An Enquiry on Forest Areas Reported to the Global Forest Resources Assessment—Is Harmonization Needed?

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Abstract: For international reporting purposes, information on forest resources often has to be supplied according to international definitions. Nevertheless, the country reports of the Food and Agriculture Organization (FAO) Global Forest Resources Assessment 2005 indicate that countries either prefer to use their own forest definitions or use national classes of forest and other biomes as a basis for reclassification to resolve the discrepancy between national and international forest definitions. These preferences are due to the complexity encountered when dealing with the problem of transforming national estimates into estimates according to an international definition but are also due to the lack of a methodological foundation. In view of the multitude of existing national forest definitions and the increasing international reporting requirements, a thorough methodological consideration of the problem appears to be particularly necessary. Therefore, a mathematical approach for comparing national definitions to an international definition is developed. After formalization of definitions and illustration of the peculiarities in national forest definitions, the basics of set theory and simple logic are applied to derive six relevant cases that describe how national definitions of forest are distinct from that of FAO. As a result, we are able to assign each country to a specific case and thus provide a basis for further analyses. We also reflect on the reclassification problem and describe two examples that illustrate the influence of assessment methods in the aim to report according to a common definition. FOR. SCI. 58(3):201–213.

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National forest inventories (NFIs) provide forest resource and forest environment information to satisfy international, national, and regional requirements. Currently, many international processes such as the Ministerial Conference on the Protection of Forests in Europe (MCPFE) (2002, 2003, 2007, 2011) [1], the Montréal Process (Montréal Process Working Group 2007) and international institutions such as the Food and Agriculture Organization (FAO) of the United Nations and the United Nations Framework Convention on Climate Change (UNFCCC) require periodic estimates based on their definitions of forest and other land use (LU) or land cover (LC) classes (Intergovernmental Panel on Climate Change [IPCC] 2003, FAO 2004). Because many NFIs have applied their own national definitions of forest, which differ from those of international organizations, national estimates must be adjusted to conform to international definitions.

The requirements for adjusting national estimates depend on the respective international reporting process and vary according to the reported variables. For reporting under the Kyoto Protocol, each country can choose its own threshold values for minimum area, minimum canopy cover, and minimum tree height within international predefined intervals (IPCC 2003, 2006). However, for reporting to the Global Forest Resources Assessment 2005 (FRA 2005), estimates should be supplied in accordance with the FAO (2004) definitions. For estimating forest area, the explicit threshold values provided by FAO are to be applied for the three FAO categories: Forest, Other Wooded Land (OWL), and Other Land (OL). However, some countries including Germany, Japan, Slovakia, Poland, and the United States of America did not report areas for OWL for the year 2005 (FAO 2006, p. 190). In contrast to reporting forest area, for reporting growing stock estimates, each country may use its own national threshold values for variables such as minimum dbh, but the country must indicate these thresholds to FAO.

A critical evaluation of the forest area estimates in the country reports of the FRA 2005 was carried out within this study to examine the actual practices of applying the FAO (2004) definitions. It revealed that many countries did not use the FAO variables and threshold values but rather used their own national variables and thresholds. Clearly, these estimates are not really comparable to the others. Several countries approached the problem of adjusting national estimates by reclassification from national LC/LU classes into

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the FAO categories. For example, according to a national definition, a parcel of land area may be classified as nonforest, whereas when applying the FAO definition it would be classified as Forest or OWL according to the FAO thresholds. Such a nonmathematical reclassification approach requires defining national classes (NCs) that describe vegetation types (biomes) without quantitative thresholds. For reclassification, each biome is then assigned to one of the land categories of FAO: Forest, OWL or OL. However, some countries split their NCs so that one portion of a single NC is reclassified as Forest and the remaining portion becomes OWL. The estimates obtained by reclassification are still unreliable concerning comparability and lack transparency of underlying methods. Thus, further efforts are necessary to achieve better harmonization.

Definitions of forest typically include two distinct components, LC criteria and LU aspects. Distinguishing between forest and nonforest would be easier if only LC criteria were used, because then measurable thresholds could be used with "greater than" or "less than" relations. The additional consideration of LU aspects causes a LC/LU dilemma: LC criteria may indicate nonforest whereas a LU class (e.g., temporarily unstocked areas) may indicate forest. Vice versa, LC criteria can suggest forest, whereas the LU class indicates nonforest as, for example, in urban parks. Until the present, no comprehensive solution has been reported for a hierarchical approach to formalizing a definition of forest that includes both LC and LU.

At the European level, COST Action E43, "Harmonization of National Forest Inventories in Europe: Techniques for Common Reporting" (COST Action E43 2010) of the program European Cooperation in Science and Technology (COST 2011) was initiated in 2004 to establish common reference definitions and to investigate harmonization techniques as a means of facilitating common reporting. The work toward common reference definitions was based on a review of existing definitions in terms of forest resources assessments. The review included definitions used by countries participating in COST Action E43 and definitions obtained from other sources to ensure that the large variability was covered. The multitude of forest definitions as illustrated by the collection of Lund (2011) suggests that an analysis of differences relative to a common reference definition necessitates a clear, exact, and reproducible methodological foundation. As an outcome of the discourse within COST Action E43, the use of a mathematical approach was found to be necessary in terms of further efforts to harmonize forest resource reporting. Although harmonization may be achieved using nonmathematical approaches such as reclassification as was frequently used for FRA 2005, the uncertainty remains unknown. However, estimates of uncertainties are important and are required for international reporting to the UNFCCC. In addition to descriptions of methods used, the Kyoto Protocol also requires information on uncertainties, meaning that the European Union (EU) as a party and each individual European country must report the uncertainties of their estimates. Reporting to the MCPFE (2011) concerning the State of Europe's Forests requires statements of the quality of data using the three quality classes "high," "medium," and "low" in the country reports.

The objective of this article is to provide a more exact and mathematical approach to address the problems of differences between national definitions and definitions relevant for international reporting. Taking the reporting to FRA 2005 as an example, a generally applicable approach is developed by following a stepwise procedure:

1. Listing the relevant FAO definitions.
2. Formalizing the definitions using mathematical notation: on the one hand, the FAO definitions of Forest, OWL, and OL with its subcategory Other Land with Tree Cover (OLwTC) and on the other hand, the national definitions.
3. Comparing the formalized national definitions to the FAO definition in a mathematical manner by deriving relevant cases based on the application of the basics of set theory and mathematical logic. These cases describe how national definitions of forest are distinct from that of FAO.
4. Describing two examples of practical implementation of the FAO definition of Forest/OWL with a method used in automated remote sensing techniques and a method which is closer to practical field assessments and geographic information system (GIS) techniques.

Consideration of the problem at hand from the set-theoretical point of view permits a rigorous assessment of the structure of forest definitions with respect to their compositional LC criteria and LU aspects. Because set theory is not typically applied in the forest sciences, special attention is paid to the description of methods accompanying the mathematical formulation. Furthermore, the topic of harmonization is relevant for many fields of research and thus places this article in a wider context than forest resources assessment.

Definitions and Methods

In this study the term *definition* is understood to describe an object whose attributes or states are observable. Examples of objects include woody plants, growing stock, or forest. Attributes are, in principle, measurable quantities such as dbh in mm, area in ha, and biomass in kg. Examples of states could include categories of forest health or naturalness.

To formalize a definition we consider each measurable quantity that is explicitly included in the definition of an object as (1) a string, i.e., a unique sequence of letters, for example "canopy cover," and as (2) a quantitative variable with one or more associated numerical threshold values. This approach facilitates development of an analytical approach for comparing the items included or not included in national or international definitions and eliminates room for interpretation of variables in a definition.

The terms and definitions applied for FRA 2005 are taken as an example to describe the formalization of international definitions. For this study, we restrict our investigations to area considerations and thus to the LC and LU classes Forest, OWL, and OL. The terms and definitions referring to these classes are available from FAO (2004). For notational convenience, we use upper case "F" for Forest when referring to the FAO definition and lower case "f" when referring to forest according to a national definition.

The methods used in this study are based on simple logic, the basics of set theory, and simple geometry. For logical and set-theoretical notation we refer to the texts on logic and set theory by Hilbert and Ackermann (1967) and Bourbaki (1970), respectively. In this section the relevant definitions of FAO (2004) are first presented, the FAO and national definitions are formalized, and finally some specifics of national forest definitions are discussed.

FAO Definitions of Forest, Other Wooded Land, and Other Land

The reports of the FRA 2005 provide a set of definitions as the basis for their information content to produce compatible information across countries and time and to facilitate harmonization of information (FAO 2004, p. 5). The FAO definitions of Forest, OWL, and OL and explanatory notes (FAO 2004, p. 16, 20) as specified in Working Paper 83 on terms and definitions for FRA 2005 are presented below.

