Effects of Different Definitions on Forest Area Estimation in National Forest Inventories in Europe

Berthold Traub, Michael Köhl, Risto Päivinen, and Olaf Kügler

Abstract.—International forest statistics such as those provided by the UN/ ECE-FAO Temperate and Boreal Forest Resource Assessment (TBFRA) are typically compiled from national surveys. However, the national systems of nomenclature as well as the definition of the attributes often vary considerably. The European Commission, DG VI, initiated a study to investigate the potential of a European Communication and Information System (EFICS). In the framework of the EFICS study, the effect of different definitions of forest key attributes was investigated. The main focus was on the forest area and growing stock attributes.

The study presented here shows the effect of different forest area definitions, applied to artificially generated forest pattern types, which are typical for southern, central, and northern European forests. In a simulation study, forest area was estimated according to crown coverage, width, and area criteria, applied in the 19 European countries. Forest area differed by up to 13 percent. The effect of different forest area definitions is highly correlated with the amount of area covered by open forest types. Moreover, different rules to delimit the potential forest area from non-forest land have been proven to be very decisive for forest area estimates.

To collect, coordinate, standardize, and distribute data of the forest sector, the European Forest Information and Communication System (EFICS) was launched by an EC regulation in 1989. In 1995, a study on EFICS was started to investigate the potential, feasibility, and realization efforts of EFICS (European Commission 1997). The EFICS study focused on the possibility of harmonizing national information on forest resources. Part of this study was done to investigate the effect of different assessment techniques, definitions, and measurement rules on forest resource information by the integration of national assessments. The study provided quantitative and qualitative figures about the variation of different key statistics caused by this heterogeneity of definitions. On the basis of those results, the need for harmonization efforts with respect to costs and benefits can be judged.

This paper focuses on the effect of differences in national forest area definitions when combined with European forest statistics, which was quantified by means of a simulation study. The assessments of forest area according to the methodology applied in the European Union (EU) Member States as well as in Norway, Switzerland, Liechtenstein, and Iceland (called European countries here), were simulated to facilitate a comparison between the different systems applied.

Most of the results presented in forest inventories are ratio estimates that relate attributes, such as total volume, to unit area, i.e., the forest area of the country. Therefore, the definition of forest area is of major concern, because it affects all area-related results. Individual forest area definitions applied in Europe are presented in table 1. The main criteria included in the definitions are width of forested patch, crown coverage, and size of forested area. Further criteria are productivity and the height of trees. These measures determine whether land covered by trees is assigned to forest or non-forest. The national forest area definitions consist of an individual set of these criteria with different minimum threshold values.

Forest area structure ranges widely in Europe from the Mediterranean types to those occurring in hilly areas and lowlands of central and western Europe to forests in the northern, boreal regions. Changes and differences in the spatial structure are due to differences in climate, soil, due to altitude and geographical location (natural timberlines or coniferous limit in the alpine or northern regions) and also due to recent and historical activities of humans. In an open forest type, changing the minimum crown cover

Research Forester, Swiss Federal Institute for Forest, Snow and Landscape Research, Birmensdorf, Switzerland; Professor, Dresden University of Technology, Faculty of Forest- Geo- and Hydro Sciences, Chair of Forest Biometrics and Computer Sciences, Tharandt, Germany; Deputy Director, European Forest Institute, Joensuu, Finland; and Graduate research assistant, Virginia Polytechnic Institute and State University, Blacksburg, VA, USA, respectively.

Table 1.—*Forest area definitions in Europe (from Köhl* et al. *1997)*

Country	Minimum width	Minimum crown cover	Minimum area	Minimum production	Region/ comments
	Meters	*Percent*	*Hectare*		
Austria(A)	10	30	0.05	-	central
Belgium(B1/2)	9 /25	-/20	0.01/ 0.05	-	central[1]
Denmark(DK))	20	30	0.5		north[2]
Finland(FI)	-	-	0.25	1 m^3/ha/a	north
France(F)	15	10	0.05		central[3]
Germany(D)	10	-	0.1	-	central
Greece(GR)	30	10	0.5	-	south
Iceland(IC)	-	-	0.25		north
Ireland(IR)	40	20	0.5	4 m^3/ha/a	central
Italy(I)	20	20	0.2	-	south
Liechtenstein(LI)	25 to 50	20	-	-	central[4]
Luxembourg(LU)	-	-	-	-	central
the Netherlands(NL)	30	20	0.5	-	central
Norway(N)	-	-	0.1	1 m^3/ha/a	north
Portugal(P)	15	10	0.2	-	south
Spain(SP)	20	5	0.2	-	south
Sweden(S)	-	-	0.25	1 m^3/ha/a	north
Switzerland	25 to 50	20	-	-	central[5]
the United Kingdom(UK)	50	20	2		central

