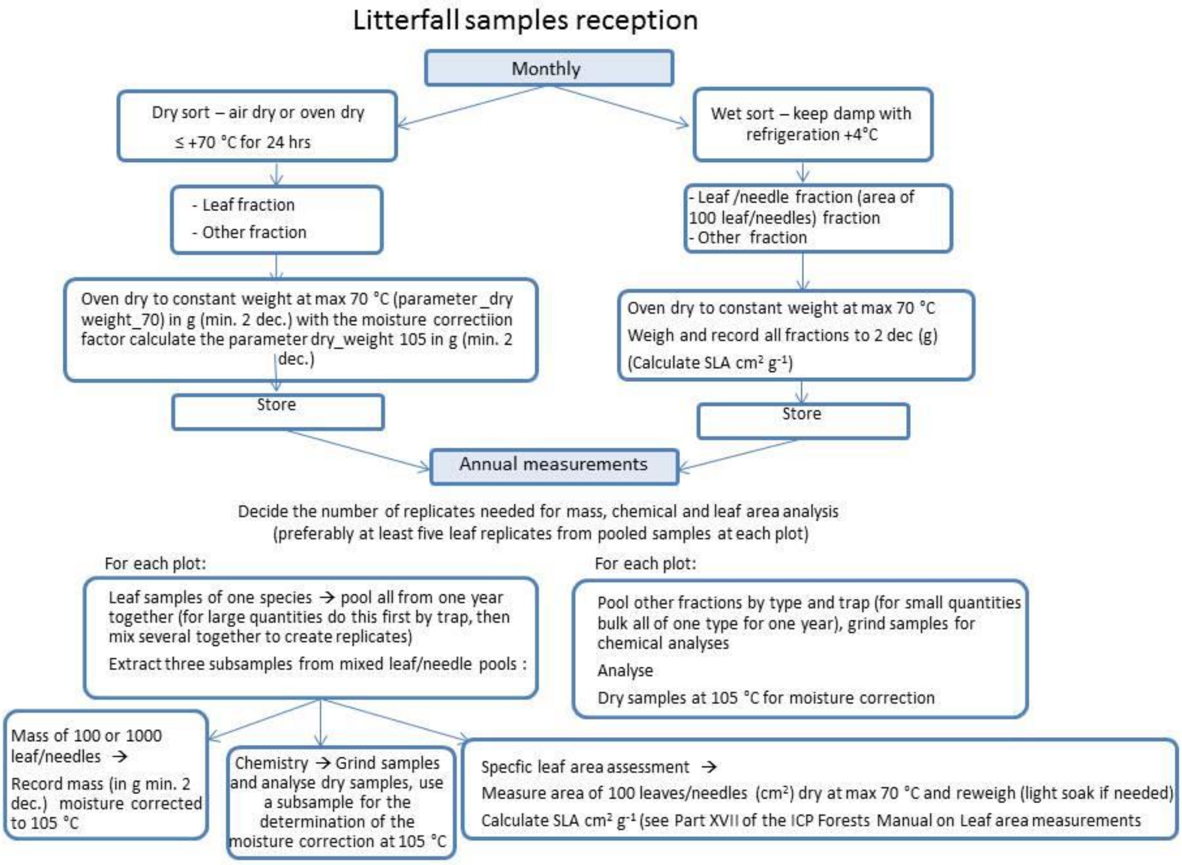

Figure 2: Procedural flow diagram for pretreatment of litter samples

5.2 Litter sorting and quantity measurement

All litter sorting into fractions should be made wearing non-contaminatory gloves, both for personal safety and to allow chemical analysis afterwards. 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.

Table 2: Fractionation of litterfall

Fraction of Litterfall	Level II	Level II core plot
Total litter biomass kg/m^2 (all species)	o	m
Foliar litter total (all species)	o	m
Foliar litter (main species)	o	m
Foliar litter (other tree species)	o	m
Non foliar litter total (all species)	o	m
Flowers total (including catkins)	o	o
Flowers (main species)	o	o
Flowers (other species)	o	o
Fruits/seeds total (all species)	o	m
Fruits/seeds total incl. green cones (main species)	o	m
Fruit capsules + empty cones (main species)	o	o (m*)
Rest of fruiting	o	o
Fruits /seeds total incl. green cones (other species)	o	m
Fruit capsules + empty cones (other tree species)	o	o
Bud scales	o	o
Wood fraction (Twigs <2 cm D/branches/bark)	o	o
Fines, frass, insects[#] (not included to the total litter biomass)	o	o
Other biomass (lichen, moss etc)	o	o

o = optional, m = mandatory

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

[#] If the organism involved can be identified, the scientific name must be reported, using the codes of 7 letters. Codes for the most common damaging species are listed in the internet file: https://www.icp-forests.org/documentation/ExplanatoryItems/58.html -> listed in dictionary *d_cause_sc_name* Add the name in column *other_ obs*

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 kg m-2, 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.