Forest

Forest is defined as land spanning more than 0.5 ha with trees higher than 5 m and a canopy cover of more than 10%, or trees able to reach these thresholds in situ. Forest does not include land that is predominantly under agricultural or urban land use.

Explanatory notes

1. Forest is determined both by the presence of trees and the absence of other predominant land uses. The trees should be able to reach a minimum height of 5 m in situ. Areas under reforestation that have not yet reached but are expected to reach a canopy cover of 10% and a tree height of 5 m are included, as are temporarily unstocked areas, resulting from human intervention or natural causes, which are expected to regenerate.
2. Forest includes areas with bamboo and palms provided that height and canopy cover criteria are met.
3. Forest includes forest roads, firebreaks, and other small open areas; tree stands in national parks, nature reserves, and other protected areas such as those of specific scientific, historical, cultural, or spiritual interest.
4. Forest includes windbreaks, shelterbelts, and corridors of trees with an area of more than 0.5 ha and width of more than 20 m.
5. Forest includes plantations primarily used for forestry or protection purposes, such as rubber-wood plantations and cork oak stands.
6. Forest excludes tree stands in agricultural production systems, for example, in fruit plantations and agroforestry systems; the term also excludes trees in urban parks and gardens.

Other Wooded Land

OWL is land not classified as Forest, spanning more than 0.5 ha, with trees higher than 5 m and a canopy cover of 5–10%, or trees able to reach these thresholds in situ, or land with a combined cover of shrubs, bushes, and trees greater than 10%. OWL does not include land that is predominantly under agricultural or urban land use.

Other Land

OL is all land that is not classified as Forest or OWL.

Explanatory notes

1. OL includes agricultural land, meadows and pastures, built-up areas, barren land, etc.
2. If a country has areas with meadows and pastures and it is difficult to determine whether they should be classified as Forest, OWL, or OL, the country should explain the criteria used and how this classification is done.
3. OL includes areas classified under the subcategory OLwTC.

Other Land with Tree Cover

OLwTC is classified as OL, spanning more than 0.5 ha with a canopy cover of more than 10% of trees able to reach a height of 5 m at maturity.

Explanatory notes

1. OLwTC includes groups of trees or scattered trees in agricultural landscapes, parks, and gardens and around buildings, provided that the area, height, and canopy cover criteria are met.
2. OLwTC includes tree plantations established mainly for purposes other than wood, such as fruit orchards.

Although the FAO definition for Forest refers only to trees, the definition for OWL additionally contains the terms "shrubs" and "bushes" and suggests that the distinction between these categories of woody perennials is necessary for properly classifying delineated parcels of land as Forest, OWL, and OL. In fact, tree and shrub are also defined in the terms and definitions of FRA 2005 (FAO 2004, p. 32), although a definition of bushes is not available. The FAO definitions of trees and shrubs follow.

Tree

A tree is a woody perennial with a single main stem, or in the case of coppice with several stems, having a more or less definite crown.

Explanatory note

1. Includes bamboos, palms, and other woody plants meeting the above criteria.

Shrub

Shrubs refers to vegetation types for which the dominant woody elements are woody perennial plants, generally more than 0.5 m and less than 5 m in height at maturity and without a definite crown. The height limits for trees and shrubs should be interpreted with flexibility, particularly the minimum tree and maximum shrub height, which may vary between 5 and 7 m.

Formalizing the FAO definitions

With the FAO definitions as presented above in mind, we formalize the FAO land categories as δ_k where $k = 1$ denotes Forest, $k = 2$ denotes OWL, and $k = 3$ denotes OL with $k = 4$ denoting the OL subcategory OLwTC. The number of quantitative variables equals the number of thresholds. Thus for each k, we define a set of quantitative variables denoted $\boldsymbol{X}^{(k)} = \{\chi_j^{(k)}; j = 1, 2, \ldots, \eta_k\}$ and a set of threshold values denoted $\mathcal{T}^{(k)} = \{\tau_j^{(k)}; j = 1, 2, \ldots, \eta_k\}$ where η_k is the respective number of quantitative variables associated with a category. Note that only the categories δ_1, δ_2, and δ_3 form a disjoint partition, so that "Total land" of a country is simply and logically the union ($\cup$) of these land categories:

$$\text{Total land} = \delta_1 \cup \delta_2 \cup \delta_3 \qquad (1a)$$

Thus, the total land area of a country (denoted A_{total}) is simply the sum of the respective areas associated with these categories, denoted $A(\delta_k)$, where $k = 1$, 2, or 3, hence,

$$A_{\text{total}} = A(\delta_1) + A(\delta_2) + A(\delta_3) \qquad (1b)$$

Forest

As stated above, each category typically includes two distinct components, LC criteria and LU aspects. For the LC component of the FAO land category Forest δ_1, we have

$$\begin{array}{lll}
\chi_1^{(1)} \textit{ minimum area} & > & \tau_1^{(1)} = 0.5 \text{ ha} \\
\chi_2^{(1)} \textit{ minimum canopy cover} & > & \tau_2^{(1)} = 10\% \\
\chi_3^{(1)} \textit{ minimum tree height} & > & \tau_3^{(1)} = 5 \text{ m} \\
\chi_4^{(1)} \textit{ minimum area of wsc} & > & \tau_4^{(1)} = 0.5 \text{ ha} \\
\chi_5^{(1)} \textit{ minimum width of wsc} & > & \tau_5^{(1)} = 20 \text{ m}
\end{array}$$

where *wsc* abbreviates "*w*indbreaks, *s*helterbelts and *c*orridors of trees." Note that for *wsc,* FAO (2004) defines *minimum area* and *minimum width* as quantitative variables but specifies no explicit *minimum canopy cover.* For future reference, this LC class of windbreaks, shelterbelts, and corridors of trees is denoted as LC[*wsc*].

If these criteria for the quantitative variables are not satisfied during a field assessment at the sample plot location, then there is no Forestland cover present at that location. However, one can apply the same threshold values and ask whether these criteria would be satisfied in the near future. Such a consideration is based on the second component in the Forest definition which refers to LU aspects. For example, *t*emporarily *u*nstocked *a*reas (*tua*), resulting from human intervention or natural causes, which are expected to regenerate, are considered Forest provided that a land use change (LUC) will not occur and that the criteria for Forest will be satisfied in the future. Such a situation is denoted LU[*tua*]. Introducing the LU class LU[*tua*] is necessary to avoid the dilemma arising when there is no tree stocking on Forestland for the selected reference date.

Because the LC criteria given above can be satisfied by other conditions such as fruit orchards, FAO included in its Forest definition an additional LU class by *excluding* "land that is *p*redominantly under *a*gricultural or *u*rban land use" (*pau*); denoted here LU($\neg$*pau*) where the symbol $\neg$, denotes "not."

In accordance with the FAO definition we also have *add*itional land uses, denoted LU(*add*), that include the remaining cases of LU for which no quantitative thresholds are given, such as areas under reforestation and forest roads. Having denoted all LC criteria and LU aspects, we formulate a mathematical definition of Forest as follows:

$$\text{Forest} = \{\{\text{LC}[\text{Tree} > 10\%] \vee \text{LU}[\textit{tua}]\} \wedge \text{LU}(\neg \textit{pau})\} \vee \text{LC}[\textit{wsc}] \vee \text{LU}(\textit{add}) \qquad (2)$$

where the square brackets, [.], indicate that quantitative thresholds must be considered and parentheses, (.), indicate that qualitative criteria (nominal scale) must be considered. To simplify notation, we aggregated $\chi_1^{(1)}$ to $\chi_3^{(1)}$ with their thresholds into an expression for land cover with trees denoted LC[Tree $>$ 10%], which refers to a minimum area of 0.5 ha and indicates that tree cover must be greater than 10% and tree height must reach 5 m.