[1] Walloon region / Flemish region.
[2] Trees in the forest should be able to grow taller than 6 m.
[3] 500 stems/ha with dbh < 24.5 cm.
[4] Same definition as CH.
[5] Functional relationship between minimum width and minimum crown cover.

threshold in the definition can greatly affect the total amount of estimated forest land. As minimum crown cover threshold values decrease, forest areas should steadily increase. In areas where forests mainly consist of small patches, alleys, or gallery forest with closed crown canopy, the criteria width and forest area are more decisive and the crown cover criterion should then play a minor role.

Kleinn (1991) investigated the effect of varying minimum crown cover values on forest area estimation. He showed the relationship of different minimum values; the spatial structure of the forests; and the size of the reference area; and found a high sensitivity of the crown cover criterion in open forest types. According to Kleinn, the effect of the size of the reference area has proven to be "not as obvious and easy to describe" as the effect of the crown cover criterion.

In this study, the effect of different minimum threshold values of the criteria crown cover, width, and size of forest area will be quantified by simulation. The results of the simulation study indicate the variation of forest area statistics resulting from revisions of the forest area definition, as they were suggested, for example, for the Temperate and Boreal Forest Area Assessment 2000 (TBFRA 2000) (Nyyssönen and Ahti 1996). It can be expected that figures of forest area change will be substantially affected by those revisions, resulting in a lack of comparability in time.

METHOD

Forest/non-forest images were generated by computer for the simulation study. The images consist of a binary set of 800 x 800 pixels, which represent a distribution of single trees (fig. 1). Four main types of forest spatial patterns were investigated. Image 1 shows a sparsely distributed forest type with a high number of single trees and a gradual transition between forest and non-forest land. Image 2 represents a clustered type of forest where a clear border exists between forest and non-forest land. Images 3 and 4 in figure 1 are composed from different proportions of images 1 and 2 to simulate transitions between these basic patterns.

Forest Cover Assessment Procedure

In national forest inventories, forest size is often assessed by using a systematic sampling of aerial photo plots,

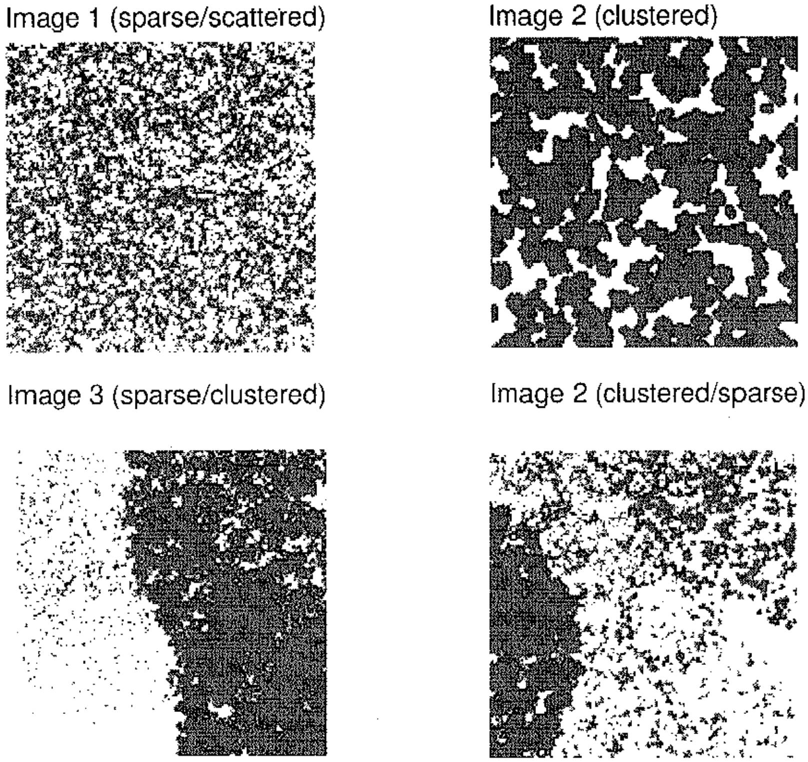

Figure 1.—*Artificially generated forest cover structure types after delineation process (distance 35 m). Black: area covered by tree crowns (each pixel represents the vertical projection of a tree crown); gray: potential forest area (forest land), not covered by tree crowns; white: non-forest land. Each image consists of 800 x 800 pixels with a resolution of 10 x 10 m (images kindly provided by Kleinn* et al. *1995).*

