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Common Tree Definitions for National Forest Inventories in Europe

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At the international level, various definitions have been established for the compilation and publication of forest resources assessment results over the last decade. These international definitions frequently rely on terms that are not precisely specified for inventory purposes and do not completely cover the requirements arising from the application of National Forest Inventory (NFI) data. Also, with respect to conventional topics such as forest area and growing stock estimation, several terms and expressions referring to individual trees are not, or are only vaguely, defined until now. Since the individual tree is the basic element of any forest resources assessment, the clarification of tree-related terms is an important part of COST Action E43 to harmonise common reporting of National Forest Inventories. Based on a review of existing definitions and on the requirements for harmonised reporting, common tree-related definitions are established. One objective of this study is to refine and enhance the applicability of available tree and shrub definitions, in particular with regard to the distinction between trees and shrubs. The study also focuses on the parts or "elements" of trees and on the distinction between these elements as they are of particular importance in growing stock and biomass definitions. Furthermore, several definitions for tree characteristics such as "living" and "standing", as well as tree variables such as height, length, diameter at breast height, and crown projection area are adjusted with respect to NFI purposes. A concluding discussion reflects upon the reviewed, refined and newly established definitions. The definitions presented in this paper provide a firm basis for a common set of harmonised reference definitions developed by COST Action E43 and contribute to the precise and consistent use of terms.

Keywords COST Action E43, harmonisation, tree definitions, shrub definitions, tree elements, tree variables, tree characteristics
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1 Introduction

European National Forest Inventories (NFIs) are involved in several international reporting programs and conventions. They provide information on forest resources at the national and sub-national level to processes like the Forest Resources Assessment (FRA) conducted by FAO and UNECE/FAO, the Intergovernmental Panel on Climate Change (IPCC), the United Nations Framework Convention on Climate Change (UNFCCC), the Convention on Biological Diversity (CBD) and the Ministerial Conference on the Protection of Forests in Europe (MCPFE). Information from European NFIs has gained an excellent reputation for the statistically sound methodologies applied, the representativity of data, and the data quality. However, European NFIs were originally designed for national and sub-national information needs. The applied terms and definitions vary between European NFIs, reflecting different historical backgrounds of NFIs and the different role of forests in individual countries.

In recent decades, the scope of NFIs has broadened, information needs have increased, and the scale of inventories has changed. While NFIs traditionally had focussed on economic oriented matters such as wood production and supply, they are nowadays involved in relatively new topics, such as carbon pool estimation, biodiversity assessment and the evaluation of forests potential as a renewable energy source. Further evolution in this context can be expected, implying new requirements and applications of National Forest Inventory data. Since these topics are of international relevance, they gave rise to the need for comparable information and the harmonisation of European NFIs. In particular, the demand for comparable results for international reporting processes has increased.

Existing definitions at the national and international level often refer to and rely on terms that leave room for interpretation. For example, the definitions for forest, other wooded land, growing stock, and numerous other definitions for biomass according to FAO (1998), UNECE/FAO (2000), IPCC (2003) and FAO (2004) frequently use terms that are not precisely defined. In particular, these definitions often refer to trees or shrubs. Although FAO (1998, 2004) and UNECE/FAO (2000) specify trees and shrubs in their terms and definitions, these definitions are difficult to apply for distinguishing trees from shrubs as often required in NFIs. However, it is important to emphasise that, due to variations in nature, the distinction between trees and shrubs can be difficult. Moreover, existing definitions often employ terms that are not defined for the purpose of reporting, primarily at the international level. This is particularly true for the parts of a tree like stem, branches, bark and foliage, but also for variables such as height, crown cover, diameter at breast height, and for the characteristics of living and dead, and standing and lying trees.

The objective of COST Action E43 is to harmonise the NFIs in Europe in such a way that inventory results are comparable (Tomppo et al. 2007). Working Group 1 of COST Action E43 reviews the current practices and definitions of the NFIs in participating countries and proposes a common set of precise and unique reference definitions which are the basis for harmonisation. These reference definitions are derived from analysis of existing national and international definitions. They take into account the principles of neutrality, objectivity, practicability, sustainability, clearness, acceptability and independence of measurement devices (Vidal et al. 2008). Reference definitions that meet international requirements are recommendations for existing and emerging NFIs. Results in accordance with the reference definitions are comparable and can be aggregated at a multi-national level. In this article existing tree-related definitions and concepts are reviewed. The findings from this review are taken into account and enhanced, commonly agreed definitions are presented.

2 Material and Methods

Several sources were taken into account for establishing the definitions presented in this paper. The database of Working Group 1 of COST Action E43 (Tomppo et al. 2007) stores information collected with two questionnaires from the individual European National Forest Inventories. It is the

basic material for creating common definitions and contains – among other aspects – information on the applied threshold values, various tree characteristics and to some extent on national tree and shrub definitions. From FAO (1998), UNECE/FAO (2000), IPCC (2003) and FAO (2004) definitions were obtained that have been established at the international level for the purpose of publication of forest resources assessment results. Dictionaries on forestry (Delijska and Manoilov 2004, Ford-Robertson 1971, Helms 1998) were consulted to obtain additional definitions in the context of this discipline. To augment the above information concerning tree, shrub and tree parts, the viewpoint of plant sciences was taken into consideration (Allaby 1998, Bailey 1999). For questions concerning the branching systems of trees, literature on plant architecture was also consulted (Barthélémy and Caraglio 2007, Scott 1995). General explanations were obtained from Simpson and Weiner (1991) and Crystal (1997). These sources were also used to clarify terminological aspects and to choose the most adequate term when no commonly used terminology had been established up to now.

The work involved several steps. First, the existing international definitions were reviewed with respect to the requirements of common tree-related definitions and shortcomings were identified. The definitions from forestry dictionaries were considered to support the identification of shortcomings. Second, information on National Forest Inventory guidelines was obtained from the database of COST Action E43 and supported the finding of solutions to overcome the shortcomings. Third, based on the findings, existing definitions were refined and new definitions for inventory purposes were established. Fourth, the new definitions were proposed to the national inventory experts in Working Group 1 of COST Action E43, discussed and revised until final agreement.

3 Common Definitions

3.1 Definition of Tree and Shrub

NFI methodology involves tree and shrub definitions at several stages during the assessment of forest resources. Primarily, the definitions are required in the decision process that classifies individual NFI plots as forest, other wooded land or other land. The classification is based on the assessment of variables such as tree height, tree crown cover, and the combined cover of shrubs and trees. The variables tree height and crown cover for example, are assessed on trees or trees and shrubs distributed over a delineated area. This means that these variables are assessed on individual trees, and an average height and a percentage of area covered by crown projections (usually without overlapping) is deduced to represent the delineated area. Several NFIs determine a borderline based on individual woody plants to separate forest, other wooded land and other land. The determination of forest and other wooded land is the basis for the estimation of the area of these land classes. For these areas, further variables including biomass, growing stock, and increment have to be estimated. To define these variables a distinction between trees and shrubs is required.

International tree and shrub definitions use similar characteristics for specifying the features of trees and shrubs (FAO 1998, FAO 2004, UNECE/FAO 2000). According to these definitions a tree has mainly three characteristics:

- It is a woody perennial plant,
- with a single main stem or in case of coppice several stems,
- and has a more or less definite crown.