Other Wooded Land

The FAO definition for OWL contains quantitative variables that are similarly found in the definition of Forest, i.e., minimum area, minimum cover, and minimum tree height. Because the OWL definition as presented above contains two separate definitions, we can derive $\text{OWL}^{(2a)}$, which includes only trees, and $\text{OWL}^{(2b)}$, which includes woody plants such as shrubs and bushes that are combined with tree cover. The quantitative variables and their respective threshold values are for $\text{OWL}^{(2a)}$:

$$\begin{array}{lll}
\chi_1^{(2a)} \textit{ minimum area} & > & \tau_1^{(2a)} = 0.5 \text{ ha} \\
\chi_2^{(2a)} \textit{ minimum tree cover} & = & \tau_2^{(2a)} = 5\% \\
\chi_3^{(2a)} \textit{ maximum tree cover} & = & \tau_3^{(2a)} = 10\% \\
\chi_4^{(2a)} \textit{ minimum tree height} & > & \tau_4^{(2a)} = 5 \text{ m}
\end{array}$$

and for $\text{OWL}^{(2b)}$:

$$\begin{array}{lll}
\chi_1^{(2b)} \textit{ minimum area} & > & \tau_1^{(2b)} = 0.5 \text{ ha} \\
\chi_2^{(2b)} \textit{ minimum tree cover} & > & \tau_2^{(2b)} = 0\% \\
\chi_3^{(2b)} \textit{ maximum tree cover} & < & \tau_3^{(2b)} = 5\% \\
\chi_4^{(2b)} \textit{ minimum tree height} & > & \tau_4^{(2b)} = 5 \text{ m} \\
\chi_5^{(2b)} \textit{ minimum combined cover} & > & \tau_5^{(2b)} = 10\%
\end{array}$$

The second OWL definition [$\text{OWL}^{(2b)}$] as per FAO includes no *minimum tree height* or maximum shrub height criteria. However, the FAO definition of shrub explicitly specifies a 5-m height threshold (FAO 2004, p. 32). Therefore, *minimum tree height* was incorporated into the

$OWL^{(2b)}$ definition; otherwise, there would be no reason to distinguish between trees and shrubs when considering a combined cover. Obviously, the FAO definition of $OWL^{(2b)}$ is not very clear with respect to the FAO definition of shrubs, so that a rigorous formalization may require inclusion of shrub heights (minimum 0.5 m and maximum 5 m). However, the FAO definition of shrub includes the guidance that "height limits for trees and shrubs should be interpreted with flexibility." Therefore, we did not include sharp threshold values for shrub height.

The term *minimum combined cover* as used in the FAO definition of OWL lacks clarity, because it is not clear if tree cover is required for an area to qualify as OWL. For this study, the *minimum combined cover* is understood as follows: *maximum tree cover* is less than 5% but greater than 0, so that the minimum cover of shrubs and/or bushes is at least 5% on the strict condition that the *combined cover* (tree + shrubs, bushes) is greater than 10%. Note that tree cover percentages are partitioned into disjoint intervals: greater than 10% for Forest, 5–10% for $OWL^{(2a)}$, and less than 5% (but greater than 0) in $OWL^{(2b)}$.

Concerning LU, OWL "excludes land that is predominantly under agricultural or urban land use" too. Thus, LU(OWL) = LU(¬*pau*), where the symbol ¬, denotes "not." As for the category Forest we have mathematical definitions for OWL:

$$OWL^{(2a)} = LC[Tree\,|\,5, 10\%] \wedge LU(\neg pau) \qquad (3a)$$

$$OWL^{(2b)} = LC[Tree < 5\%] \wedge LU(\neg pau) \wedge LC[Tree + shrubs, bushes > 10\%] \qquad (3b)$$

Other Land

Having once defined Forest and OWL, the area of the remaining category, OL, must be the remainder of total land area. The category OL (δ_3) includes all land that is not classified as Forest (δ_1) or OWL (δ_2). Thus, OL is the complementary category, i.e., in symbols

$$\delta_3 = \overline{\delta_1 \cup \delta_2} \qquad (4)$$

For OL, no *minimum area* is explicitly defined by FAO, so that for this study *minimum area* of OL may be less than 0.5 ha (but greater than 0), because stands smaller than 0.5 ha do not qualify as Forest and are classified then as OL. However, for the OL subcategory, OLwTC, *minimum area* must be greater than 0.5 ha. Thus, for OLwTC we have the following quantitative variables and associated threshold values:

$$\chi_1^{(4)} \text{ minimum area} > \tau_1^{(4)} = 0.5 \text{ ha}$$
$$\chi_2^{(4)} \text{ minimum canopy cover} > \tau_2^{(4)} = 10\%$$
$$\chi_3^{(4)} \text{ minimum tree height} > \tau_3^{(4)} = 5 \text{ m}$$

which refer to areas where LU is *pau,* so that the definition of OLwTC in mathematical notation can be formulated as

$$OLwTC = LC[Tree > 10\%] \wedge LU(pau) \qquad (5)$$

As an outcome of this section, formalized definitions for the FAO land categories Forest, OWL, OL, and its subcategory OLwTC are available. The formalized FAO definitions are summarized in Table 1.

National Definitions of Forest and Their Formalization

When reporting to the FAO FRA, each country must provide the definition used for obtaining the national estimates. Based on a review of selected country reports that focuses on European countries but also represents the global reporting process, we list the applied quantitative variables in forest definitions and point out the associated peculiarities. Because national definitions usually distinguish between forest and nonforest, the following discussion considers these two land categories. However, the category forest sometimes also includes areas that actually would qualify as OWL. To establish a general mathematical notation for national definitions, the categories of land are denoted d_l where $l = 1$ denotes forest and $l = 2$ denotes nonforest. As for the case of FAO definitions we define a set $\mathbf{X}^{(l)} = \{x_i^{(l)}; i = 1, 2, \ldots, n_l\}$ for the quantitative variables $x_i^{(l)}$ and a set $\mathbf{T}^{(l)} = \{t_i^{(l)}(p_i^{(l)}); i = 1, 2, \ldots, n_l\}$ for its

Table 1. Formalized FAO definitions.

Category	Formal description	Description text
Total land	$\delta_1 \cup \delta_2 \cup \delta_3$	Union (∪) of the categories Forest, δ_1, OWL, δ_2, and OL δ_3. Clearly, the respective land
Total land area	$A(\delta_1) + A(\delta_2) + A(\delta_3)$	areas $A(\delta)$, ($X^2 = 1, 2, 3$) can be simply added, because of the disjoint partition.
Forest	{{LC[Tree > 10%] ∨ LU[*tua*]} ∧ LU(¬*pau*)} ∨ LC[*wsc*] ∨ LU(*add*)	Actual tree cover of >10% or temporarily unstocked and associated with a LU that is not predominantly agricultural or urban, or LC (windbreaks, shelterbelts, corridors), or remaining additional LU according to explanatory notes.
$OWL^{(2a)}$	LC[Tree|5, 10%] ∧ LU(¬*pau*)	Actual tree cover between 5 and 10% with a LU that is not predominantly agricultural or urban.
$OWL^{(2b)}$	LC[Tree < 5%] ∧ LU(¬*pau*) ∧ LC[Trees + shrubs, bushes > 10%]	Actual tree cover <5% (but not 0) with a LU that is not predominantly agricultural or urban and a minimum combined cover of trees, shrubs and/or bushes that is at least 10%.
OL	$\delta_3 = \overline{\delta_1 \cup \delta_2}$	OL is the complementary category that includes those areas of a country which are neither classified as Forest (δ_1) nor OWL (δ_2).
OLwTC	LC[Tree > 10%] ∧ LU(*pau*)	Actual tree cover of >10% associated with a LU that is predominantly agricultural or urban.

associated threshold values $t_i^{(l)}(p_i^{(l)})$, where n_l is the respective number of quantitative variables associated with a land category d_l and $p_i^{(l)}$ is a parameter indicating that there is no one-to-one relation between the variables and associated threshold values. In other words, a quantitative variable may have more than one threshold value, which is in contrast to the FAO definition of Forest. Thus, we can have a one-to-many relationship between a quantitative variable and its associated threshold values; hence, introduction of the parameter $p_i^{(l)}$ is necessary. For instance, this parameter may describe a set of distinct tree height thresholds associated with the quantitative variable *minimum height of woody plants* $x_3^{(1)}$, if, for example, the variable's thresholds depend on tree species. Taking the quantitative variables of the reviewed definitions into consideration, we express forest d_1 for a national definition as follows:

$x_1^{(1)}$ *minimum area*	$t_1^{(1)}(p_1^{(1)})$ in ha
$x_2^{(1)}$ *minimum canopy cover*	$t_2^{(1)}(p_2^{(1)})$ in percent
$x_3^{(1)}$ *minimum height of woody plants*	$t_3^{(1)}(p_3^{(1)})$ in m
$x_4^{(1)}$ *minimum width*	$t_4^{(1)}(p_4^{(1)})$ in m
$x_5^{(1)}$ *minimum rotation period*	$t_5^{(1)}(p_5^{(1)})$ in years
$x_6^{(1)}$ *minimum width of wsc*	$t_6^{(1)}(p_6^{(1)})$ in m
$x_7^{(1)}$ *minimum (averaged) productivity*	$t_7^{(1)}(p_7^{(1)})$ in m^3/ha per year
$x_8^{(1)}$ *maximum size of small open areas*	$t_8^{(1)}(p_8^{(1)})$ in m^2
$x_9^{(1)}$ *maximum width of roads*	$t_9^{(1)}(p_9^{(1)})$ in m

Each of these quantitative variables is crucial for making the forest/nonforest decision, although NFIs do not necessarily apply the same variables in their national definitions. Clearly, additional variables, conditions, or specified NCs can be included in a definition, depending on the specific situation in a country. Because national definitions are influenced by ecological, economic, and cultural aspects, they may include peculiarities to cover particular situations in the respective countries. In the subsequent section several specifics of national forest definitions are described and explained with regard to reporting to FRA 2005.