distributed in a grid over the entire area of interest. This procedure is applied in several European countries, but the techniques used are quite different. In this study, the method of the second Swiss National Forest Inventory (NFI) for forest/non-forest decisions on photo samples has been applied (Köhl 1997, Keller 1999). Each plot is interpreted to decide whether the area covered by the plot belongs to the forest or not. The photo plot sampling was simulated on the computer-generated images and can be divided into three steps:

Step 1: Delineation phase

To assess quantitative values of attributes used in forest area definitions, i.e. crown cover, size, and width of forest area, the potential forest area, subsequently called *forest land,* has to be delimited. The measurements of the three criteria have to be applied within these boundaries. According to Kleinn (1992), "an exact boundary has to be found when line transects are used as sampling techniques." This problem can be transferred to the measurement of the width of forest patches. If trees are distributed sparsely with pronounced gaps between closed forest patches, a decision has to be made about which trees belong to *forest land* and which are single trees located in non-forest land. For this reason, Zingg and Bachofen (1988) established a delineation rule based on a threshold value for the maximum distance of single trees from a forest patch to define a *forest land* boundary. This procedure can be interpreted as a pre-step of the forest area estimation. In the simulation study, delineation distances of 25, 35, and 50 m were applied in order to investigate the importance and impact of the delineation rule. The delineation step modifies the original images, which consist of single trees, to new images subdivided into two land categories: *forest land* (potential forest area) and *non-forest land.* The proportion of each category depends on the delineation distance.

Step 2: Simulation of photo plot samples

After the delineation procedure, the forest cover percentage was calculated by systematic sampling. For each sample located within or near *forest land*, a forest/non-forest decision was made according to the definitions of the European countries. About 6,000 squared samples of 50 x 50 m systematically distributed in a 100 m grid were drawn from the images.

The forest cover percentage of the entire area was calculated from the simulated photo plot sampling procedure. It is defined as the quotient of plots assigned to forest and the total number of sample plots drawn from the image times 100. If the plot center is located in *forest land,* the forest/non-forest decision is made according to the minimum threshold values for crown cover, size and width of the forest area. If the plot center is located in *non-forest land,* close to the forest borderline, the length of the shortest virtual line intersecting the plot center and two borderlines are measured instead of the width of the forest area patch. If the length of this line exceeds 25 m, the plot is assigned to non-forest.

Table 1 demonstrates the considerable variation in the definitions of forest applied in the national forest inventories of the European countries. The criteria are not used by all countries nor do the threshold values for the certain criteria coincide. Threshold values for minimum crown cover range between 10 and 30 percent, the minimum width values range between 9 m and 50 m, and the minimum area values range between 0.05 ha and 2 ha. Since it was not possible to integrate the criterion "minimum production" in this type of simulation study, the simulation for the northern countries was difficult. Because those countries also do not use forest cover and minimum width as a criteria, the parameters were set to zero. This approach, however, does not completely reflect the forest area estimation procedure of these countries. Päivinen (personal communication 1998) stated that a minimum threshold for crown cover of 20 percent obviously would be a proper value. However, this problem was left unsolved in this study and could be the subject of further studies.

Step 3: Relating the four forest structure types to European regions

The objective of the simulation study was to investigate the effect of the individual country definitions on forest area estimation. The four artificially generated images represent typical pattern types, but they are not evenly distributed over all of Europe. Since the importance of the individual definitions is assumed to depend on the structure types, the results should be weighted according to the proportion to which these types occur in the several regions. The proportions used in this study for northern, central, and southern Europe were derived from questionnaires submitted to the experts of these regions and can be seen in table 2.

