CHAPTER 17

ASSESSING THE WORLD'S FORESTS

ANNIKA KANGAS

University of Helsinki, Finland

17.1 GLOBAL ISSUES

17.1.1 Issues of interest

The Food and Agricultural Organization (FAO) of the United Nations has a long history of global forest resource assessments (FRA). The FRA programme has two major components (FFRI2003):

1. Global assessment and reporting
2. Support for national forest assessments

The global assessment component has two objectives: to compile, analyse and report forest information covering all countries, and to maintain mechanisms and arrangements for global reporting. The support component also has two major objectives: to support countries in developing, packaging and using forest information and to establish an international framework for reporting on forest resources.

R. Zon, in collaboration with the United Stated Forest Service, prepared the first report on global forest resources in 1910 (Zon 1910), and this was updated in 1923 (Zon and Sparhawk 1923). The first world forest inventory was carried out by the FAO in 1947-1948, and it subsequently conducted such inventories every fifth year from 1953 to 1963. In these first assessments the FAO used a questionnaire to obtain the information from the individual countries (Holmgren and Persson 2002), but this approach could not be used later as the capacity for forest inventories had decreased in many countries. Thus expert judgments, in which all possible information from different sources was collected and an expert tried to infer the state of the country's forests from this, were also used in the 1970s and 1980s (Holmgren and Persson 2002). The assessments made in the 1970's were essentially regional, but a global synthesis of them was prepared as well (Persson 1974).

In the latest two assessments, the assessments of forests in the tropical

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region are based on remote sensing, but those in the temperate and boreal zones on questionnaires. A panel of experts (FFRI 1996) made recommendations with respect to the major issues of data acquisition and the compilation of information for FRA 2000 at the Kotka III meeting, and work for the new assessment, FRA 2005, discussed at the Kotka IV meeting (FFRI 2003), is currently going on.

Forest areas and area changes have been a major issue in the assessment of global forest resources. The forest area has been seen as a simple indicator of the status of the world's forests, and therefore as an important means of monitoring changes. Changes in forest area may be due to land use changes, such as afforestation, deforestation and expansion of the natural forests, or internal changes within a forest class, such as reforestation, regeneration of natural forests, forest degradation and improvement.

Forest area can also be a problematic concept, however, as an indicator of the health of the ecosystem. The environmental, social or economic values of forests may not necessarily be related to their absolute extent, for instance. Thus the forests that are of the greatest environmental importance may be scattered and involve a small area, and their economic value may be related more to species distribution and volume than to forest area, while social values may be interrelated with other local interests such as agriculture.

The shortage of forest resources has always been a concern, and balancing of the supply with the needs requires information. Wood is needed for construction, for pulp and paper, for fuel and energy and for carbon sequestration, among other things, so that wood volume and biomass have been among the most important parameters in assessments of global forest resources. The issues considered in the Forest Resources Assessment 2000 (FRA 2000) were much wider than those of earlier assessments, however, the topics of interest being:

forest area and its changes,
wood volume and woody biomass,
forest plantations,
trees outside the forests (TOF),
biological diversity,
forest management,
forests in protected areas,
fires,
wood supplies and
non-wood forest products.

Ideally, a global forest assessment should address all the benefits of forests and the full range of potential beneficiaries, from local users to the global population (Holmgren and Persson 2002). This chapter will briefly review the most important results, namely forest area, volume and biodiversity considerations, although the main attention will be focused on methodological issues.

17.1.2 Forest area

Up to the more recent assessments, the definition of forest was 20% canopy cover in the temperate and boreal zones and 10% cover in the tropical zone. In FRA 2000, however, 10% cover was used for all countries, and while a canopy cover between 5% and 10% was classified as an "other wooded area", a category which in earlier inventories had required a 10%-20% canopy cover. This change required much work in order to compare the results with earlier assessments, the discrepancies being largest in Russia and Australia, where extensive areas of forests with a canopy cover between 10%-20% exist.

Even a specific canopy cover threshold is not a straightforward definition of forest, however, for the definition used in FRA 2000 also involved a land use classification. When another land use, e.g. agriculture, predominates in an area, it cannot be defined as a forest. Thus oil palms and rubber trees are included in forests, but fruit orchards and agroforestry areas are not. Similarly national parks are included but urban parks are not (FRA 2000).

According to FRA 2000, the global forest area is 3 869 million hectares and accounts for 30% of the land area. The net change has been a decrease of 9.4 million hectares per year, implying 14.6 million hectares of deforestation of natural forests and an increase of 5.2 million hectares in the area of forest plantations.