Some Specifics in National Forest Definitions

A comparison of the FAO definitions for reporting to FRA 2005 with the definitions applied at national levels reveals differences that must be considered when one is aiming for harmonized reporting. For example, some quantitative variables in national definitions may have different meanings and may be applied differently than in the FAO definition. Other differences concern the classification of land use types or vegetation types instead of applying a definition per se or the distinction among particular strata within a country where assessments are carried out differently. Subsequently, several particular situations are described using selected country reports from FRA 2005 as examples.

Specifics on Minimum Height

With regard to the *minimum tree height of woody plants* $x_3^{(1)}$ and its thresholds $t_3^{(1)}(p_3^{(1)})$, the date to which this variable refers is of importance as is the extent to which it can be used to distinguish between trees and shrubs. FAO uses the term "able to reach these thresholds in situ," whereas some NFIs define minimum heights according to their national Forest Acts, which specify the minimum heights that must be attained for afforestation to be considered forest. For *minimum height of woody plants,* the FAO guidance that "the height limits for trees and shrubs should be interpreted with flexibility" should be kept in mind (FAO 2004, p. 32). The use of the term "woody plants" in a national definition indicates that there is no distinction between trees and shrubs, which suggests that the definition of forest partially includes OWL. However, countries such as Australia state that "it is not possible to discriminate using the 5 meters threshold" and "it is not generally possible using LANDSAT imagery to distinguish crown cover classes below 20%" (FRA 2005-139, p. 10). Thus, Australia did not report estimates for OWL to FRA 2005.

Specifics on Minimum or Maximum Width

For *minimum width* $x_4^{(1)}$, some countries such as Austria (FRA 2005-140, p. 6) apply threshold values $t_4^{(1)}(p_4^{(1)})$ for all land categories, not just for forest and OWL. However, several other countries do not apply *minimum width* so generally but rather just use it for strips of trees such as windbreaks and shelterbelts. For example, in the United States, shelterbelts must have a crown width of at least 37 m (120 ft) to qualify as forestland (FRA 2005-040, p. 7). In contrast to FAO definitions, national definitions may include specific threshold values for the width of roads, sizes of small open areas, and others. In the United States, "unimproved roads and trails, streams, and clearings in forest areas are classified as forest if they are less than 37 m (120 ft) wide" (FRA 2005-040, p. 7). The forest definition of the Swiss NFI (FRA 2005-215, p. 6) actually uses a variable threshold $t_4^{(1)}(p_4^{(1)})$ of *minimum width* $x_4^{(1)}$: "For positive forest decisions the following conditions apply: The minimum width is 25 meters with crown coverage of 100% and the required dominant stand height. With increasing width the minimum crown coverage is allowed to decrease. The smallest acceptable threshold for crown coverage is 20% at a minimum width of 50 meters" (Brassel and Lischke 2001, p. 51, 52). This variable threshold for *minimum width* $x_4^{(1)}$ of forestland affects the comparability with a fixed threshold as used in the forest definition of FAO (2004).

National Classes

Many countries apply their own sets of NCs for specified land use and/or vegetation types (biomes). These NCs may or may not include quantitative variables with threshold values. For example, Spain has a NC named "Forestal arbolado disperso" with a canopy cover criterion of between 5 and 10% and a NC denoted "Forestal desarbolado" with a canopy cover criterion of less than 5%. Clearly, both NCs were reported as OWL (FRA 2005-211, p. 7, 9). NCs without quantitative thresholds were also applied (e.g., by Nigeria). However, some NCs were named but had no descriptions, and a few NCs had remarks on the range of tree heights (FRA 2005-196, p. 7–11).

Stratification

Sampling designs sometimes include different sampling methods for different predefined strata as a means of reducing assessment costs. One such method is stratification into geographic regions as is done in northern countries such as Finland and Sweden (Tomppo et al. 2008) and France (Vidal et al. 2007). Stratification may also be based on terrain accessibility in alpine regions where forest areas are assessed using a different sampling design or using only remote sensing techniques. Finally, stratification may be based on criteria related to forest productivity as is done in the northern parts of the globe. Strata that include sites with low productivity or inaccessible sites are frequently excluded from national forest definitions.

Nonforest on Forestland and Forest on Nonforest Land

A forest is present when the observed or measured value of each quantitative variable is equal to or greater than the associated thresholds selected by a country. Therefore, if at least one of the observed or measured values is less than its associated threshold value, then the decision is nonforest. Obviously, in the case of afforestation areas, potential forests are included in some forest definitions such as "unestablished forest" in China (FRA 2005-051, p. 14). Those areas under afforestation have no actual and observable LC that would qualify as actual forest but can reach the thresholds of forestland during 4 years. Areas of the NC "unestablished forest" were reported "100%" as part of the category Forest (FRA 2005-051, p. 18). A step toward a solution of the LC/LU dilemma was taken by Slovakia. Their NC *Forestland resources* is split into *Forest stands* (= Forest) and *Nonwooded lands,* and estimates for areas of both classes were reported. However, "the area of *Nonwooded lands* on forestlands which is part of *Forestland resources* was placed in the *Other land* (OL) category because there is not any tree cover on them" (FRA 2005-086, p. 7). Because OL is non-Forest, Slovakia selected OL based on actual LC and not on LU. In India, the term "forestland" is the area of land *legally* notified by the government as "forest" and is recorded in the government revenue as "forests." However, for reporting to FRA 2005, India defined a special NC "Forest Cover" as follows: $x_1^{(1)}$, *minimum area* is greater than 1 ha, $x_2^{(1)}$, and *minimum canopy cover* is greater than 10%, and such lands may not be statutorily notified as forest area. This NC "Forest Cover" was reported "100%" as Forest (FRA 2005-001, p. 11, 13).

Results

Extracting Relevant Cases

In this section we compare the mathematically formulated definition of the FAO land category Forest δ_1 with that of the national definition forest d_1 and describe the relevant cases that are characterized as dissimilarity classes. The comparison of definitions first focuses on the sets of quantitative variables $\mathbf{X}^{(1)}$ and $\mathcal{X}^{(1)}$ to derive two basic cases and afterwards focuses on the sets of associated threshold values $\mathbf{T}^{(l)}$ and $\mathcal{T}^{(k)}$ for identifying the relevant subcases. After extraction of the relevant cases, examples for each case are given using country reports from several continents.

For deriving relevant cases, we start with the definitions of Forest δ_1 and forest d_1 as formalized previously. We apply the set-theoretical operations intersection ($\cap$) and union ($\cup$) to the sets $\mathbf{X}^{(1)}$ and $\mathcal{X}^{(1)}$ and obtain the expressions $\mathbf{X}^{(1)} \cup \mathcal{X}^{(1)}$ and $\mathbf{X}^{(1)} \cap \mathcal{X}^{(1)}$. The elements of the sets $\mathbf{X}^{(1)}$ and $\mathcal{X}^{(1)}$ comply with the quantitative variables, which are considered as strings (sequences of letters); for example, $x_1^{(1)}$ *minimum area* and $\chi_1^{(1)}$ *minimum area* without regard to their associated threshold values. However, the same string may have different meanings in the FAO and national definitions. Therefore, a term must necessarily have the same meaning in both definitions. For example, in a comparison of the FAO definition of OL with the corresponding definition from another internationally important reporting process, IPCC (2003), it is evident that the same term is used differently. The reason is simply that IPCC applies six disjoint LU categories, whereas FAO uses only three disjoint categories.

If the relation

$$\mathbf{X}^{(1)} \cup \mathcal{X}^{(1)} = \mathbf{X}^{(1)} \cap \mathcal{X}^{(1)} \tag{6}$$

holds, then we have an unambiguous result denoted case 1, stating that both sets contain the same quantitative variables:

Case 1:
$$\mathbf{X}^{(1)} = \mathcal{X}^{(1)} \tag{7}$$

Otherwise, if the operations intersection ($\cap$) and union ($\cup$) do not yield the same result, we have case 2 with different quantitative variables in the compared sets:

Case 2:
$$\mathbf{X}^{(1)} \cup \mathcal{X}^{(1)} \neq \mathbf{X}^{(1)} \cap \mathcal{X}^{(1)} \tag{8}$$

Because the relation 8 holds, we determine in the next step whether the intersection of $\mathbf{X}^{(1)}$ and $\mathcal{X}^{(1)}$ is the empty set, denoted $\emptyset$. If not, then a subset denoted $\mathbf{M}^{(1)}$ exists, which contains the set of common quantitative variables,

$$\mathbf{M}^{(1)} \subset (\mathbf{X}^{(1)} \cap \mathcal{X}^{(1)}) \tag{9}$$

Otherwise, if no common quantitative variables exist in $\mathbf{X}^{(1)}$ and $\mathcal{X}^{(1)}$, then $\mathbf{M}^{(1)} = \emptyset$. If a country did not apply quantitative variables with associated threshold values, then its set $\mathbf{X}^{(1)} = \emptyset$. Because the intersection of $\mathcal{X}^{(1)}$ with $\emptyset$ always yields $\emptyset$, there are no common quantitative variables. Furthermore, a country may apply quantitative variables that are all different from the variables in the FAO definition, in which case the intersection of the sets $\mathbf{X}^{(1)}$ and $\mathcal{X}^{(1)}$ then would also yield an empty set.