In the northern countries, closed coniferous forests cover wide areas. This structure type is represented by image 2. However, in peatlands or in forests near the coniferous timberline, the crown closure decreases, and the forest structures represented by images 1, 3, and 4 occur and are estimated to make up about 40 percent of the forests. In the central and western parts of Europe, forest land is mainly covered by closed forest types. Their typical properties are sharp, well-defined boundaries to the *non-forest land* categories. However, the forest area is lower and the spatial structure of the forests is more patchy than in northern countries. More than 50 percent of the area in central Europe is covered by agricultural land. This and the closed forest cover of central Europe is represented in image 2. Near the forest timberline, open forest types are dominant with gradual transitions from *forest land* to *non-forest land*, represented in images 1, 3, and 4. However, the amount of open forest types is significantly less than in northern countries. In southern locations, gradual transitions from forest to shrub or other wooded land are very frequent, which makes a clear definition of forest and other wooded land difficult. The phenotypes of forest trees occur both as trees and as shrubs. The wide variety of forest structure types leads to a more or less even representation of the four images.

RESULTS

Comparison of the Forest Area Definitions Based on the Basic Structure Types (Images 1-4)

For each image, the forest cover percent was estimated based on the systematic photo plot sampling simulation procedure. The first part of the results refers to the principal structure types of forest pattern represented in images 1-4; the second part refers to the results found for the European regions.

As a primary result, three groups of countries referring to the level of estimated forest cover percentages can be detected (table 3). This result is more or less independent of the forest structure type. Due to the different forest area definitions from each country, the forest cover estimated by the Austrian definition, for example, is always higher than the estimation derived from the Irish forest definition. Luxembourg was excluded from the study because forest area is assessed from maps in this country, where the distinction between forest and non-forest is "normally obvious" (Kalmes 1997). These principal results have also been proven to be independent from the delineation distance. In table 4, the ranges of forest cover estimation derived from the simulation study, referring to a delineation distance of 35 m, are given. The highest value of forest cover estimation range was found for image type 1 (sparse/scattered). The difference of 29.17 percent was derived from the forest cover estimation according to the Norwegian definition and the

Table 2.—*Percentages of the four forest structure types related to the European regions, from a questionnaire submitted to country experts involved in the EFICS study.*

European regions	Image 1 'scattered'	Image 2 'clustered'	Image 3 'mixed 1'	Image 4 'mixed 2'
Northern	10	60	20	10
Central	5	80	5	10
Southern	30	20	20	30

Table 3.—*Levels of forest cover estimation derived from the four image types (fig. 1). The grouping means that the definition of Austria would always lead to a higher forest cover estimation than, for example, the definition of the United Kingdom, irrespective of the structure of the forest to be assessed.*

Level of forest cover estimation	Countries	
High	A, B1, D,	(FIN, IC, N, S)
Medium	B2, CH, DK, F, FL, I, P, SP	
Low	GB, GR, IRL, NL	

Table 4.—*Differences between highest and lowest forest cover percentage estimation (range) of the four forest cover structure types (images 1-4), derived from the photo plot sampling simulation. The results are given for all the countries as well as for a subset of countries from which Finland, Norway, Sweden, and Iceland were excluded. The range of values for all countries were found from the comparison of the definitions of Norway and the United Kindom; those for the subset of countries originate from the comparison of Belgium/Walloon and the United Kingdom.*

Image	1	2	3	4
Range (all countries)	29.17	1.48	8.29	11.75
Range (subset of c)	24.92	1.23	7.42	10.83

definition of the United Kingdom. However, the range for image 1 probably is not accurate since the forest area definitions of Finland, Norway, Sweden, and Iceland do not apply a minimum crown cover or a minimum width as already stated. Since the simulation of the forest area estimation for these countries is based on incomplete definitions, the results have to be interpreted carefully. In the second row of table 4, which is built from a subset of countries excluding Finland, Norway, Sweden, and Iceland, the largest range for image 1 is approximately 25 percent. This result is derived from the definition of Belgium/Walloon and the United Kingdom. The smallest range between forest cover estimations was found in image type 2 (clustered). The difference of forest cover estimation according to the definition of Belgium/ Walloon and the United Kingdom is 1.23 percent.

Comparison Between European Regions

To get an idea of the effect of forest area definitions in northern, central, and southern European regions, the differences of the forest cover percentage estimations originating from images 1-4 were related to the shares of forest structure types in the three regions. The values of table 4 are calculated as the weighted mean of the ranges of table 3. The weights refer to the proportions in table 2; the results, which were calculated for a delineation distance of 35 m, are given in table 5. In table 2, it can be seen that the central region is mainly covered by image type 2 (clustered), which means that the range values are strongly influenced by this structure type. The opposite situation occurs with the figures of the southern region where the results were influenced by all images with more or less equal proportions. The largest ranges occur in the southern region because of the high proportion of scattered forest types. The mean range was built mainly from images 1, 3, and 4. Smallest ranges occur in the central region where clustered types are dominant and the mean range is mainly influenced by image 2.