17.1.3 Wood volume and woody biomass

The wood volume was defined in global assessments as the stem volume of all living trees more than 10 cm in diameter at breast height (or above buttresses if these are higher) over bark, measured from the stump to the top of the bole (volume over bark, VOB). The above-ground biomass was defined as that of the woody parts of trees (stem, bark, branches, twigs), alive or dead, shrubs and bushes, excluding stumps and roots, foliage, flowers and seeds.

Suitable data were available for most developed countries, while estimates for the developing countries had to be based on local inventories in many cases, inventories that only covered certain aspects such as commercial forests, or inventories limited to a few species. Biomass studies in these countries were even less common.

Another problem was that the national results were seldom compatible with the FAO definitions. The volume could be defined to include trees above 5 cm or 50 cm at breast height, for example. The largest minimum diameters were often used in humid regions such as Indonesia, and the smallest in dry regions of Africa. The volumes of the missing dbh classes were estimated with regression equations between dbh class and volume, or with volume expansion factors (VEF) when regression could not be used.

The volume data were converted to biomass with the formula (FRA 2000)

$$\mathrm{TFB} = \mathrm{VOB} \cdot \mathrm{WD} \cdot \mathrm{BEF}, \tag{17.1}$$

where TFB is the total forest biomass (t/ha), VOB is volume over bark (m^3/ha), WD is volume-weighted average wood density (t/m^3) and BEF is the biomass extension factor, i.e. the ratio of whole tree oven-dry biomass to the oven-dry biomass of the inventoried stem volume.

The estimated global volume of forests in 2000 was 386 billion cubic metres and the above-ground woody biomass was 422 billion tonnes. The wood volume increased by 2 percent between FRA 1990 and FRA 2000, and at the same time the woody biomass decreased by 1.5%.

There are considerable numbers of trees, however, that are not located in forests but grow in gardens and parks, in cities, on farms, in fruit orchards or beside roads. These, too, may be important both environmentally and economically. They may provide shade, shelter and food, they may improve the landscape and they may protect the soil. No global assessment of the volume or biomass of such TOF trees has ever been made, although many studies exist for specific areas. In many areas TOF may be more important than forests, e.g. in Kerala, India, where as much as 93% of the wood production was estimated to be from trees growing outside the actual forests.

17.1.4 Biodiversity and conservation

Biodiversity is a complicated issue, and for that reason only certain specific aspects can be monitored. The variables considered must be simple, uniform and easily understood, and they should represent major values in forest biodiversity. Such variables are typically based on indicators or indirect (surrogate) measures. The FAO Expert Consultation on Global Forest Assessment 2000 (FFRI 1996) recommended the following variables:

naturalness (natural forests, semi-natural forests and plantations)
protection status (IUCN categories, Table 17.1)
fragmentation
better information on forests in specific ecological zones.

There are obstacles even to the assessment of such simple-looking variables as these, however. World maps indicating diversity at the ecosystem or species level, for instance, typically have a resolution of 10 kilometres or more, and national-level summaries are even less detailed. Therefore, part of the meaning of diversity may be lost when the data are averaged over large areas (FRA 2000).

As data on biodiversity are scarce, two separate studies were carried out in the assessment: a review of the literature in each country on the number of species occurring in forests and a consideration of the spatial attributes of forests.

The literature review was carried out in order to estimate the importance of forests as habitats. Typically, fairly good information was available on all species, but only limited information on those occurring in forests. The data concerning trees are limited, for example, due to the problems of defining this group, and no data at all were available on reptiles, birds and mammals occurring in forests. The value of assessments based on the number of endangered species is therefore seriously limited (FRA 2000).

The spatial analysis could be carried out fairly easily. Three aspects of fragmentation were considered, namely area effects, edge and gradient effects and isolation effects. Area effects are based on the assumption that small patches support fewer species and are more vulnerable than larger patches, edge effects imply that the interface with non-forest ecosystems has negative effects on environmental variables, and isolation effects means that the gene flow between one population and others of the same species will be reduced. This approach was found to be technically feasible, but the problem remains that its relevance to biodiversity has not been determined (FRA 2000).

The area under protection was determined in two ways, through questionnaires sent to national and regional land management agencies and by overlaying global protected area maps on global forest cover maps. Since the global protected area map in some cases included only a reference point and not the actual shape of the area, a circular area had to be used. The result is that the map is not accurate for any given protected area but is mainly a cross-tabulation of the two maps (FRA 2000).