Ford-Robertson (1971) states, that a tree is typically large. Crystal (1997) mentions a self-supporting stem as an additional feature. Several sources refer to the minimum size of a tree, e.g. a height of 3 m (Delijska and Manoilov 2004), or a diameter of 12.7 cm and a height of 4.6 m (Helms 1998). Allaby (1998) gives a minimum height of more than 10 m.

International definitions (FAO 1998, FAO 2004, UNECE/FAO 2000) specify shrubs as

– woody perennial plants,
– often without a definite crown,
– and generally with heights between 0.5 m and 5 m.

Moreover, UNECE/FAO (2000) states that shrubs are often without a definite stem, and according to Simpson and Weiner (1991), a shrub has several stems growing from the same root. A similar definition is given by Bailey (1999), although it limits the size of a shrub to below 10 m in height. Additional information can be obtained from the shrub definitions of FAO (1998, 2004), which state that they refer to vegetation types where the dominant woody elements are shrubs and that the height limits of 0.5 m to 5 m refer to heights at maturity. Moreover, FAO (1998, 2004) mentions that this minimum and maximum height should be interpreted with flexibility, particularly the minimum tree and maximum shrub height, which may vary between 5 m and 7 m.

From the outlined definitions, no clear and unambiguous criteria for the distinction of tree and shrub are available. The terms 'stem' and 'crown' are not specified, and the "definiteness" of a crown can hardly be quantified. Also the height limit that separates trees from shrubs ranges between 5 and 7 m. Furthermore, all FAO definitions restrict the existence of multiple stems to shrubs and to trees in coppice forests. But multi-stemmed trees may also occur under other management practices or specific site conditions. The difficulties of distinguishing between trees and shrubs are mentioned in the shrub definitions provided by Ford-Robertson (1971), Delijska and Manoilov (2004), Helms (1998) and Crystal (1997).

Taking into account the previous arguments, refined definitions for trees and shrubs are formulated:

A **tree**, for NFI purposes, is *a woody perennial of a species typically forming a single self-supporting main stem and having a definite crown.*

A **shrub**, for NFI purposes, is *a woody perennial of a species typically not forming a single main stem and not having a definite crown.*

The presence of a single main stem and definite crown as stated in the tree definition is also described as acrotony, which is the preferred development of lateral axes in the distal part of the main stem. Contrarily, a shrub is defined by the absence of a single main stem and definite crown. This feature is denoted as basitony, which is the preferred development of lateral axes in the basal part of the vertical stems (Bartélémy and Caraglio 2007).

These general definitions of a tree and a shrub can serve as basis for the construction of a species list if required by individual NFIs. A species list is a register of woody plant species. It can be appropriate to assign to each species in the species list the attribute being a tree or the attribute being a shrub according to the definitions above. However, in some cases species that are commonly recognised as trees can show the features of a shrub under specific site conditions, and similarly, shrub species can have the morphology of a tree. The morphology of a species in a certain location depends on a number of factors including latitude, altitude, exposure, soil condition and silvicultural treatment. Generally, a species is either a tree or a shrub at a particular NFI plot. In certain cases a species can be a tree and a shrub at one NFI plot, because it occurs in two sub-species at the same location like for example *Salix caprea* in northern Scandinavia. A distinction of tree and shrub at the sub-species level is proposed in these situations.

3.2 Tree Parts and Tree Elements

3.2.1 Tree Parts in National and International Definitions

One of the most important information compiled from NFIs is the volume or biomass of trees growing in forest and other wooded land. Reported volumes usually include only parts of the total volume of single trees, and only trees fulfilling certain characteristics and minimum thresholds. An example is growing stock which is differently defined in European NFIs. A survey in 24 European NFIs reveals that the bole (woody part) is integrated into all national growing stock definitions. Also the bark of the bole is included by most NFIs. The stem top, branches and the

Table 1. Tree parts included in growing stock definitions of 24 European NFIs.

Tree part	Number of countries	Growing stock (10^6 m^3)	%
Bole wood	24	21483	100.0
Bole bark	21	20076	93.5
Stem top	16	17325	80.6
Stump above-ground	12	11485	53.5
Large branches	4	3488	16.2
Small branches	0	0	0.0
Foliage	0	0	0.0
Below-ground part	0	0	0.0

above-ground part of the stump are not necessarily included in national growing stock estimates (Table 1). These tree parts are defined differently at the national level and clarification is required when harmonising volume and biomass estimations.

Different parts of a tree are mentioned in the definitions or glossaries of FAO (1998), UNECE/FAO (2000), FAO (2004) and IPCC (2003) (Table 2), but a definition is only available for stumps and roots in UNECE/FAO (2000). A systematic terminology and definitions for the different parts of a tree for NFI purposes and common reporting are missing.

3.2.2 Partitioning of a Tree into Elements

To establish a clear specification for each tree part, a hierarchical partitioning approach has been chosen, in which the whole tree is stepwise divided into disjoint parts or elements. The objective of this general and flexible approach is to lay the basis for a broad range of additive and comparable volume or biomass estimates, which include or exclude well-defined elements of trees depending on the respective information needs. The proposed partition of the whole tree into elements and the established terminology covers the basic needs for current reporting requirements within the framework of FRA, MCPFE and IPCC. But it also allows further division into smaller elements if needed in the future.

The partitioning approach involves five steps, or levels of differentiation (Fig. 1). At each level, any part of the tree belongs only to one element. Starting from the whole tree (level I), we distinguish between above-ground part and below-ground part (level II). At level III the above-ground part is divided into stem, lateral parts and foliage. At level IV the stem is subdivided into stem top, bole and stump, and the lateral parts are partitioned into large and small branches. In the last step (level V) the bole is partitioned into wood and bark. The distinction of wood and bark may also be relevant for stump, stem top, large and small branches, and the below-ground part as indicated in Fig. 1. Corresponding to Fig. 1 the individual tree elements at the currently highest level of differentiation are illustrated in Fig. 2.

Table 2. Tree parts mentioned in international definitions.

Tree part	Source			
	FAO (1998)	UNECE/FAO (2000)	FAO (2004)	IPCC (2003)
Bark	x	x	x	x
Bole	x			
Branch	x	x	x	x
Branch, large		x		
Branch, small		x	x	
Foliage	x	x	x	x
Root	x	x	x	x
Root, small		x	x	
Stem	x	x	x	x
Stem, top of		x		
Stump	x	x	x	x
Stump, below-ground			x	
Twig	x	x	x	

The partitioning approach refers to woody perennials that are classified as tree according to the general tree definition presented in section 3.1. In the following an individual tree – as starting point of the partition into its elements – is defined as the sum of its distinct and disjoint elements:

The **whole tree** *comprises all parts or organs of a tree, ranging from the leaves, flowers, fruits and buds to the branches, stem, roots and fine roots.*

The whole tree also contains the fine roots, although they are considered as part of soil organic matter or litter in some definitions on the basis of measurement practicability (FAO 2004, IPCC 2003).