The impact of different delineation distances is shown in table 6. Highest range values between forest cover

Table 5.—*Mean values of the ranges of forest cover estimation (table 4) weighted with the shares of structure types 1-4 related to the European regions (table 2). The results are given for the ranges derived from all country definitions as well as for a subset of countries in which Finland, Norway, Sweden, and Iceland were excluded.*

Region	North	Central	South
Range (all countries)	6.65	4.24	14.26
Range (subset of c.)	5.78	3.68	12.45

Table 6.—*Range values of forest cover estimation derived from the subset of country definitions (excluding Finland, Norway, Sweden, and Iceland) for the European regions as a function of the delineation distance. The bold values correspond to the values given in table 5.*

Region	**Delineation distance**		
	25 m	*35 m*	*50 m*
Central	4.48	**3.68**	3.02
North	7.19	**5.78**	5.09
South	16.17	**12.45**	10.86

principally occur in the southern regions; lowest range values occur in central regions. It also can be seen that the magnitude of the range values is negatively correlated with the delineation distance, i.e., the effect of definition differences diminishes with increasing delineation distance. If *forest land* area enlarges, the forest criteria, particularly the criteria "width" and "area," obviously lose their sensitivity. This phenomenon leads to an indifference of the certain minimum threshold values for these criteria and thus to smaller ranges of forest cover percentage. As a general result, it can be stated that the effect of varying delineation distances is greatest in regions covered by open forest types. The number of gaps converting from *non-forest land* to *forest land* by increasing the delineation distance in this region is much higher than in areas covered by clustered forest types.

As already stated, the sensitivity of the forest definition criteria is correlated to the structure types and to the delineation rule applied. A differentiated examination of the non-forest assignments should give a clear understanding of the importance of the single criterion. Knowledge about the effect of a specific criterion could support considerations on harmonization efforts in more detail. A non-forest assignment can be caused by one single criterion or by a combination of criteria, i.e., more than one criterion would lead to the non-forest decision. Figure 2 shows that the width criterion most frequently led to the non-forest decision. In this study, this holds true for all regions and steps of delineation distance. The forest area criterion and the combination of criteria play a minor role; their importance decreases with increasing delineation distance. The crown cover criterion is important when the delineation distance is bigger than 35 m. This is an obvious effect of the increasing *forest land* area, which reduces the amount of small and narrow patches and thus diminishes the effect of the criteria "width" and "size" of forest area. If *forest land* increases, the crown cover percentage decreases because the number of single tree crowns is stable. This effect raises the sensitivity of the crown cover criterion. The differences between the three regions are important only for delineation distances bigger