After comparing the sets $\mathbf{X}^{(1)}$ and $\mathcal{X}^{(1)}$ of quantitative variables and identifying the basic cases 1 and 2, we compare the sets of threshold values $\mathcal{T}^{(k)}$ and $\mathbf{T}^{(l)}$ associated with the quantitative variables. One must consider in detail the threshold values of FAO and the thresholds or intervals as defined by a country. The latter may include functional relationships between thresholds such as those used by the Swiss NFI for which the minimum canopy cover threshold depends on the width. Although a "smallest minimum" for crown coverage of 20% is defined, this threshold does not apply in every case because the threshold of crown coverage depends on a parameter, which is basically the width. This example shows that the set-theoretical approach cannot be applied in every case for the sets $\mathcal{T}^{(k)}$ and $\mathbf{T}^{(l)}$. However, most NFIs apply fixed thresholds in their forest definitions and thus their definitions can be compared with the FAO definition. If a national definition applies quantitative variables not given in the FAO definition, then we have an extra dimension for a national definition. This could lead to problems, because such a quantitative variable and its threshold values are crucial for the forest/nonforest decision using a national definition but are irrelevant when the FAO definition is used.

Consequently, the key is the set of threshold values in the FAO definition $\mathcal{T}^{(k)}$, because each threshold value $\tau_j^{(k)}$ is a constant value in every case and is uniquely assigned to its associated quantitative variable because of the one-to-one relation. Thus, case 1 and case 2 as defined above can be further subdivided into relevant subcases by considering the sets of threshold values. If each threshold value in the FAO definition of Forest can be found in a national definition, then we can define a subset of $\mathbf{T}^{(1)}$ denoted $\tilde{\mathrm{T}}^{(1)}$ that is equal to the set $\mathcal{T}^{(1)}$:

$$\mathcal{T}^{(1)} = \tilde{\mathrm{T}}^{(1)} \subseteq \mathbf{T}^{(1)} \tag{10}$$

where $\subseteq$ is the set relational symbol for subset. If $\tilde{\mathrm{T}}^{(1)} = \mathbf{T}^{(1)}$, then we can define a subcase of case 1, denoted case 1.0, in which a country strictly applies the FAO definition in its NFI. Otherwise, we define a set $\mathbf{V}^{(1)}$ as a proper subset of the threshold values in the FAO definition $\mathcal{T}^{(1)}$. $\mathbf{V}^{(1)}$ contains those threshold values that are both in $\mathbf{T}^{(1)}$ and in $\mathcal{T}^{(1)}$, that are associated with the same quantitative variable, and that have the same meaning in both definitions. For example, in the FAO definition of Forest and in the corresponding national definition we have the variable *minimum area* and the same associated threshold values; hence, we can state that $x_1^{(1)} \equiv \chi_1^{(1)}$ and $t_1^{(1)} = \tau_1^{(1)} = 0.5$ ha. The set $\mathbf{V}^{(1)}$ may be an empty set $\varnothing$, for instance when the sets $\mathbf{X}^{(1)}$ and $\boldsymbol{X}^{(1)}$ consist at least partially of the same quantitative variables, but have no common threshold values in their sets $\mathbf{T}^{(1)}$ and $\mathcal{T}^{(1)}$. After some considerations following the outlined procedure, we finally obtain six distinct cases as dissimilarity classes whose descriptions are presented in Table 2 and 3.

The extracted cases represent situations that countries can encounter when required to report according to the Forest definition of FAO. As a result, each country can be uniquely assigned to a specific case. Using the country reports from FRA 2005 as examples, the extracted cases are discussed in detail.

For case 1.0 (Table 2), there is no need to adjust estimates for international reporting, because the same quantitative variables and associated thresholds are applied in the FAO and the national definition. A few countries altered their national definitions to be in accordance with FAO definitions. For example, Italy decided to base its new NFI (conducted in the years 2003–2007) on the FAO-FRA 2000 definitions (United Nations Economic Commission for Europe/Food and Agriculture Organization 1997) to include both Forest and OWL (Tabacchi et al. 2007). France did likewise (FRA 2005-048, Vidal et al. 2007). Some NFIs such as those in Finland, Norway, and Sweden conduct assessments using both their national definitions and the FAO definitions (Ståhl et al. 2012).

Cases 1.1 and 1.2 are not often found in practice, because the special case of windbreaks, shelterbelts, and corridors of trees with specified threshold values is usually not explicitly addressed in national forest definitions. An exception is the United States, which defines a minimum width of 37 m (see above), but also uses a minimum area of 0.4 ha instead of 0.5 ha as specified in the FAO definition (FRA 2005-040, p. 7).

Case 2.0 (Table 3) is given in the Vlaams region of Belgium, because the same quantitative variables are not used owing to the absence of *minimum height.* The common variables have only partially the same threshold values because although the *minimum area* is 0.50 ha, the *minimum canopy cover* is 20% and *minimum width* is 25 m (FRA 2005-131, p. 7). Some countries apply a *minimum canopy cover* of 10%, but a *minimum area* different than that of FAO; China uses 0.0667 ha (FRA 2005-051, p. 14), and Spain uses 0.25 ha (FRA 2005-211, p. 6–7).

In case 2.1, NFIs use partially the same quantitative variables, but with different threshold values. This situation can be illustrated with the example of Australia where a *minimum area* of 0.2 ha, a *minimum canopy cover* of 20%, and a *minimum height* of 2 m are applied (FRA 2005-139, p. 7). According to the Austrian NFI, the minimum area is

Table 2. Distinct cases relating to case 1: relevant subcases describing dissimilarities for case 1 where the sets of quantitative variables are the same both in the definition of FAO [set $\boldsymbol{X}^{(1)}$] and in the national definition [set $\mathbf{X}^{(1)}$].

Case	Formal description	Description text
1.0	$\mathbf{X}^{(1)} = \boldsymbol{X}^{(1)} \wedge \mathbf{T}^{(1)} = \mathcal{T}^{(1)}$	Quantitative variables to be applied and their threshold values are the same in both definitions.
1.1	$\mathbf{X}^{(1)} = \boldsymbol{X}^{(1)} \wedge \mathbf{V}^{(1)} \neq \varnothing$	The same quantitative variables have to be applied, but at least one (but not all) of them have no common threshold value.
1.2	$\mathbf{X}^{(1)} = \boldsymbol{X}^{(1)} \wedge \mathbf{V}^{(1)} = \varnothing$	The same quantitative variables have to be applied, but there are no common threshold values at all.

$\mathbf{T}^{(1)}$ and $\mathcal{T}^{(1)}$ are the set of threshold values for the national definition and FAO definition, respectively. $\mathbf{V}^{(1)}$ is a subset of $\mathcal{T}^{(1)}$ and contains the common threshold values of both the FAO definition and the national definition; $\varnothing$ is the empty set.

Table 3. Distinct cases relating to case 2: relevant subcases describing dissimilarities for case 2 where the sets of quantitative variables in the definition of FAO [set $X^{(1)}$] and in the national definition [set $\mathbf{X}^{(1)}$] are different.

Case	Formal description	Description text
2.0	$\mathbf{M}^{(1)} \neq \varnothing \wedge \mathbf{V}^{(1)} \neq \varnothing$	There are partly the same quantitative variables where at least one (but not all) of them have a common threshold.
2.1	$\mathbf{M}^{(1)} \neq \varnothing \wedge \mathbf{V}^{(1)} = \varnothing$	There are partly the same quantitative variables, but there are no common threshold values at all.
2.2	$\mathbf{M}^{(1)} = \varnothing$	There are no common quantitative variables at all.

A subset of the intersection of $\mathbf{X}^{(1)}$ and $X^{(1)}$, denoted $\mathbf{M}^{(1)}$, is used. $\mathbf{V}^{(1)}$ is a subset of $\mathcal{T}^{(1)}$ and contains the common thresholds of both the FAO definition and the national definition, where $\mathcal{T}^{(1)}$ is the set of threshold values for the FAO definition; $\varnothing$ is the empty set.