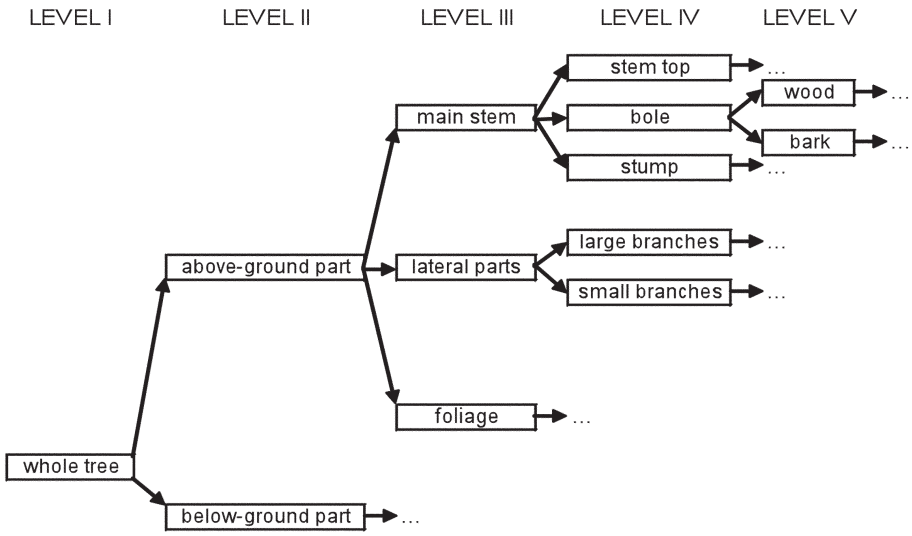

Fig. 1. Approach of partitioning a tree into elements. … further possible steps of partitioning.

The distinction of the above-ground and below-ground part of a tree is important in terms of biomass estimation. Relevant definitions can be found in FAO (1998), FAO (2004) and IPCC (2003), although the location of the dividing line is not specified. The ground surface, in our terms the boundary between the litter layer and the adjacent horizon, is a reasonable and generally identifiable dividing line for distinguishing the above-ground and below-ground part of a tree:

The **above-ground part** and the **below-ground part** of a tree *are separated by the surface of the ground.*

Crucial for the further partitioning of the above-ground part is that a tree typically has a single main stem. In terms of forestry, the stem is described as the main trunk or principal axis or body of a plant (Delijska and Manoilov 2004, Ford-Robertson 1971, Helms 1998). Any side axes develop from the main axis or stem through stem branching. Branches are of secondary order and grow out of the main stem (Allaby 1998, Simpson and Weiner 1991, Helms 1998, Delijska and Manoilov 2004). Thus, the above-ground part of a tree can be partitioned into stem, lateral parts or branches and foliage that comprises leaves, reproductive parts and buds:

The **stem** of a tree is *the above-ground part of the main (off) shoot with apical dominance*.

The above-ground **lateral parts** of a tree *are separated from the main stem by the theoretical intersection surface of the main stem.*

The **foliage** of a tree *comprises all above-ground temporary parts such as leaves and needles, reproductive parts and buds. It is separated from the main stem and the lateral parts by the location where the foliage is attached to the main stem or lateral parts.*

The main stem of a tree can be further divided into stump (above-ground part), bole and stem top. The distinction of stump, bole and stem top is frequently implied in international growing stock definitions (FAO 1998, FAO 2004, UNECE/FAO 2000, IPCC 2003). This step in the partitioning process implies size-dependence, since the distinction of the bole and the stem top requires an – economically relevant – top diameter threshold $Z_{\text{stem top}}$. Eight out of 24 European NFIs do not take into account the stem top in their growing stock definition. Therefore they define the diameter threshold $Z_{\text{stem top}}$ that separates the bole from the stem top. These diameter thresholds are given in Table 3.

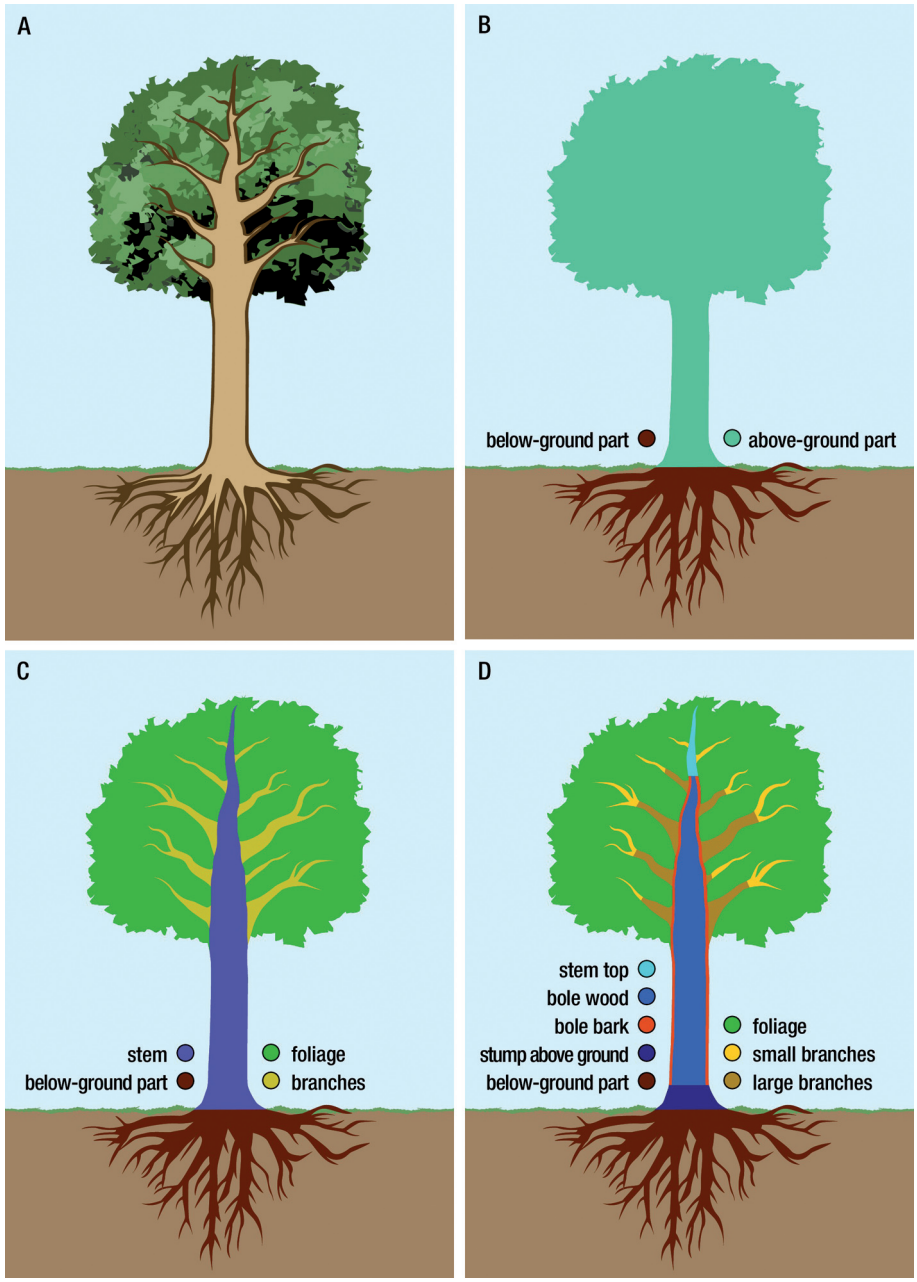

Fig. 2. The whole tree and its elements. A: whole tree, B: distinction of the above- and below-ground part, C: partitioning of above-ground part into stem, branches and foliage, D: further partitioning of the stem into stump, bole (wood and bark), and stem top, and branches into large and small branches.