5.3 Quality of litterfall – chemical analysis

The chemical analysis of litter is similar to that of the 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)

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. For Quality control recommendations see section 6.

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

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.,2009). 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 (LAImax) 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):

SLA = A/m (cm^2 per g) LMA = m/A (g per cm^2)

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 can be made on both fresh weight and dry weight bases, but the latter gives 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 on the reported chemical composition of litterfall samples. It is anticipated that these limits will be frequently 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.

Table 3a: Plausible range of element concentrations in a) the foliar, b) flower, c) seeds, and d) twigs-litter **of different species.** Source: Litterfall Database, ICP Forests.

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	Hg ng/g	Ni µg/g
FOLIAR (11)																					
20	*Fagus*	min	46.0	7.6	0.6	0.2	2.5	0.4	0.9	15	900	90	3.0	0.4	20.0	80	50	0.3	0.10	*n.d*	1.4
	sylvativa	max	58.0	25.0	2.1	2.0	18.0	5.0	8.0	65	3400	500	18.0	7.0	45.0	360	120	1.2	0.30	*n.d*	3
118	*Picea abies*	min	40.0	4.6	0.4	0.2	1.5	0.2	0.6	11	194	13	1.0	0.1	3.0	30	50	0.2	0.07	61	0.5
		max	62.0	18.0	1.8	1.8	19.0	2.8	6.2	120	3400	550	10.0	14.0	35.0	280	180	2.2	0.50	80	5
134	*Pinus*	min	45.0	1.2	0.2	0.2	0.2	0.2	0.2	10	100	10	2.0	0.1	3.0	35	10	0.2	0.07	*n.d*	0.5
	sylvestris	max	58.0	50.0	3.8	3.5	15.0	3.8	10.0	200	2500	400	25.0	15.0	50.0	600	800	2.0	0.50	*n.d*	20
10	*Betula*	min	53.0	7.0	0.5	1.2	3.0	0.5	0.5	80	300	45	2.5	2.0	6.0	120	*n.d*	0.4	4.00	*n.d*	1.5
	pendula	max	57.0	40.0	3.0	3.5	14.0	3.5	10.0	220	1700	400	10.0	9.0	19.0	450	*n.d*	5.0	16.00	*n.d*	8
44	*Querqus*	min	41.0	6.0	0.5	0.3	5.0	0.5	0.5	15	300	80	2.0	0.3	*n.d*	100	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*
	frainette	max	58.0	20.1	2.0	2.0	20.0	2.8	10.0	40	3500	300	13.0	5.0	*n.d*	110	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*
51	*Querqus*	min	42.0	1.1	0.4	0.2	2.0	0.4	0.5	5	200	80	1.0	0.5	20.0	10	10	0.01	0.01	*n.d*	0.07
	robur	max	60.0	30.0	5.0	10.0	40.0	10.0	20.0	50	3500	300	20.0	30.0	50.0	600	800	2	0.40	*n.d*	4.5
48	*Querqus*	min	35.0	5.0	0.3	0.2	2.0	0.2	0.2	8	250	50	3.0	0.2	10.0	20	30	0.1	*n.d*	*n.d*	1
	petraea	max	58.0	37.0	5.0	6.0	40.0	10.0	10.0	50	4000	300	15.0	50.0	40.0	400	50	1.5	*n.d*	*n.d*	7
120	*Picea*	min	41.0	6.0	0.6	0.4	1.5	0.5	0.5	6	70	50	1.5	0.2	*n.d*	10	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*
	sitchensis	max	57.0	20.0	2.0	2.0	15.0	3.0	5.0	40	1200	200	5.0	5.0	*n.d*	100	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*

Table 3b: Plausible range of element concentrations in a) the foliar, **b) flower**, c) seeds, and d) twigs-litter **of different species.** Source: Litterfall Database, ICP Forests.