Table 17.1 Categories of protected areas according to IUCN (McNeely and Miller 1984).

Category	Definition
I - Strict nature reserve / wilderness area	Protected area managed mainly for science or wilderness protection
II - National park	Protected area managed mainly for ecosystem protection and recreation
III - Natural monument	Protected area managed mainly for conservation of specific natural features
IV – Habitat / species management area	Protected area managed mainly for conservation through management intervention
V – Protected landscape / seascape	Protected area managed mainly for landscape / seascape conservation and recreation
VI – Managed resource protection area	Protected area managed for the sustainable use of natural ecosystems

The total extent of forests in protected areas was estimated to be 479 million hectares, or 12.4% of the total forest area (Tables 17.2 and 17.3). In Europe the proportion is only 5.0%, which is partly explained by the fact that Siberia has no officially protected areas. There were considerable discrepancies in the comparisons between the answers to the country questionnaires and the global maps, especially since some countries had reported that the whole country was a protected area, since a general law to this effect existed, whereas others reported only strictly protected areas.

Table 17.2 Forests in protected areas, based on the global protected area map (FRA 2000).

Region	Forest area in 2000 (million hectares)	Forest in protected areas	Proportion (%)
Africa	650	76	11.7
Asia	548	50	9.1
Oceania	198	23	11.7
Europe	1039	51	5.0
North and Central America	549	111	20.2
South America	886	168	19.0
Total	3869	479	12.4

Table 17.3 Forests in protected areas by ecological domain, based on the global protected area map (FRA 2000).

Ecological domain	Forest area 2000 (million hectares)	Forest in protected areas	Proportion (%)
Tropical	1997	304	15.2
Subtropical	370	42	11.3
Temperate	507	83	16.3
Boreal	995	49	5.0
Total	3869	479	12.4

17.2 METHODOLOGY

17.2.1 Global forest resources assessment

The formal requests sent to country representatives in 1996 and 1998 in order to compile the latest national-level statistics included specific guidelines aimed at obtaining data that would be well structured and compatible with the terms and definitions of FRA 2000. For those countries that had no suitable inventory data, assessments were compiled from partial inventories and/or subjective estimates (FRA 2000). Also, validation of the results was required from all countries (Holmgren and Persson 2002). This work could not have been done without the collaboration of forestry professionals in each country. The assessment represents 212 countries, of which 160 participated in workshops or worked with FAO staff in their countries (FRA 2000).

The forest assessment information collected is subject to many sources of uncertainty. The information is very variable with respect to terms and definitions, for example, to the extent that over 650 definitions of forest were noted in 110 independent surveys representing 132 developing countries (FRA 2000). A massive effort was made to harmonize the results (FAO 2002), but there is still no means of assessing the accuracy of such adjustments. Another aspect is that it may be in the interest of the countries to exaggerate or hide some issues. A country may want to give exaggerated deforestation figures, for example, in order to gain international assistance for their forestry sector, while another may exaggerate the area of protected forests, and so on (Holmgren and Persson 2002).

Another source of uncertainty is the fact that in many countries the national inventory is not based on sampling but on management plan inventories (Holmgren and Persson 2002). Only a few countries could derive statistical confidence intervals even for the forest area or area change data (FRA 2000), and in some cases there may not be a long enough time series available for estimating the changes. Of the 137 developing countries, for example, only 22 have repeated inventories, 54 relied on a single inventory, 33 had only data from a partial inventory and 28 had had no inventory at all (Holmgren and Persson 2002, FRA 2000).

17.2.2 Temperate and boreal forest assessment

Assessment in the temperate and boreal regions, i.e. in the 55 industrialized countries, was entrusted to a team of government-nominated specialists formed in Geneva by UN/ECE and FAO and was carried out using questionnaires. The representatives of each country received a number of tables to be filled in according to FAO definitions (FAO 2002). Thus they were obliged to adjust their national definitions. They were also asked to give the likely range for their assessments. The representatives were aided in this by meetings and personal communications.

The main issues affecting the reliability of the data were 1) the differences in definitions (definition error) and 2) non-response. The possible effects of these are analysed in the main report (TBFRA 2000). Differences in the reference period may also have caused some errors, as the oldest data for TBFRA 2000 were from 1986 (Germany) and most recent data from 1998 (Iceland). It should also be noted that the forest area of the four largest countries, Canada, the USA, Russia and Australia, accounts for about 85% of the world's total forest area, so that possible errors in their figures will have had a major effect on the results.