Table 3. Inclusion of stem tops in growing stock definitions and stem top diameter thresholds in European NFIs.

Growing stock definition includes stem top	Stem top diameter (cm)	Number of countries	Growing stock (10^6 m^3)	%
No	5.0	1	177	0.8
	7.0	6	3093	14.4
	7.5	1	888	4.2
Yes	–	16	17325	80.6
Total		24	21483	100.0

The stem top diameter threshold refers to standing trees and is a over-bark diameter. Apart from the stem top, several NFIs exclude the stump from their growing stock definition. For this purpose a definition for the stump height is required. UNECE/FAO (2000) defines this stump height to be that at which a tree would be cut under normal felling practices. European NFIs either use a constant value of e.g. 30 cm, a relative value of 1% of the tree height, or the end of the root neck to locate the height where a tree would be cut. Concluding the preceding explanations the elements to which a stem is partitioned are defined as follows:

The **stump** of a tree is *the above-ground base part of the stem which would remain after a tree was cut under normal felling practices*.

The **stem top** of a tree is *the topmost part of the stem from an over-bark base-diameter of* $Z_{stem\ top}$ *cm to the stem tip.*

The **bole** of a tree is *the above-ground part of the stem between stump and the stem top*.

As already mentioned, the main stem bears, as a result of branching, the secondary or lateral parts of a tree. Four European NFIs distinguish between large and small branches by the means of a diameter threshold $Z_{branches}$, since they include large branches in their growing stock estimates (Table 1). These branch diameter thresholds range from 5.0 to 7.0 cm. The objective of this threshold is to distinguish between the usable parts of the branches from the ones that are usually left in the forest. Also UNECE/FAO (2000) and FAO (2004) mention the distinction between large and small branches. Twigs are mentioned by FAO (1998), UNECE/FAO (2000) and FAO (2004). Diameter thresholds for twigs, and equations that predict the biomass of twigs are not readily available. Therefore, we restrict the partitioning of the lateral parts into large and small branches:

The **large branches** of a tree are *the portion of the above-ground lateral parts with a diameter of more than or equal to* $Z_{branches}$ *cm.*

The **small branches** of a tree are *the portion of the above-ground lateral parts with a diameter of less than* $Z_{branches}$ *cm*.

All woody parts of trees and shrubs are normally covered by a protective layer of bark. In plant sciences and in forestry, the bark comprises the tissues outside the cambium (Allaby 1998, Bailey 1999, Helms 1998, Delijska and Manoilov 2004). In terms of wood-processing only the xylem is relevant. Therefore, all tissues outside the xylem should be assigned to the bark from a wood-manufacturing point of view. Ford-Robertson (1971) defines bark in these terms and thus provides a guideline for the formulation of a bark definition for NFI purposes:

The **bark** of a tree *includes all tissues of the main stem, lateral parts and below-ground parts between the xylem and the epidermis of the phellem*.

In all ligneous tree elements, it is possible to make the distinction between wood and bark. However, NFI definitions usually only refer to ‘over bark’ or ‘under bark’ volume. For economical reasons the distinction between wood and bark is particularly important when considering the bole of a tree

which is the part usable for timber industries. Therefore, we currently distinguish wood and bark only for the bole.

3.3 Tree Variables

Basic international definitions contain variables and threshold values that refer to individual trees, for example diameter at breast height, tree height and crown area. The definitions for forest and other wooded land imply a specified tree height and crown or canopy cover, whilst definitions for growing stock, increment and felling refer to trees of certain size in terms of diameters at breast height (FAO 1998, UNECE/FAO 2000, FAO 2004, and IPCC 2003). Since COST Action E43 aims at a common set of unambiguous applicable reference definitions, clear specifications of these variables and clear guidelines for their assessment are required.

3.3.1 Tree Height and Stem Length

Tree height is a relevant variable in the definitions of forest and other wooded land (FAO 1998, UNECE/FAO 2000, FAO 2004, and IPCC 2003). This height can be interpreted as the vertical distance between the highest point on the tree and the ground surface. Volume estimation requires the determination of the stem length rather than vertical height. Therefore, it is proposed to distinguish between the height of a tree and the stem length of a tree and define them as follows:

The **height** of a tree is *the vertical distance between the base point and the highest point of the tree.*

The **stem length** of a tree is *the distance along the stem axis between the base point and the stem tip.*

The base point is the common starting point of all height and length measurements including the localisation of breast height and stump height. On level terrain the base point is the point resulting from the intersection of the stem axis and the ground surface. On sloped terrain and on inclined trees the identification of the base point requires the previous identification of an intersection point.

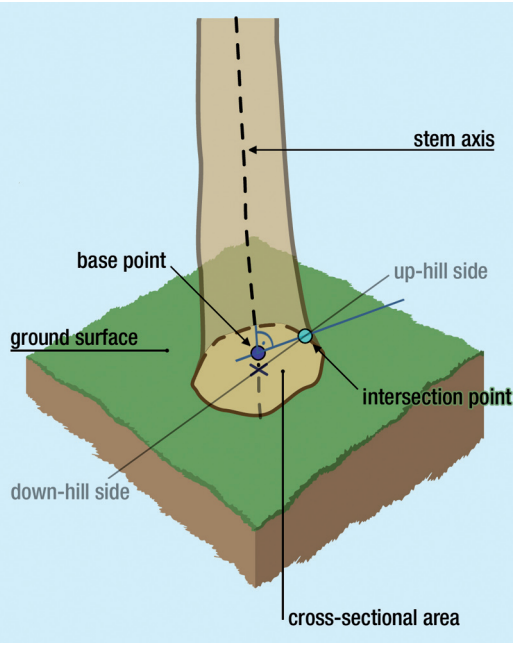

Fig. 3. The identification of the base point on sloped terrain.

This intersection point is the highest point on the cross-sectional area that results from the intersection of the ground surface with the stem. A line through the intersection point and perpendicular to the stem axis yields the base point in these cases (Fig. 3).

Usually the height and the stem length of a tree are similar, although the height measurement usually does not account for the minor deviations of the stem axis from a vertical straight line. In inclined or bent trees, the difference between tree height and the stem length of a tree becomes more obvious. Several examples of tree height and measurements along the stem axis are given in Fig. 4.

The level of the ground surface can change over time (e.g. in inundation areas, peat lands). If the actual ground level is lower than the original ground level, the base point is proposed to be located at the height of the root collar (Fig. 5). The tree variables like tree height, stem length and breast height are defined with reference to the original ground level. In this case the tree volume between the actual and the original ground level