0.05 ha, the *minimum canopy cover* is 30%, and the *minimum width* is 10 m (FRA 2005-140, p. 6). In the forest definition of the Swiss NFI, the *minimum area* is not defined, the *minimum canopy cover* is 20%, and the *minimum width* is 25 m (FRA 2005-215, p. 6). However, as mentioned before Switzerland uses a functional relationship between the *minimum canopy cover* and the *minimum width.*

Case 2.2 refers to the situation in which the FAO definition and the national definition have no common quantitative variables at all. A classic example is a definition of forest that is based solely on productivity such as the Norwegian definition for the period 1998 to 2002 (FRA 2005-135, p. 7) that specified a minimum of 1 m^3/ha per year of wood including bark. Further, some regions such as Greenland have no definitions or classifications for Forest and OWL (FRA 2005-033, p. 5). However, an attempt has been made to use local expert knowledge to estimate these areas using the FAO definition and to report that the estimates are only approximate. Case 2.2 also includes Nigeria (FRA 2005-196, p. 7–11) and México (FRA 2005-189, p. 8–19) that use only national LU and vegetation type classes, which are defined on a nominal scale including species lists. These NCs and their areas, partially estimated from maps, were used to reclassify into Forest, OWL, and OL.

Reclassification from National to FAO Definitions

According to the country reports of FRA 2005, many countries apply definitions different from the FAO definitions and evidently prefer simple reclassification or bridging techniques (Ståhl et al. 2012) for obtaining results corresponding to the FAO definition. Some countries might ignore the special case of *wsc* as negligible thereby risking only a rather small, insignificant underestimation of Forest and/or OWL areas. If we focus on the most relevant quantitative variables, namely *minimum area* in ha and *minimum tree cover* in percent, and ignore *minimum tree height,* LC[*wsc*] and its associated *minimum width,* we can then describe Forest and OWL in a slightly reduced form using only two dimensions (Figure 1).

If the same quantitative variables are applied in the FAO definition of Forest and in the national forest definition, and if at least one of the variables (but not all) has no common threshold value, we have in the two-dimensional space the following two distinct situations: (1) only one threshold is different from that of the FAO definition and (2) both thresholds are different from those of the FAO definition.

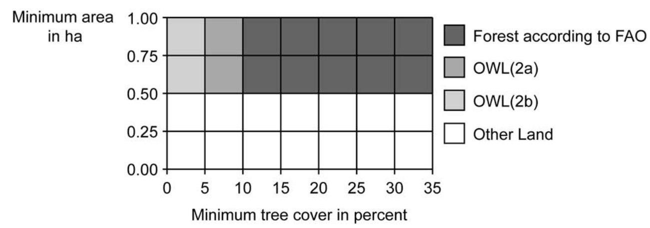

Figure 1. The FAO definitions Forest, OWL and OL when considering the two dimensions *minimum area* in ha and *minimum tree cover* in percent.

For example, (1) a *minimum area* of 0.25 ha in a national definition implies that a part of forest according to the national definition would be OL according to the FAO definition. For (2) the *minimum area* in a national definition is 0.25 ha and the *minimum tree cover* is 20%. In this case, some parts of nonforest according to a national definition are Forest as defined by FAO, whereas other parts of forest according to a national definition are OL according to the FAO definition. Consequently, for obtaining estimates according to the FAO definition, certain areas according to a national definition must be reclassified.

Reclassification for obtaining results according to the FAO definition can be conducted by different means. The reclassification techniques found in the country reports of FRA 2005 that were reviewed usually use different kinds of NCs such as LU types or vegetation types. The LU or vegetation types are defined more or less precisely and are assigned based on their definitions to the land categories of FAO. Some countries split their NCs so that one portion of a single NC is reclassified as Forest and the remaining portion becomes OWL or OL. Clearly, such techniques are not very satisfactory with respect to transparency of methods and comparability of results. However, reclassifications from nonforest into Forest are not so simple, because areas classified as nonforest according to a national definition may qualify as Forest when the FAO definition is applied. Data about nonforest are not available in such detail as in the case of forest. This leads to potential problems such as reporting on growing stock of nonforest areas that have been reclassified into forest. For example, a country's national definition may apply the $x_7^{(1)}$ *minimum (averaged) productivity* of, say, 1 m^3/ha per year as is used in Nordic countries, where the exclusion of areas with low productivity gives a forest area 15–20% smaller than reported to FAO (FAO 2007).

Harmonization Challenges Arising from Different Methodologies

Developments in the field of remote sensing open additional opportunities for reporting according to a common international reference definition. Therefore, we present two distinct approaches that are designed to satisfy the requirements of the FAO definition. In doing so, we focus on *minimum area* and *minimum tree cover* as the most relevant quantitative variables. Approach 1 is a method that resembles remote sensing procedures on aerial photographs using fixed windows of a predetermined size for interpretation. Approach 2 is similar to GIS applications using polygons that contain the NFI sample plots. The overall aim of approach 1 and approach 2 is to point out that they can lead to different assessments and thus lead to different results. For the purpose of comparing approaches, we examine the forest/nonforest decision at an individual NFI plot location that was classified as forest according to a national definition.

In consideration of the fact that the FAO definition uses a *minimum area* of 0.5 ha, an area of similar size must be assessed for deciding whether the *minimum canopy cover* threshold of 10% is satisfied. Yet, we note that the typical NFI sample plot size is rarely as large as 0.5 ha. Thus, the reference area for interpretation will be larger than the sample plot. Now we have two possibilities which are illustrated by approach 1 and approach 2. To overcome the weakness of having different sized plot and interpretation areas, we enlarge the plot size to obtain a fixed reference area of 0.5 ha for approach 1. With approach 2, the reference area has no fixed size and no predefined shape, although the polygon containing the NFI plot must have an area of at least 0.5 ha. Figure 2 shows the two different approaches.

Whereas approach 1 is similar to remote sensing assessments that use moving windows, the aim of approach 2 is to search for areas that are in accordance with a FAO land category similar to Forest or OWL, including areas outside the field plot. However, depending on the area surrounding the NFI plot, the two approaches may not yield the same result in every case (Figure 3). When approach 1 is used, the assessment result depends on the size and the canopy cover of the forested part within the circle of 0.5 ha. When the canopy cover related to the whole circle of 0.5 ha is less than 10% the plot will be classified as OL. For example, given that half of the circle is OL without any tree cover and the other half is forested and has a canopy cover of, say, 20%, then we would have a canopy cover of 10% on the whole circle and would reach exactly the threshold value of the FAO definition for Forest. However, if the forested part has a canopy cover less than 20%, the plot would be classified as OL because on the circle of 0.5 ha, the canopy cover would be less than 10%. In contrast, when the method of approach 2 is applied, the NFI plot is classified as Forest in the same situation because it is located in a polygon covered by Forest. Consequently, when using approach 1, we may obtain a reclassification from forest into OL, whereas using approach 2, no reclassification is necessary because forest is classified Forest.

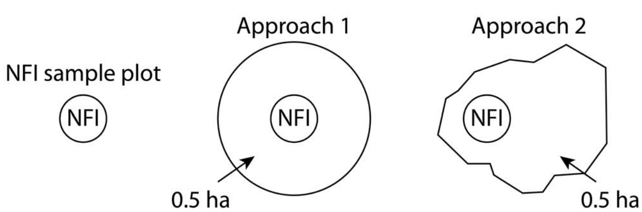

Figure 2. Schemes of reference areas in approaches 1 and 2. For approach 1, we select a fixed reference area of 0.5 ha with a predefined shape. For approach 2, additional area as delineated by a polygon with the same FAO category as that of the NFI plot must be considered to reach the 0.5-ha threshold.

Discussion and Conclusions

Countries use many procedures for reporting on their forest resources and increasingly must deal with the need for harmonized reporting. The EU, as a party, signed many international conventions (Kyoto Protocol, the Convention on Biological Diversity, and others) and must provide harmonized estimates and tables for the entire EU apart from the member states that will report individually. Further, the EU environment policy needs more and more comparable information for many topics involving forestry data. So, for European purposes and policies, a closer harmonization between definitions is needed and encouraged by EU institutions. Our analysis of the reported results of FRA 2005 showed that many countries use their own national definitions and associated threshold values rather than the FAO definitions. Some countries made their own transformations, basically reclassifications of national classes of forest and other vegetation types, to report to the FRA process. The applied transformations and experience from COST Action E43 indicate that countries prefer simple rather than sophisticated approaches. The reasons for this preference relate to the complexity of the problem and the lack of a methodological foundation. Until now, the problem of transforming national estimates to conform to the FAO definition has not been approached from the methodological point of view.