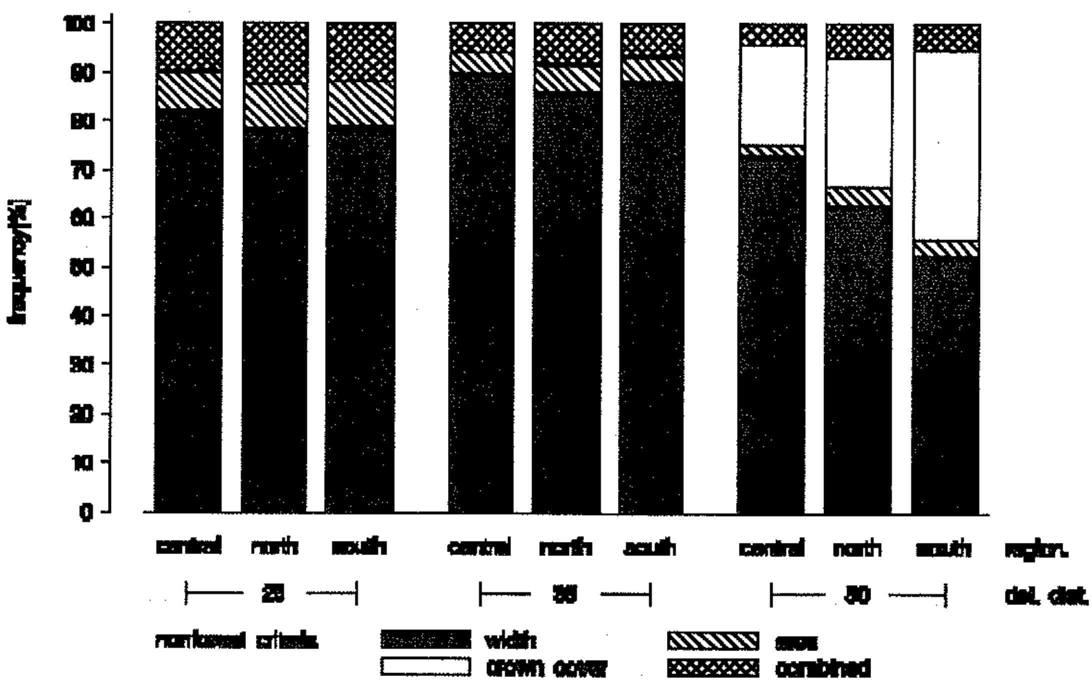

Figure 2.—*Frequency of criteria that led to the decision non-forest, derived from the simulated 50- x 50-m air photo samples located inside or close to the forest land. The results are presented for different delineation distances and separated by the European regions.*

than 35 m. In nearly all cases, the width criterion has been proven to be the most restrictive criterion, which leads most frequently to the non-forest decision.

To get an idea about the effect of certain forest area definitions applied to individual countries, figure 3 shows the effect of country definitions on forest area estimates in Switzerland and the United Kingdom. Positive differences mean that forest area definitions that are applied to a certain country would lead to a higher forest cover compared to the estimate by its own definition. The forest area definition under concern could be interpreted to be more tolerant compared to the definition of the reference country. However, if the definition is more restrictive compared to the reference country, negative differences could occur.

As can be seen in figure 3, the Swiss definition is a moderate one, because some country definitions lead to lower forest area, while others lead to higher forest area in