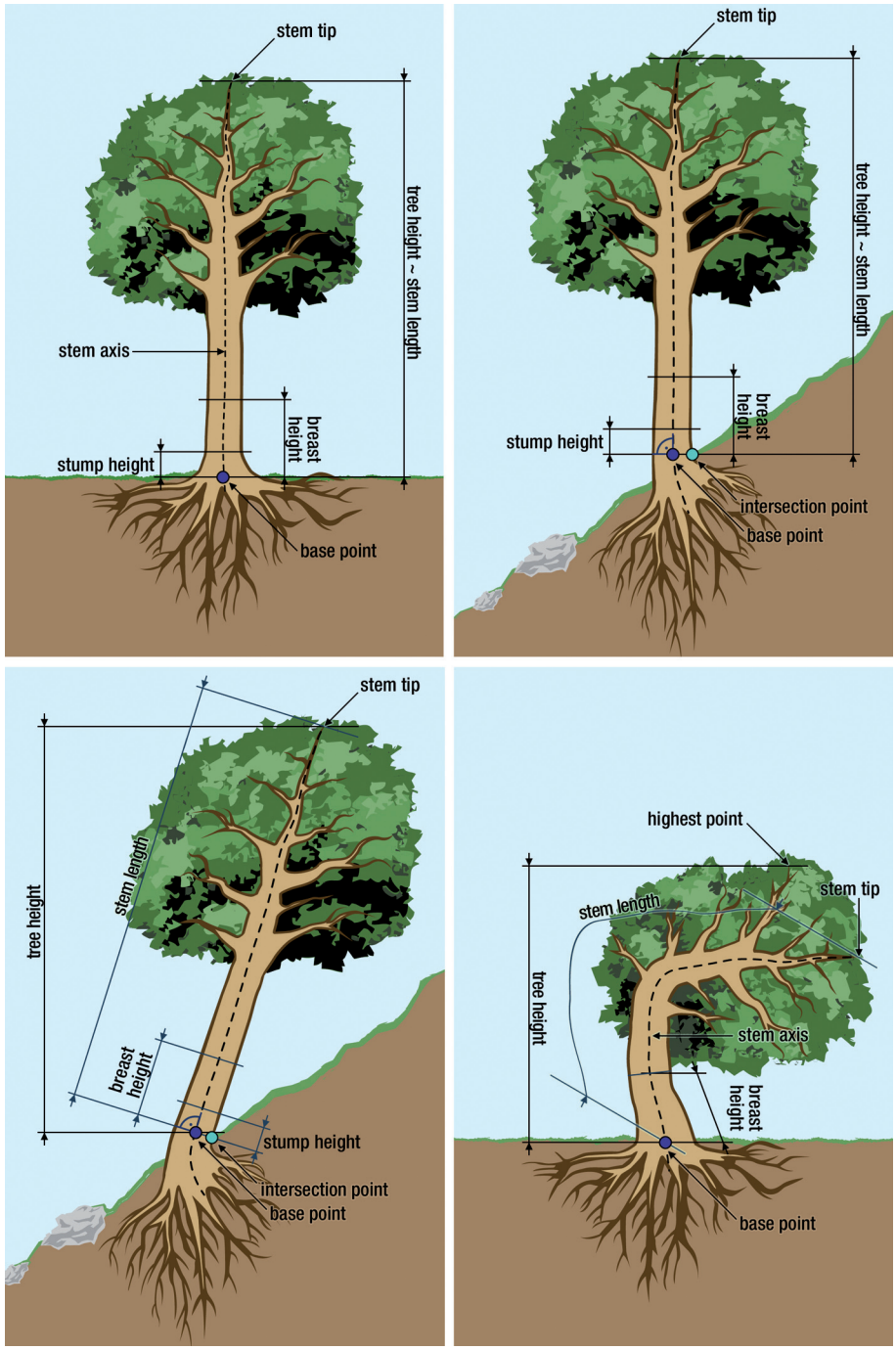

Fig. 4. Examples of tree height, stem length, breast height and stump height in several conditions.

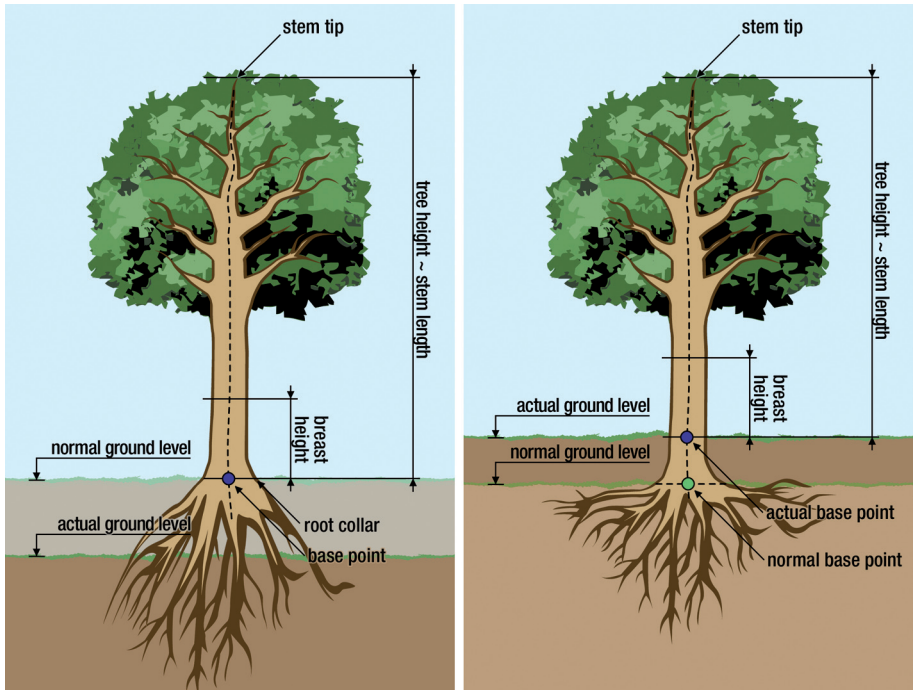

Fig. 5. Tree height, stem length and breast height in locations with changing ground level.

is not part of the above-ground volume or biomass, which includes only tree parts above the root collar. If the actual ground level is higher than the original ground level, tree variables like tree height, stem length and breast height as well as above-ground tree volumes and biomass are defined by referring to the actual ground level (Fig. 5). In most NFIs with permanent plots there is an exception to this latter rule. The breast height is re-identified by a mark on the stem and the diameter or circumference is measured at the same location as in previous assessments.

3.3.2 Breast Height and Diameter at Breast Height

One of the basic variables in NFIs is the diameter (or circumference) of a tree stem at breast height. It is an explanatory variable in most volume functions. The diameter at breast height (dbh) is also an important threshold value in the existing international definitions for growing stock, fellings and increment (FAO 1998, UNECE/FAO 2000, FAO 2004, and IPCC 2003). European NFIs apply dbh-thresholds for growing stock estimation ranging from 0 cm to 12 cm (Table 4).

Table 4. Minimum diameters at breast height of European NFIs.

Minimum dbh (cm)	Number of countries	Growing stock (10^6 m^3)	%
0.0	7	7457	34.7
2.1	2	999	4.7
4.5	1	1447	6.7
5.0	2	1336	6.2
6.4	1	172	0.8
7.0	4	4208	19.6
7.5	3	3703	17.2
8.0	1	1347	6.3
10.0	1	357	1.7
12.0	2	457	2.1
Total	24	21483	100.0

The breast height is usually located by means of a 1.3-meters-stick from the base point along the stem axis. This base point is equal to the base point as defined previously in the context of height

and stem length measurement. A definition for the location of the breast height is as follows:

The **breast height** of a tree is *located at 1.3 m from the base point along the axis of the stem.*

At the breast height location, NFIs measure either the diameter or circumference of a stem. In an ideal case of a circular cross-section, this would yield a unique value for the diameter. However, the shape often deviates from a circle wherefore either measurement directions have to be defined or, better, a theoretical definition independent of the measurement direction and measuring instrument has to be proposed. The average of the diameters using all possible different measuring directions is proposed as the basis for the definition:

The **diameter of a tree at breast height** is *the average of the diameters measured perpendicular to the stem axis at breast height over all possible measurement directions from zero to 180 degrees.*

The theoretical formulation can be expressed using the concept of mathematical expectation and a diameter in an arbitrary direction. A diameter of an arbitrary direction is the distance between two randomly oriented, but parallel tangents, on the opposite sides of the cross-section of a tree. The dbh is the expected diameter value $E[dbh]$ measured perpendicular to the stem axis at breast height. The measurement direction is randomly chosen under uniform distribution between 0 and π. In mathematical notation

$$E\left[dbh\right] = \int_0^{\pi} f(\alpha)x(\alpha)d\alpha = \frac{1}{\pi}\int_0^{\pi} x(\alpha)d\alpha$$

where $f(\alpha) = \frac{1}{\pi}$ is the probability density function of the measurement direction α, $x(\alpha)$ is the diameter corresponding to the measurement angle α (starting from the selected direction, e.g. perpendicular to the azimuth of a tree). An arbitrary measurement direction is required due to systematic variation of diameters and shall ensure that an unbiased average diameter is obtained.