COST Action E43 conducted investigations to facilitate common reporting with comparable results on essential indicators such as forest area and growing stock. Vidal et al. (2008) proposed a method that is based on analytical decomposition of the existing national definitions. After reaching a consensus among information providers, common reference definitions were established. The establishment of reference definitions is followed by the development of methods for obtaining estimates according to those definitions and primarily requires a reproducible approach for comparing definitions. Therefore, we first considered the problem of comparability from the mathematical perspective. As a result each country can now be assigned to one of six cases of dissimilarity. A revision of national definitions based on the presented findings is a basic requirement toward harmonization of NFI estimates.

The mathematical formalization of the problem not only provides a clear analysis of the problem but also reveals the peculiarities that may be encountered when aiming for

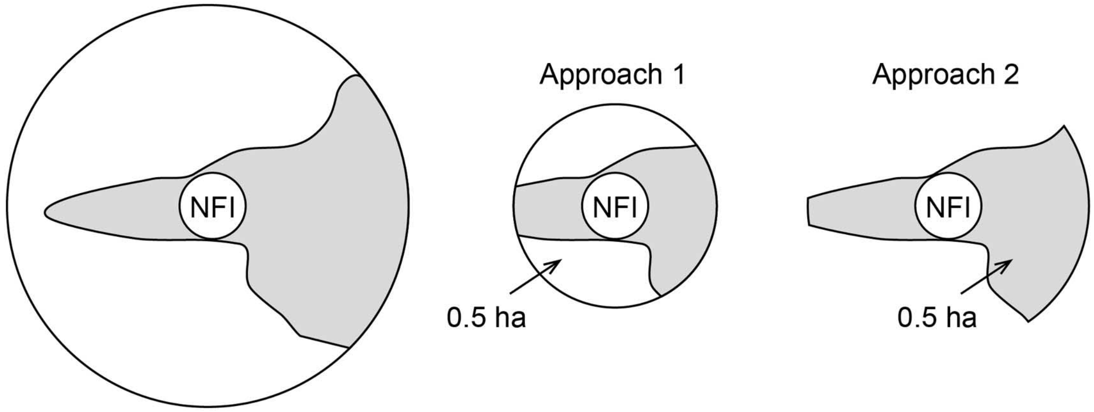

Figure 3. Classification of a sample plot according to approaches 1 and 2 (gray, Forest; white, OL). For approach 1, depending on the size and the canopy cover of the forested part within the circle of 0.5 ha, the sample plot will be classified into the FAO category Forest or OL. For approach 2, there are at least 0.5 ha properly connected having the same category as the NFI sample plot, so that forest is classified into Forest.

comparable estimates. The mathematical approach presented leads to a solution at each step, reveals the items that are ignored, and identifies the additional assumptions necessary to close the gap between the meanings of variables in definitions. The mathematical approach also reveals possible inconsistencies in a common definition. For example, it is not clear whether each country reporting to FRA 2005 had the same understanding of OWL. In the formalized definition for OWL$^{(2b)}$, we assumed that the tree cover is less than 5% but greater than 0. However, the OWL definition according to FAO (2004) could also be interpreted differently by assuming that only shrub cover and no tree cover is required. In addition, the term "bushes" is not defined at all in the terms and definitions of FAO (2004), although it is used in the OWL definition. Based on mathematical considerations, additional studies on the ignored items and the influence of different meanings of variables can be conducted to obtain information regarding uncertainties and to determine whether they can be reduced at reasonable costs. Of course, the burden of bridging the gap between a national definition and the common FAO definition increase as the differences between the definitions increases. Because of the numerous reporting obligations, several countries have responded to the reporting requirements and conduct extra assessments by applying the FAO definition or even replacing their national definition with the FAO definition (Tomppo et al. 2010).

One solution to the reclassification problem and its methodological deficiencies is the application of remote sensing techniques with high spatial resolution that complement NFI sample-based methods. Therefore, we presented two examples with practical relevance. The examples basically describe the assessment of NFI sample plots and their surrounding area according to the FAO definition and indicate that results can differ, depending on the method used. The use of moving windows (approach 1) may be preferred in many cases because of its simplicity, although the results depend on the size and shape of the window. The more resource-intensive delineation of forest polygons as applied by approach 2 is regarded to give more reliable and comparable estimates. Automated methods based on geometric criteria facilitate a reproducible determination of the forest border line (Eysn et al. 2010) and improve the efficiency of the forest delineation. Considering the historical development of NFIs (Gabler and Schadauer 2007), evaluation techniques such as the k-nearest neighbors method (Tomppo and Halme 2004) and other classification methods become more and more important in NFIs to produce wall-to-wall maps to close some gaps that cannot be filled using only terrestrial sampling. The examples highlighted in the last part of this article will become increasingly important in the near future and should be envisaged carefully to avoid new differences in the results. Tests with real data for checking the relevance of the differences in estimates resulting from different methodological approaches as well as simulation studies should be sought. Case studies from European countries on the influence of definitions and methods on forest area estimates are crucial for further advancement in harmonization of NFIs.

Endnote

[1] In 2009 the Ministerial Conference on the Protection of Forests in Europe changed its brand name from MCPFE to FOREST EUROPE.

Literature Cited

Brassel, P., and H. Lischke (eds.). 2001. *Swiss National Forest Inventory: Methods and models of the second assessment.* Swiss Federal Research Institute WSL, Birmensdorf, Switzerland. 336 p.

Bourbaki, N. 1970. *Éléments de mathématique théorie des ensembles.* Hermann, Paris, France. 350 p.

COST. 2011. *European Cooperation in Science and Technology.* Available online at www.cost.esf.org/; last accessed July 12, 2011.

COST Action E43. 2010. *Harmonization of National Forest Inventories in Europe: Techniques for common reporting.* Available online at www.metla.fi/eu/cost/e43/; last accessed July 12, 2011.

Eysn, L., M. Hollaus, M. Vetter, W. Mücke, N. Pfeifer, and B. Regner. 2010. Adapting alpha shapes for forest delineation using ALS Data. In *Proc. of the 10th International conference on LiDAR applications for assessing forest ecosystems* (Silvilaser 2010), September 14–17, Freiburg, Germany. 10 p.

Food and Agriculture Organization. 2004. *Global Forest Resources Assessment update 2005. Terms and definitions (final version).* Forest Resources Assessment Programme, Working Paper 83/E. Forestry Department, Food and Agriculture Organization of the United Nations, Rome, Italy. 34 p.

Food and Agriculture Organization. 2006. *Global Forest Resources Assessment 2005. Progress towards sustainable forest management.* Forestry Paper 147. Food and Agriculture Organization of the United Nations, Rome, Italy. 323 p.

Food and Agriculture Organization. 2007. *State of the world's forests 2007.* Food and Agriculture Organization of the United Nations, Rome, Italy. 144 p.

FRA 2005-001. *Global Forest Resources Assessment 2005. INDIA country report 001.* Food and Agriculture Organization of the United Nations, Forestry Department, Rome. Italy. 128 p.

FRA 2005-033. *Global Forest Resources Assessment 2005. GREENLAND (DENMARK) country report 033.* Food and Agriculture Organization of the United Nations, Forestry Department, Rome, Italy. 6 p.

FRA 2005-040. *Global Forest Resources Assessment 2005. USA country report 040.* Food and Agriculture Organization of the United Nations, Forestry Department, Rome, Italy. 54 p.

FRA 2005-048. *Évaluation des ressources forestières mondiales 2005. FRANCE rapport national 048.* Organisation des Nations Unies pour l'alimentation et l'agriculture, Département des forêts, Rome, Italy. 70 p.

FRA 2005-051. *Global Forest Resources Assessment 2005. CHINA country report 051.* Forestry Department Food and Agriculture Organization of the United Nations, Rome, Italy. 67 p.

FRA 2005-086. *Global Forest Resources Assessment 2005. SLOVAKIA country report 086.* Food and Agriculture Organization of the United Nations, Forestry Department, Rome, Italy. 46 p.

FRA 2005-131. *Évaluation des ressources forestières mondiales 2005. BELGIQUE rapport national 131.* Organisation des Nations Unies pour l'alimentation et l'agriculture, Département des forêts, Rome, Italy. 61 p.

FRA 2005-135. *Global Forest Resources Assessment 2005. NORWAY country report 135.* Food and Agriculture Organization of the United Nations, Forestry Department, Rome, Italy. 48 p.

FRA 2005-139. *Global Forest Resources Assessment 2005. AUSTRALIA country report 139.* Food and Agriculture Organization of the United Nations, Forestry Department, Rome, Italy. 48 p.