Tree species code	name	Limit	C	N	S	P	Ca	Mg	K	Zn	Mn	Fe	Cu	Pb	B	Cd	As	Cr	Co	Hg	Ni
			g/100g	mg/g	mg/g	mg/g	mg/g	mg/g	mg/g	µg/g	µg/g	µg/g	µg/g	µg/g	µg/g	ng/g	ng/g	µg/g	µg/g	ng/g	µg/g
FLOWERS (13)																					
20	*Fagus*	min	48.0	3.3	0.2	0.2	1.0	0.2	0.2	5	70	25	4.0	0.2	8.0	55	30	0.2	0.05		1.0
	sylvativa	max	57.0	35.0	3.0	3.1	7.0	2.5	10.0	50	1500	450	20.0	3.0	35.0	420	150	4.5	0.50		5.0
118	*Picea abies*	min	50.4	5.7	0.4	0.5	0.3	0.3	0.9	16	78	21	2.9	0.2	2.0	38	30	0.2	0.18		3
		max	58.0	28.0	2.3	2.4	4.4	3.6	7.1	104	900	487	16.5	12.4	27.9	330	60	0.9	1.80		20
134	*Pinus*	min	50.0	1.2	0.1	0.1	0.2	0.3	0.7	10	27	10	1.5	0.1	2.9	52	10	0.2	0.07		0.6
	sylvestris	max	56.0	25.0	2.3	3.5	4.0	2.0	9.0	45	1300	170	10.6	7.5	26.0	270	30	1	0.30		2
10	*Betula*	min	53.0	7.5	0.7	1.0	2.0	0.5	0.5	16	50	50	5.0	0.2	8.0	54	*n.d*	0.3	4.00		3
	pendula	max	57.0	30.0	2.2	4.0	6.4	2.2	5.1	130	1500	160	10.0	2.0	17.0	100	*n.d*	3	8.00		10
44	*Querqus*	min	46.0	15.0	1.0	0.2	5.0	1.0	1.0	*n.d*	500	*n.d*	10.0	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*
	frainette	max	47.0	25.0	2.5	2.0	15.0	2.5	5.0	*n.d*	1500	*n.d*	20.0	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*
51	*Querqus*	min	47.0	20.0	0.4	0.5	2.0	1.5	1.4	20	90	40	10.0	0.4	25.0	90	*n.d*	0.5		*n.d*	1
	robur	max	52.0	40.0	2.6	3.5	12.0	2.4	10.0	50	1400	290	20.0	3.0	50.0	200	*n.d*	2		*n.d*	2.5
48	*Querqus*	min	47.0	10.0	1.0	1.0	5.0	0.8	1.5	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*
	petraea	max	55.0	35.0	2.5	2.0	18.0	3.0	7.5	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*
120	*Picea*	min	50.0	15.0	*n.d*	1.0	1.6	0.9	1.3	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*
	sitchensis	max	54.0	20.0	*n.d*	2.0	5.0	2.0	5.0	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*

Table 3c: Plausible range of element concentrations in a) the foliar, b) flower, **c) seeds**, and d) twigs-litter **of different species.** Source: Litterfall Database, ICP Forests.

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	Hg ng/g	Ni µg/g
SEEDS (14)																					
20	*Fagus*	min	40.0	4.0	0.2	0.3	1.5	0.5	0.5	6	50	25	1.3	0.1	8.0	30	250	0.2	0.2	n.d	1.2
	sylvativa	max	60.0	34.0	2.6	3.9	12.0	2.5	8.5	40	2800	250	20.0	7.0	30.0	320	800	1.5	0.3	n.d	10.0
118	*Picea abies*	min	44.0	3.1	0.3	0.2	0.1	0.2	0.2	10	35	11	2.3	0.1	4.4	37	n.d	0.13	0.12	n.d	2.7
		max	60.0	32.0	3.1	6.0	12.8	3.2	13.3	105	471	402	13.8	23.3	26.6	450	n.d	1.1	0.42	n.d	7
134	*Pinus*	min	46.0	1.7	0.2	0.1	0.1	0.1	0.1	11	14	13	1.6	0.1	5.0	50	n.d	0.2	n.d	n.d	1
	sylvestris	max	59.0	35.0	4.0	8.0	6.3	3.8	10.1	140	900	550	35.0	15.0	29.0	450	n.d	1	n.d	n.d	3
10	*Betula*	min	50.0	10.0	0.7	1.0	4.0	0.5	2.0	15	350	55	4.0	0.2	8.0	100	n.d	1.2	n.d	n.d	3
	pendula	max	56.0	28.0	1.9	4.0	10.0	2.0	6.0	150	1500	200	20.0	5.0	15.0	150	n.d	1.7	n.d	n.d	10
44	*Querqus*	min	40.0	5.0	0.6	0.3	4.0	0.5	1.0	10	200	20	4.0	0.1	n.d	75	n.d	n.d	n.d	n.d	n.d
	frainette	max	59.0	22.0	2.1	2.0	25.0	2.0	9.0	110	1500	500	15.0	5.0	n.d	200	n.d	n.d	n.d	n.d	n.d
51	*Querqus*	min	40.0	0.5	0.5	0.4	0.9	0.3	1.0	5	25	10	2.0	0.1	13.0	15	n.d	n.d	n.d	n.d	0.5
	robur	max	56.0	32.0	3.5	2.5	25.0	2.5	11.0	70	1000	250	20.0	30.0	20.0	120	n.d	n.d	n.d	n.d	1.5
48	*Querqus*	min	43.0	5.0	0.3	0.3	0.6	0.3	0.1	5	50	10	4.0	0.1	8.0	15	n.d	0.05	0.01	n.d	0.25
	petraea	max	52.0	15.0	3.0	2.0	25.0	2.5	15.0	50	1300	150	30.0	50.0	22.0	450	n.d	1	0.1	n.d	4
120	*Picea*	min	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d
	sitchensis	max	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d