In practice, NFIs employ one or more diameter measurements, or measure the circumference of a tree to estimate the theoretical diameter. Usually, the diameter derived from the circumference coincides with the average diameter, although for particular cross-sectional shapes deviations can occur (Matérn 1956). Individual NFIs employ different units of recording (e.g., cm, mm) and rounding rules, as well as break-down rules when classifying trees into diameter classes. Different rules also create differences concerning dbh-measurements and reporting.

3.3.3 Stump Height

Like stem length and breast height also the stump height is a distance along the stem axis (Fig. 4). According to UNECE/FAO (2000) the height of the stump is the point at which a tree would be cut under normal felling practices in a country or region. Several European NFIs have definitions for stump height in the same sense. Definitions for stump height are of particular relevance when the growing stock definition does not include the above-ground part of the stump. Similar to UNECE/FAO (2000), the stump height is defined as:

The **stump height** is *the distance along the axis of the stem from the base point to the point where the tree would be cut under normal felling practices.*

Stump height in this context is a hypothetical assumption for the purpose of growing stock estimation. Nevertheless, NFIs measure actual stump heights for the purpose of estimating the dead wood volume or biomass of stumps. This actual stump height is defined in the same way, except that it refers to an actually cut tree and can deviate from the hypothetical stump height.

3.3.4 Crown and Crown Projection Area

Crown cover is an important variable in the definitions of forest and other wooded land. A crown definition is important for the distinction of trees and shrubs. According to Helms (1998) the crown is the part of a tree or woody plant that bears the living branches and foliage. Ford-Robertson (1971) defines the crown as the upper part of a tree or woody plant carrying the main branch system and foliage, and converging at the crown base to

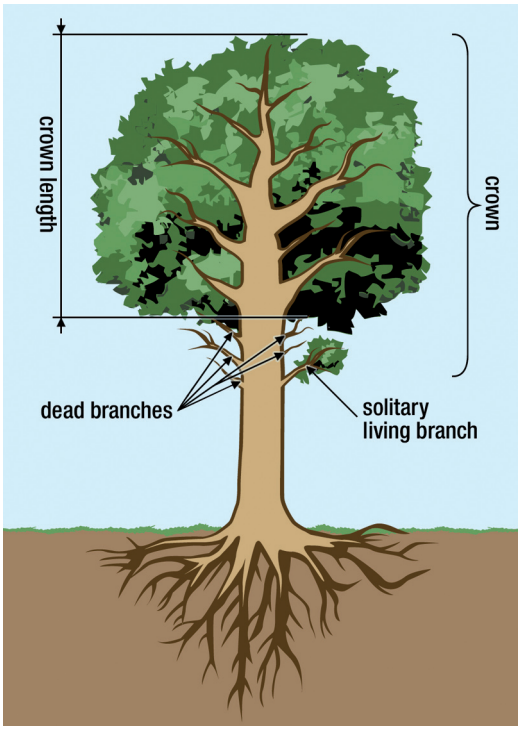

Fig. 6. The tree crown.

a more or less clean stem. These definitions were found to be inconsistent, because the part of a tree that carries the branches is the stem. Therefore, an enhanced crown definition is formulated as follows:

The **crown** *consists of the living branches and their foliage.*

NFIs usually do not define the crown itself, but employ clear instructions for the measurement of crown variables. Branches of solitary occurrence are generally not taken into account when measuring variables such as crown length. Often the number of whorls between the main crown body and the branch in question decides if an individual branch is relevant for crown length determination or not (Fig. 6).

According to IPCC (2003) and FAO (2004) crown cover, crown closure and canopy cover have the same meaning. Other sources indicate differences but also an inconsistent use of these terms. In publications concerning canopy cover and canopy closure Korhonen et al. (2006) found the correct use of these terms to be often unclear. Similarly, Jennings et al. (1999) mention that authors frequently state to measure one variable, but in fact measure the other. Reviewing Delijska and Manoilov (2004), Ford-Robertson (1971), and Helms (1998) reveals two crucial points in the existing definitions. First, according to Ford-Robertson (1971) the ground area covered by an individual tree crown is distinguished from the ground area covered by the tree crowns of a stand. Since individual tree crowns are the basis for the aggregated stand crown cover, relevant variables have to be defined primarily at the level of the individual tree. Second, definitions can refer to the area delimited by the vertical projection of the outermost perimeter of the crown, or to the portion of sky obstructed by the tree crown and thus take into account the transparency of the crown. IPCC (2003) and FAO (2004) refer to the outermost perimeter of the foliage and thus include the small openings within the crown. With regard to the forest and other wooded land definitions, a definition similar to IPCC (2003) and FAO (2004) is desirable (Fig. 7). Since this paper aims at defining the ground area covered by an individual tree crown the definition for crown projection area proposed at the individual tree level is:

The **crown projection area** of a tree is *the area of the vertical projection of the outermost perimeter of the crown on the horizontal plane.*

The aggregation of the crown projection areas of individual trees (without double-counting of overlapping crown projection areas) divided by the stand area yields the crown cover at the stand level.

3.4 Tree Characteristics

As well as the previously presented definitions of tree-related variables several other characteristics are of crucial importance, mainly in the context of volume and biomass estimation. International definitions for growing stock, biomass and fellings may imply the distinction between living and dead trees, or standing and lying trees (FAO 1998,