FRA 2005-140. *Global Forest Resources Assessment 2005. AUSTRIA country report 140.* Food and Agriculture Organization of the United Nations, Forestry Department, Rome, Italy. 36 p.

FRA 2005-189. *Evaluación de los recursos forestales mundiales 2005. MÉXICO Informe nacional 189.* Organización de las Naciones Unidas para la Agricultura y la Alimentación, Departamento Forestal, Rome, Italy. 68 p.

FRA 2005-196. *Global Forest Resources Assessment 2005. NIGERIA country report 196.* Food and Agriculture Organization of the United Nations, Forestry Department, Rome, Italy. 37 p.

FRA 2005-211. *Evaluación de los recursos forestales mundiales 2005. ESPAÑA Informe nacional 211.* Organización de las Naciones Unidas para la Agricultura y la Alimentación, Departamento Forestal, Rome, Italy. 52 p.

FRA 2005-215. *Global Forest Resources Assessment 2005. SWITZERLAND country report 215.* Food and Agriculture Organization of the United Nations, Forestry Department, Rome, Italy. 43 p.

Gabler, K., and K. Schadauer. 2007. Einige Ansätze und Stichproben-Pläne nationaler Forstinventuren [Some approaches and designs of sample-based National Forest Inventories.] *Aust. J. For. Sci./Centralbl. f. d. ges. Forstwesen* 124(2):105–133 (in English).

Hilbert, D., and W. Ackermann. 1967. *Grundzüge der theoretischen Logik,* 5 Auflage. Springer Verlag, Berlin, Germany. 188 p.

Intergovernmental Panel on Climate Change. 2003. *Supplementary Methods and Good Practice Guidance arising from the Kyoto Protocol. Good Practice Guidance for Land Use, Land-Use Change and Forestry.* Penman, J., M. Gytarsky, T. Hiraishi, T. Krug, D. Kruger, R. Pipatti, L. Buendia, K. Miwa, T. Ngara, K. Tanabe, and F. Wagner (eds.). Institute for Global Environmental Strategies, Hayama, Japan.

Intergovernmental Panel on Climate Change. 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories.* Prepared by the National Greenhouse Gas Inventories Programme, Eggleston, H.S., L. Buendia, K. Miwa, T. Ngara and K. Tanabe (eds.). Institute for Global Environmental Strategies, Hayama, Japan.

Lund, H.G. (coord.). 2011. *Definitions of forest, deforestation, afforestation, and reforestation.* Available online at home.comcast.net/gyde/DEFpaper.htm; last accessed July 12, 2011.

Ministerial Conference on the Protection of Forests in Europe. 2002. *Improved Pan-European indicators for sustainable forest management as adopted by the MCPFE expert level meeting, 7–8 October 2002, Vienna, Austria.* Ministerial Conference on the Protection of Forests in Europe, Liaison Unit, Vienna, Austria. 6 p.

Ministerial Conference on the Protection of Forests in Europe. 2003. *Background information for improved Pan-European indicators for sustainable forest management.* Ministerial Conference on the Protection of Forests in Europe, Liaison Unit, Vienna, Austria. 45 p.

Ministerial Conference on the Protection of Forests in Europe. 2007. *Inter-criteria and indicators (C&I) process collaboration workshop held on 8–10 June, 2006 in Bialowieza, Poland. Report.* A collaborative effort by the International Tropical Timber Organization (ITTO), the Ministerial Conference on the Protection of Forests in Europe (MCPFE), the Montréal Process, the Food and Agriculture Organization of the UN (FAO), the UN Economic Commission for Europe (UNECE) and the US Forest Service. Ministerial Conference on the Protection of Forests in Europe, Madrid, Spain. 75 p.

Ministerial Conference on the Protection of Forests in Europe. 2011. *Ministerial Conference on the Protection of Forests in Europe (FOREST EUROPE).* Available online at www.foresteurope.org/; last accessed July 12, 2011.

Montréal Process Working Group. 2007. *The Montréal Process.* Available online at www.rinya.maff.go.jp/mpci/; last accessed July 12, 2011.

Ståhl, G., E. Cienciala, G. Chirici, A. Lanz, C. Vidal, S. Winter, R.E. McRoberts, J. Rondeux, K. Schadauer, and E. Tomppo. 2012. Bridging national and reference definitions for harmonizing forest statistics. *For. Sci.* 56:214–223.

Tabacchi, G., F. De Natale, A. Floris, C. Gagliano, P. Gasparini, G. Scrinzi, and V. Tosi. 2007. Italian National Forest Inventory: Methods, state of the project, and future developments. P. 55–66 in *Proc. of the Seventh annual forest inventory and analysis symposium,* McRoberts, R.E., G.A. Reams, P.C. Van Deusen, and W.H. McWilliams (eds.). US For. Serv. Gen. Tech. Rep. WO-77. Washington, DC.

Tomppo, E., M. Haakana, M. Katila, and J. Peräsaari. 2008. *Multi-source national forest inventory methods and applications.* Managing Forest Ecosystems, Vol. 18. Springer, Berlin, Germany. 374 p.

Tomppo, E., and M. Halme. 2004. Using coarse scale forest variables as ancillary information and weighting of variables in k-NN estimation: A genetic algorithm approach. *Remote Sens. Environ*. 92(1):1–20.

Tomppo E., T. Gschwantner, M. Lawrence, and R.E. McRoberts (eds.). 2010. *National Forest Inventories: Pathways for common reporting*. Springer, Berlin, Germany. 612 p.

United Nations Economic Commission for Europe/Food and Agriculture Organization. 1997. *Temperate and Boreal Forest Resources Assessment* 2000, terms and definitions. United Nations, New York and Geneva, Switzerland. 13 p.

Vidal, C., T. Bélouard, J.-C. Hervé, N. Robert, and J. Wolsack. 2007. A new flexible forest inventory in France. P. 67–73 in *Proc. of the Seventh annual forest inventory and analysis symposium,* McRoberts, R.E., G.A. Reams, P.C. Van Deusen, and W.H. McWilliams (eds.). US For. Serv. Gen. Tech. Rep. WO-77. Washington, DC.

Vidal, C., A. Lanz, E. Tomppo, K. Schadauer, T. Gschwantner, L. di Cosmo, and N. Robert. 2008. Establishing forest inventory reference definitions for forest and growing stock: A study towards common reporting. *Silva Fenn.* 42(2):247–266.

Appendix

Explanation of the mathematical symbols used appears below. We use (partly) Greek letters and Latin letters denoting symbols for FAO definitions and national definitions, respectively. Sets are written with capital letters and the elements of these sets are written with lower case letters.

A_{total}	Total land area of a country
d_l	National definition of the *l*th category
δ_k	FAO definition of the *k*th category
$\mathbf{M}^{(1)}$	A subset of the intersection of the sets $\mathbf{X}^{(1)}$ and $\boldsymbol{X}^{(1)}$
η_k	Number of quantitative variables associated to a category δ_k
n_l	Number of quantitative variables associated to a category d_l
$p_i^{(l)}$	Parameter assigned to $t_i^{(l)}$
$t_i^{(l)}(p_i^{(l)})$	Threshold values ($i = 1, 2, \ldots, n_l$) assigned to $x_i^{(l)}$, depend on $p_i^{(l)}$
$\mathbf{T}^{(l)}$	Set of $t_i^{(l)}$ for fixed *l,* i.e., $\mathbf{T}^{(l)} = \{t_i^{(l)}(p_i^{(l)});\ i = 1, 2, \ldots, n_l\}$
$\tilde{\mathrm{T}}^{(1)}$	Subset of $\mathbf{T}^{(1)}$
$\tau_j^{(k)}$	Threshold values ($j = 1, 2, \ldots, \eta_k$) assigned to $\chi_j^{(k)}$
$\mathcal{T}^{(k)}$	Set of $\tau_j^{(k)}$ for fixed *k,* i.e. $\mathcal{T}^{(k)} = \{\tau_j^{(k)};\ j = 1, 2, \ldots, \eta_k\}$
$\mathbf{V}^{(1)}$	Subset of $\mathcal{T}^{(1)}$
$x_i^{(l)}$	Quantitative variables ($i = 1, 2, \ldots, n_l$) associated with d_l
$\mathbf{X}^{(l)}$	Set of $x_i^{(l)}$ for fixed *l,* i.e. $\mathbf{X}^{(l)} = \{x_i^{(l)};\ i = 1, 2, \ldots, n_l\}$
$\chi_j^{(k)}$	Quantitative variables ($j = 1, 2, \ldots, \eta_k$) associated with δ_k
$\boldsymbol{X}^{(k)}$	Set of $\chi_j^{(k)}$ for fixed *k,* i.e. $\boldsymbol{X}^{(k)} = \{\chi_j^{(k)};\ j = 1, 2, \ldots, \eta_k\}$