Table 3d: Plausible range of element concentrations in a) the foliar, b) flower, c) seeds, and **d) twigs-litter of different species.** Source: Litterfall Database, ICP Forests.

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	Hg ng/g	Ni µg/g
TWIGS (16)																					
20	*Fagus*	min	44.0	4.3	0.1	0.2	1.4	0.2	0.5	16	100	20	2.4	0.6	9.0	80	30	0.3	0.1	*n.d*	0.6
	sylvativa	max	60.0	21.1	2.0	6.0	23.0	10.0	6.0	100	2000	350	20.0	17.0	28.0	300	800	2.0	2.2	*n.d*	4.0
118	*Picea abies*	min	45.0	5.6	0.3	0.1	0.6	0.2	0.7	16	51	44	1.5	0.6	3.4	40	160	0.9	0.3	32.0	2.3
		max	63.0	27.7	8.6	2.2	12.4	2.0	8.0	170	2000	900	14.6	32.1	20.0	600	260	2.6	1.2	79.0	7.6
134	*Pinus*	min	47.7	2.4	0.1	0.1	2.0	0.2	0.3	16	50	40	2.9	0.9	4.7	150	70	0.5	0.1	*n.d*	0.5
	sylvestris	max	59.0	20.4	1.6	3.0	13.0	3.1	4.1	91	1000	500	30.0	20.0	20.0	1100	900	3	1.2	*n.d*	3.0
10	*Betula*	min	51.0	4.6	0.3	1.5	3.0	0.5	0.5	100	200	18	3.0	0.8	6.0	100	*n.d*	0.2	*n.d*	*n.d*	0.5
	pendula	max	56.0	12.0	1.0	0.7	10.0	2.0	3.0	200	500	100	9.0	3.0	15.0	420	*n.d*	0.5	*n.d*	*n.d*	3.0
44	*Querqus*	min	36.0	4.0	0.5	0.2	5.0	0.5	2.0	15	500	35	2.0	0.1	*n.d*	200	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*
	frainette	max	58.0	15.0	2.6	4.0	23.0	5.0	9.0	70	1500	300	15.0	5.0	*n.d*	350	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*
51	*Querqus*	min	37.0	4.0	0.5	0.1	1.3	0.1	0.1	10	20	10	2.5	0.4	10.0	19	90	0.2	0.1	*n.d*	1.0
	robur	max	52.0	25.0	7.0	1.6	30.0	10.0	10.0	90	500	220	25.0	50.0	24.0	500	110	0.7	0.5	*n.d*	2.0
48	*Querqus*	min	35.0	3.0	0.3	0.2	2.2	0.1	0.2	13	100	30	1.5	0.3	10.0	20	50	0.2	0.1	*n.d*	0.5
	petraea	max	54.0	35.0	7.5	1.7	20.0	10.0	9.0	100	2500	300	15.0	50.0	15.0	350	60	1	0.2	*n.d*	4.0
120	*Picea*	min	50.0	2.5	0.4	0.1	1.5	0.5	0.3	10	20	50	1.5	1.5	*n.d*	10	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*
	sitchensis	max	56.0	15.0	2.0	1.0	15.0	2.0	10.0	100	500	300	10.0	10.0	*n.d*	200	*n.d*	*n.d*	*n.d*	*n.d*	*n.d*

6.2 Data completeness

Table1 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 http://www.icp-forests.org/ Manual.htm). 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, Schleppi 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., Schlenter 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 – Minor changes after 2020

Date	Minor change to latest published version in 2020	Affected sections of this document