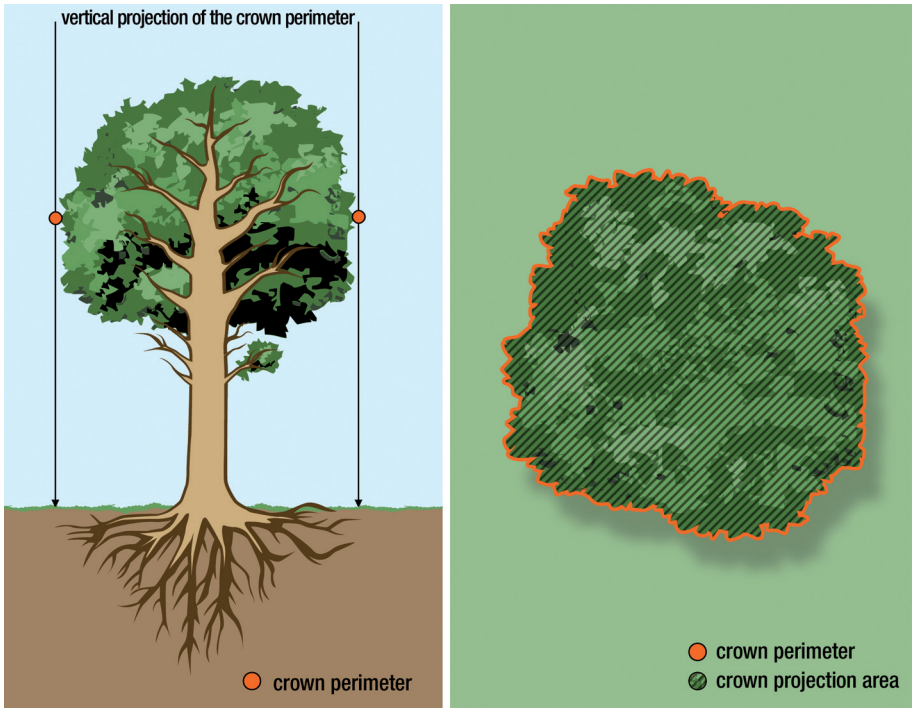

Fig. 7. Crown perimeter in the front view and plan view, and crown projection area.

UNECE/FAO 2000, FAO 2004, and IPCC 2003). Nevertheless, the criteria by which a living or dead tree or a standing or lying tree are specified are not available from these sources. Moreover, trees with an unusual shape should be defined at international level, since they are excluded from growing stock in several European NFIs.

The definitions on tree characteristics follow a dichotomous classification scheme. If a tree cannot be assigned due to its characteristics to a particular class, then the opposite class is the case.

3.4.1 Living and Dead Trees

The distinction of living and dead trees is handled by most European NFIs. Some countries use an overall approach, whereas other countries consider distinct indicators including crown condition, the presence of living bark, branches, green leaves or needles, or living cambium. UNECE/FAO (2000) defines dead trees by needle or leaf loss of 100%. In practice it can be difficult to decide on the life status of a tree. Among the numerous features that indicate whether a tree is living or dead, the presence of an active or dormant cambium was regarded as the basic prerequisite for a tree being alive:

A **living tree** is a tree having *a stem with an active or a dormant cambium.*

3.4.2 Standing and Lying Trees

In order to distinguish between standing and lying trees, several NFIs consider the angle between the stem axis and a horizontal or vertical line, or between the stem axis and the ground surface. The angle ranges from 0° to 45°. Some NFIs define lying trees in a more descriptive way as "being lying on the ground". A clear and unambiguously applicable definition is difficult to establish. An angle is not easy to assess if the stem is bent, and particularly provides difficulties on sloped terrain.

For example, a lying tree can be defined by "*a stem axis that deviates from the vertical more than 45°*". But, on slopes of more than 45° a tree stem can be lying on the ground although the angle between the stem axis and the vertical is less than 45°. If a lying tree is defined to have "*a stem that is lying on the ground*" this difficulties on steep slopes would be avoided. Otherwise, a fallen tree can be lifted by a support and thus would not have a stem that is lying on the ground. Although further considerations concerning the distinction of standing and lying trees can be required in the future, for example in the context of dead wood estimation, Working Group 1 of COST Action E43 had preference for a definition that refers to a stem that is lying on the ground:

A **lying tree** is a tree *whose main stem is in the majority of its length lying on the ground.*

In addition, the group specified that an overthrown tree with a stem which is prevented by a support (e.g. a rocky projection, another tree, branches of the fallen tree) from being lying on the ground is classified as lying tree as well.

3.4.3 Normal and Unusually Shaped Trees

A small proportion of trees show characteristics that deviate strongly from the norm due to damage or exceptional growth, for example gnarled or candelabra trees. The distinction of these trees is relevant for the description of habitats and in terms of biodiversity. The estimation of the volume or biomass of these trees, or their elements, requires particular approaches to obtain predictions within acceptable error margins. The commonly applied functions in NFIs would cause significantly high errors, because these functions were derived from data of trees with normal shape. Thus, NFIs may use other, and often simplified, estimation methods. The insufficient quality of predictions using the standard volume and biomass functions is the basic feature of these trees:

A **tree with unusual shape** is a tree *whose volume or biomass cannot be calculated with sufficient accuracy using the commonly applied volume and biomass functions due to exceptional shape characteristics.*

4 Discussion

The reference definitions established within COST Action E43 for harmonised reporting on forest resources rely on a set of tree-related terms that were not, or only partly, specified at the international level. In this paper several new or reviewed terms and definitions are presented, together with basic considerations on the requirements resulting from their application in NFIs. The main clarification needs were identified from international definitions and requirements at the national level. The clarification was mostly needed for definitions of trees and shrubs, the distinction of tree parts, and several tree-related variables and characteristics. Apart from the distinction between trees and shrubs, the focus of this paper is predominantly on trees although several definitions also apply to shrubs.

4.1 Definition of Tree and Shrub

The formulation of tree and shrub definitions and the distinction between trees and shrubs is affected by the morphological variety of woody plants that is difficult to dichotomously classify. For many woody plant species it is clear whether they belong to the category of trees or of shrubs. Some species cannot easily be assigned to a category, because they can show the morphological characteristics of trees or shrubs depending on the situation. In addition, the morphology of trees and shrubs is not described by clearly assessable variables. The presence of a (single) main stem and the definiteness of the crown can be difficult to ascertain in particular cases. A minimum size, as used in several definitions (Allaby 1998, Delijska and Manoilov 2004, FAO 1998, FAO 2004, Helms 1998, UNECE/FAO 2000), would be a clear feature, but can be applied only with flexibility (FAO 1998, 2004). Summarising, the classification of woody plants into trees and shrubs as required for the application of forest and other wooded land definitions as well as growing stock definitions is inherently complicated.

One basic idea for distinguishing trees from shrubs is to classify a species instead of each individual plant of a species. This means, that in

a specific location at a NFI plot a woody perennial plant species can be either a tree or a shrub, and that the "average morphology" has to be assessed. The classification is based on the definiteness of the crown and the presence of a single main stem. Since a size limit cannot be clearly defined, it was decided that a size criterion should not be used to distinguish between trees and shrubs. Normally, the woody plant species at a NFI plot can be rather clearly classified into trees and shrubs by their "average morphology". However, in particular growing environments some species can be difficult to classify. As already mentioned *Salix caprea* in northern Scandinavia can grow side-by-side as tree and as shrub which are different sub-species. For these exceptional cases we proposed to distinguish trees and shrubs not at the species level but at the sub-species level. Since sub-species can interbreed, a large morphological variety can occur at one location which complicates a clear classification at the sub-species level. Thus the distinction of tree and shrub still leaves some open questions. Because currently neglected species may gain more importance in the future, the classification scheme should be open to newly appearing woody plant species.

4.2 Tree Parts and Tree Elements

The partitioning of a tree into its elements is primarily relevant to growing stock and biomass estimation. An important aim of COST Action E43 was to produce a common reference definition for growing stock. Growing stock is reported in several international programs like FRA and MCPFE. The presented approach is a hierarchical partition of an individual tree into disjoint elements. The individual elements are disjoint and add up to the whole tree without overlapping. The approach is open to further differentiation into smaller elements if required in the future. For instance, a definition for twigs could be of interest in the future for estimating the amount of biomass remaining in the forest after tree harvesting.