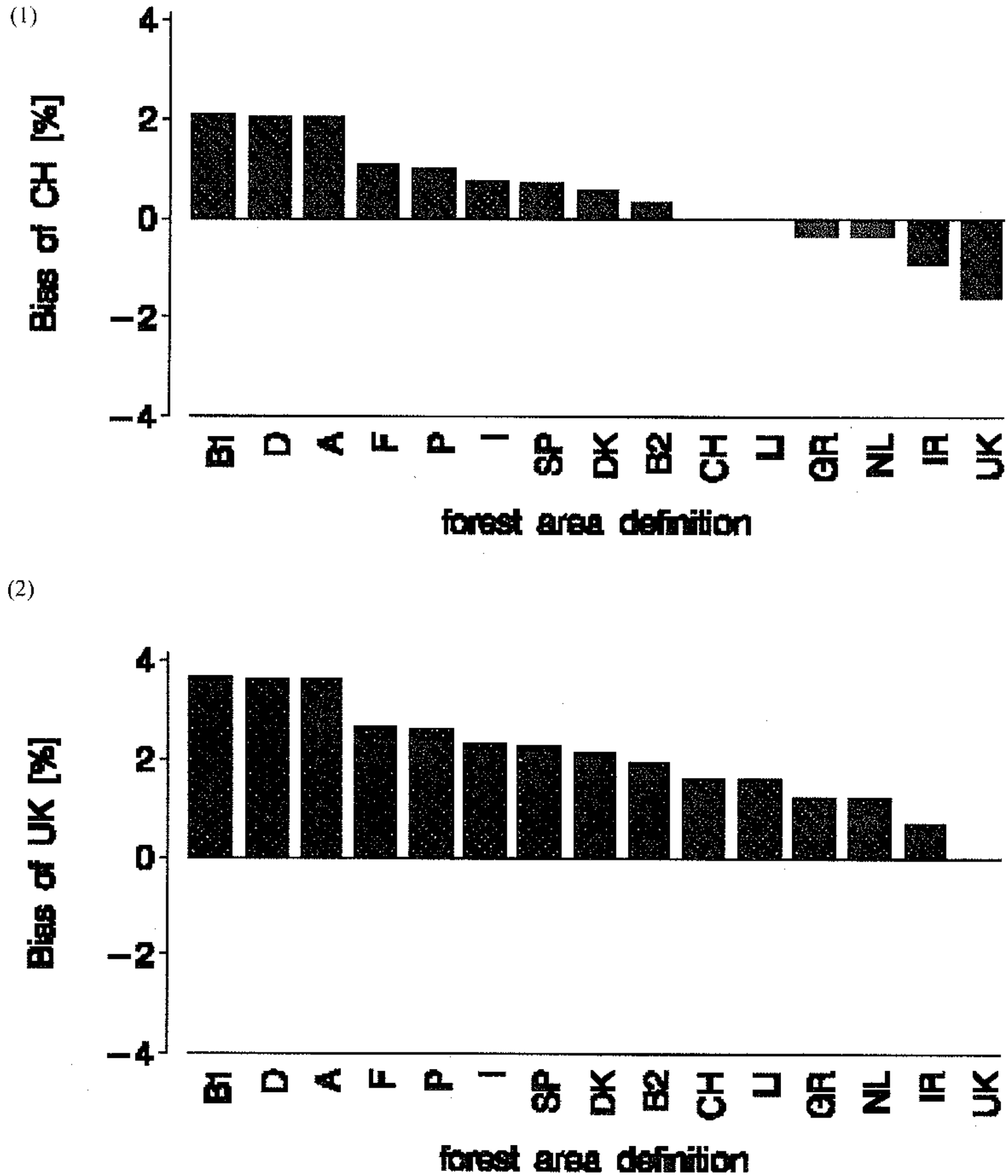

Figure 3.—*Changes of forest cover (bias [%]) for the reference definitions of Switzerland (1) and the United Kingdom(2) as a result of the application of forest definitions of the European countries. A positive bias in the top chart means that the specific country definition would increase forest area compared to the Swiss definition. A positive bias in the bottom chart is the respective to the United Kingdom definition.*

comparison to the Swiss definition. Most tolerant is the definition of Belgium/Walloon, which would increase the Swiss forest by about 2 percent. Most restrictive is the definition of the United Kingdom, which would lead to about –1.5 percent less forest area. This is probably due to the area restriction of 2 ha, which is a far higher minimum threshold value than in other countries. All forest area definitions applied to the United Kingdom forests would lead to an increase of forest area.

CONCLUSIONS

The largest range between forest cover estimations, found from the comparison of the Belgium/Walloon and the United Kingdom definitions, is 24.92 percent and refers to image type 1 (sparse/scattered). The smallest range is 1.23 percent, which is found in clustered image type 2. When combining the theoretical image types to forest patterns according to the proportion they occur in the northern, central, and southern regions, the maximum differences due to the different forest definitions are 5.8 percent, 3.7 percent, and 12.4 percent, respectively. This means that the biggest differences occur for forest types structured similar to image 1. This type mainly occurs in southern regions with a high proportion of scattered forest types and in regions with natural timberlines, as in mountainous (alpine) or northern regions. Lowest ranges occur in the central region where clustered types are dominant.

This leads to the conclusion that harmonization needs are particularly important when forest area statistics are to be compiled from countries located in southern European regions, and from countries with a huge amount of forest approaching the natural timberline in alpine and northern regions.

The importance of the three criteria defining the forest/non-forest decision (width, crown cover, and size of area) depends on the forest structure type. The width criterion has proven to be the most important one for all forests; the crown cover criterion plays an important role in open forest types; and the forest area size criterion plays a subordinate role. It is also important to learn from this study that both the forest area definition and the delineation rule, which separates potential forest land from *non-forest land*, influence the effect of the different definitions. It can be stated that big or "tolerant" delineation definitions lead to small differences of forest cover estimation. Specifically, increasing the delineation distance results in a decrease of the ranges of the forest cover estimates. As can be seen in table 6, these general rules do not depend upon forest structure. Nevertheless, the magnitude of the differences is highest in southern European countries. This leads to the conclusion that the delineation procedure of potential forest area should be treated with great attention in harmonization efforts of the forest area definition.

In this study, forest area definitions from the European countries were applied to artificially generated forest structure types by means of a photo plot sampling simulation. The results from this study should be interpreted as an approach that provides an idea of the dimension of the differences in forest area estimation due to the application of individual country definitions to a certain forest structure type. Some definitions could not be simulated satisfactorily, e.g., those that include minimum height criteria or minimum productivity measures. The implementation of these criteria, as well as the improvement of the comparability of definitions that do not use a unique set of criteria, could be subject to further studies.

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