Five out of the 55 countries did not answer the questionnaire at all: two countries from the former Yugoslavia together with Kyrgyzstan, Turkmenistan and Uzbekistan, but they comprise only 2.2% of total land area and 0.6% of forest area involved. Non-response was more severe in the case of certain attributes, however. Every country was able to give its total forest area and the area of other wooded lands, but it was difficult in many countries to give an assessment of annual removals, especially on other wooded lands.

The effects of definition errors were considered with respect to two variables, namely the definition of forest and the definition of the volume of a single tree. The definitions accepted, 10% crown cover and the possibility of achieving a height of 5 m, are the "lowest common denominators" for all the countries. The definitions of crown cover varied from 0% to 30% in 19 western Europe countries, those of minimum area from 0 ha to 0.5 ha, those of minimum production from 0 m^3/ha to 4 m^3/ha and those of minimum width a forest patch from 0 m to 40 m. The definition of forest used in Ireland (20%, 0.5 ha, 4 m^3/ha and 40 m) would give the lowest forest area and that used in of Luxemburg (0%, 0 ha, 0 m^3/ha and 0 m) the largest (TBFRA 2000).

The volume of a single tree depends on three issues: 1) the minimum dbh threshold, 2) the starting point for stem volume (ground or stump) and 3) the minimum top diameter. The definitions for the first varied from 0 in Finland to 12 in Switzerland, and those for the third from 0 in Finland to 7.5 in Spain. The FRA definition was 0 cm minimum dbh, stump height and 0 cm minimum top height (the same as in Finland and Sweden), and therefore the top volumes, stump volumes and volumes of small trees had to be analysed separately in many countries. Adjustments were made by means of models, special investigations or expert judgments. The forest area was analysed in Finland, for instance, with a model applying parameters from the Finnish NFI, and in Switzerland from a survey using aerial photographs (TBFRA 2000).

17.2.3 Pan-tropical remote sensing survey

Since the greatest deficiencies were in the tropical data, a separate tropical survey based on remote sensing was carried out. The objectives were (FRA 2000):

1) to monitor tropical forest cover and its changes over the past 20 years at the regional and pan-tropical levels
2) to analyse trends in forest cover change in the intervals 1980-1990 and 1990-2000
3) to study the dynamics of changes in forest cover
4) to identify the causal mechanisms behind deforestation, and
5) to complement existing country-specific information by providing spatially and temporally consistent data on the state of the forests and changes in this.

The survey was designed on a two-stage stratified sampling basis, in which the areas were divided into regions and sub-regions and the sub-regions further into a maximum of three strata corresponding to their forest cover and expected deforestation rates (FRA 2000, Czaplewski 2002). Those strata with higher expected deforestation rates were sampled proportionally more intensively (Czaplewski 2002).

The population was defined as consisting of 1203 LANDSAT frames, representing all the frames in which the forest cover was more than 10% and the land area more than a million hectares (FRA 2000). Based on the country data, 87% of the tropical forests belonged to a sampling frame. Of these frames, 117 were selected for the sample, representing 10% of the area. This small percentage has been criticized (e.g. Tucker and Townshend 2000) and may indeed not be large enough for inference on a national scale, but it is large enough on a continental or global scale, which was the intention (Czaplewski 2002).

There were three LANDSAT images used for each unit in the sample, and those were taken that came as near as possible to the reference years 1980, 1990 and 2000. All the images were interpreted visually from hard copies. They were processed in three bands as standard false-colour infrared prints to a scale of 1:250 000 (FRA 2000). The older images had been interpreted previously for an earlier assessment, but where new data such as vegetation maps were available, they were re-interpreted. All the images were interpreted at the same time, not independently.

The classification, carried out using a 2·2 km^2 grid, was into ten classes, of which nine were visible (Table 17.4). Analyses of forest cover were then performed on this classification using three definitions of forest. In the strictest one (f1) only the closed forests were included, in f2 both the closed and open categories were used, together with some of the fragmented forests, a definition that comes closest to the country reports, and in the last definition (f3) the long fallow class was also included, as well as a higher proportion of the fragmented forests. The result of the analysis is a matrix of changes between classes from one image to another (FAO 1999a) that enabled calculating forest change rates according to the different definitions. The aggregated results were calculated by treating each image as a cluster, and by calculating the results with ratio estimators, as the land area in each image is a random variable (FRA 2000).

Table 17.4 Classification used in the pan-tropical image analysis (FRA 2000).