The boundaries between the elements of a tree were defined with the objective of facilitating the unambiguous distinction of the individual elements. However, additional remarks shall be mentioned, for example concerning the distinction of the above-ground and below-ground part of a tree. The location of the ground surface was defined to be at the level of the boundary between the litter layer and the adjacent horizon. Since the surface of the litter layer is not stable due to drift processes, we refer to the level were the texture starts to be more consolidated. Depending on the soil type, this is either the onset of the adjacent fermented horizon, the humus horizon or the mineral horizon. In this context it is also important to note that the ground level can change over time and is subject to disturbances. Also the determination of the height where a tree would be cut under normal felling conditions is difficult, it primarily depends on the harvesting practice which may be difficult to predict, and may even change over time.

Some tree elements are separated by threshold values in terms of diameter, for example the base-diameter of the stem top $Z_{\text{stem top}}$ and the minimum diameter for large branches Z_{branches}. These threshold values have not been specified. They may change over time due to market conditions and technical capacities which have not been discussed in Working Group 1. As far as possible, the partitioning approach was kept free from economic but also ecological and biodiversity related considerations. A commonly accepted partitioning approach and terminology that is expected to be useful under the current and near-future broad information needs was the main objective.

In exceptional trees some elements may not exist or are difficult to identify. Damaged trees or trees of unusual shape provide difficulties, but also broadleaved tree species often do not have a continuous main stem up to the tree top (Fig. 8). A thorough review on the various categories of branching systems as for example described by Scott (1995) or Barthélémy and Caraglio (2007) could lead to more specific partitioning approaches for these various categories of branching systems and unusually shaped trees.

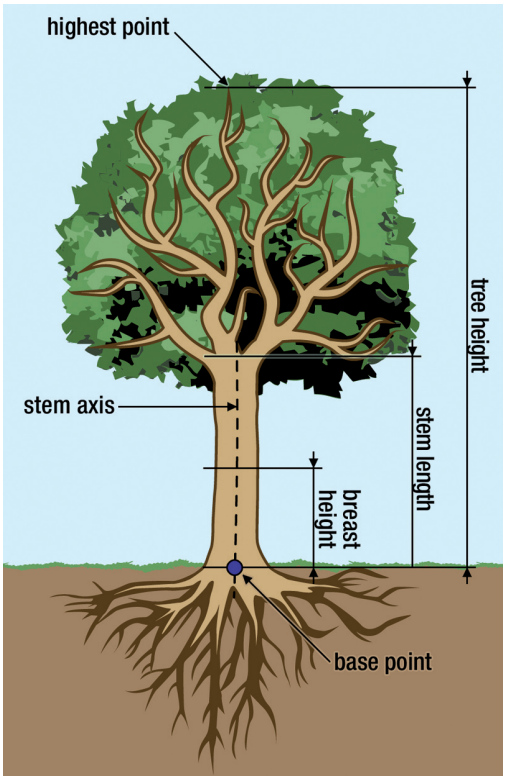

Fig. 8. Tree without continuous main stem.

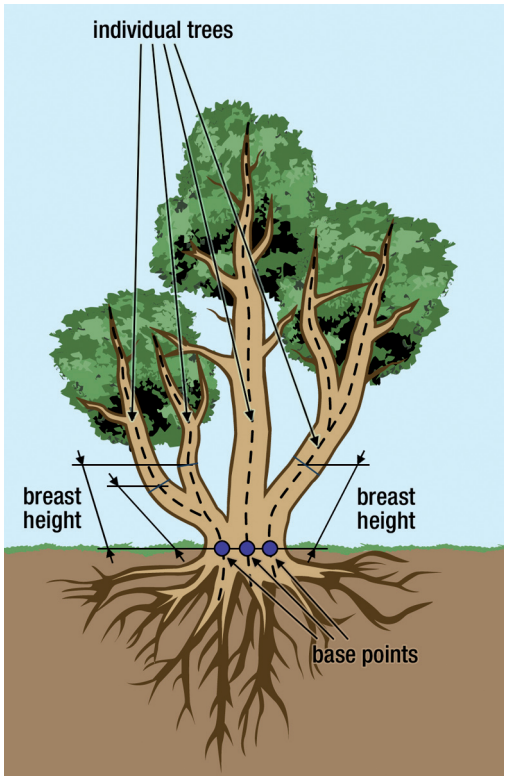

Fig. 9. Individuals of a multi-stemmed tree.

4.3 Tree Variables

Tree height, stem length, breast height, diameter at breast height and stump height all require a point of origin at the tree base for their measurement. For the sake of clearness a common point of origin for all length and height measurements was regarded as desirable. This common point, the base point, was clearly defined and its identification was precisely described.

Since crown cover is an important variable in international forest definitions and definitions for other wooded land, we also consider the crown and the crown projection area at individual tree level. The distinction of trees and shrubs also relies on a crown definition. According to the presented tree definition trees usually have a definite crown, which is a crown that is "lifted" from the ground by a stem. The quantification of the "definiteness" of a crown is desirable for the sake of a more clear distinction of trees and shrubs. However, this seems to be difficult to achieve and needs further consideration. The definition of the crown projection area takes into account branches of solitary occurrence as far as they form part of the perimeter of the crown. This is important for the assessment of the stand level variable crown cover. Remote sensing of crown cover may become a frequently used method, but requires field measurements for validating the assessment results. Thus for the sake of comparability of remote sensing and field assessment, the crown cover should also take into account the solitary living branches, because they are difficult to identify in remote sensing material. The canopy cover definitions given by IPCC (2003) and FAO (2004) apparently also consider any living branch.

The presented variables tree height, stem length, breast height, diameter at breast height, and crown area, and also the following tree characteristics refer to individual trees with a single main stem.

Nevertheless, trees can have more than one stem, for example, in coppice forest, or forked trees in high forest. On each individual stem NFIs measure diameter at breast height, stem length and/or tree height, and crown variables when the stem starts below the breast height and reaches a specified minimum diameter at breast height. The measurements are used to calculate the volume of each individual stem. Furthermore the measurements are used to obtain the volume or biomass of other tree elements like the branches that belong to the individual stem. Thus, each stem of a multi-stemmed tree with a specified minimum measurable diameter at breast height is treated as part of an individual tree (Fig. 9).

4.4 Tree Characteristics

Reference definitions also require the specification of tree characteristics such as "living" or "dead" and "standing" or "lying". Among several indicators the presence of a stem with a living, i.e. an active or dormant cambium was found to be the most basic feature to distinguish living from dead trees. The distinction of standing and lying trees is handled by NFIs often by the use of the angle between the vertical and the stem axis or the horizontal and the stem axis. Some NFIs use a more descriptive definition like "lying on the ground". The use of an angle was found to provide difficulties on steep slopes. Therefore a "stem that is lying on the ground" was regarded to be a more useful feature for defining a lying tree. Nevertheless, a clear solution was not found by Working Group 1 of COST Action E43. However, the impact of this definition can be expected to have a minor influence on reported estimates.

Because some NFIs exclude trees of unusual shape from their growing stock, a definition has been established to address this concern and to point out that trees can deviate strongly from the expected shape. The definition represents the large diversity of unusual tree shapes. These unusually shaped trees are relevant in terms of biodiversity aspects which can be expected to receive additional attention in the coming years. Further definitions for tree characteristics may be required depending on the future developments and information needs.

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