Land cover categories	Land cover classes	Description
Natural forest		
Continuous forest cover	Closed canopy	Canopy cover > 40%
	Open canopy	Canopy cover 10-40%
	Long fallow	Forest affected by shifting cultivation
Fragmented forest	Fragmented forest	Mosaic of forest/non-forest
Non-forest		
Other wooded land	Shrubs	
	Short fallow	Agricultural areas with short fallow periods
Non-woody areas	Other land cover	Includes urban and agricultural areas, areas with less than 10% woody vegetation cover
	Water	
Human-made woody vegetation	Plantations	Forest and agricultural plantations
Non-visible	Non-interpreted	Clouds, burnt woodland, shadow

Since the average dates of the images were 1977, 1989 and 1998, the observed deforestation rates had to be adjusted to obtain estimates of trends between the target years. This was done by two methods (FRA 2000): a constant method, in which it was assumed that the changes in land cover were constant and unchanging during the period and could be calculated using one reference date, and a linear method in which the changes were assumed to occur gradually requiring the use of both the available change rates. Both methods inevitably introduce errors into the analysis, but there is no general methodology to account for this uncertainty.

The results of the survey were fairly well correlated with the country data obtained by means of the questionnaires, although the satellite-based survey gave lower rates of deforestation than the country data, especially in Africa, where the difference was statistically significant. The major cause of deforestation in Africa was the establishment of small-scale agriculture, while in Asia and Latin-America it was the establishment of large-scale agriculture.

17.2.4 Global mapping

One result of the FRA 2000 project was a global map of the forests, as had already been proposed at the Kotka III meeting (Lund and Blue 1997). This map is based on AVHRR data, with a pixel sizeof 1 kilometre (FAO 2001). Such data are suitable, because the resolution is coarse enough and there is enough material, on account of the daily imaging schedule (FAO 2001). The daily data cycle also means that the AVHRR data could be formed into 10-day composites. This was done by the EROS Data Center (EDS). The data initially consisted of five calibrated AVHRR bands, and a NDVI (normalized difference of vegetation index) band. For global mapping purposes, the 10-day composites were used to form a monthly composite and the number of bands was reduced to two (red and infrared), together with the NDVI band:

$$NDVI = \frac{NIR - R}{NIR + R}, \tag{17.2}$$

where NIR is the near-infrared value and R is that of the red channel. The areas on the global map are classified into five classes (Table 17.5). The most problematic parts for mapping are to obtain cloud-free data for all the areas and to piece together a large number of images. In spite of the efforts made, some Pacific islands could not be mapped because of deficiencies in the data. The last three classes could be fairly directly derived from the U.S. Geological Survey (USGS) EDC database (FAO 2001), but the closed and open/fragmented classes could not be directly inferred from the USGS seasonal forest cover type classes.

A new methodology was therefore developed for this latter task, based on spectral mixture analysis (SMA), which means that the pixels are assumed to consist of fractions of surface components. As the resolution of the AVHRR data is coarse, this is obviously the case. Mixture analysis aims at estimating the number of surface components, or end members, within the target pixels. The endmembers can be, for instance, green vegetation, soil and rocks and shadow (see Smith et al. 1990, Roberts et al. 1993 for details). In mixture analysis, also other data with better resolution, such as LANSAT TM data are required.

As the variation on a global scale is paramount, and a sufficiently large TM dataset would be difficult to obtain, geographical stratification was used. Moreover, the analysis was performed separately for pixels with low, medium and high infrared reflectance. Pixels with low infrared reflectance contain burned areas, new forests and water, for instance. These pixels were classified on the basis of their NDVI values, as NDVI is considered to be insensitive to illumination variation (Holben et al. 1986). The pixels with high infrared reflectance contained forest land, agricultural land and non-vegetated land and were classified using mixture analysis with three end members, while those with mid-range infrared reflectance contained coniferous and mixed forests, fragmented forests, open woodlands, shrubland and grassland and were classified using linear scaling with red band reflectance, as forest cover density is closely correlated with red band reflectance (Yang and Prince 1997). Thus stratification was performed in order to improve the classification (for further details, see FAO 1999b, 2001).

Table 17.5 Classification used in the global mapping (FRA 2000).

FRA 2000 class	FAO definition
Closed forest	Canopy cover of trees more than 40% and height over 5 metres
Open or fragmented forest	Canopy cover of trees between 10% and 40% and height over 5 metres
Other wooded land	Canopy cover of trees between 5% and 10% and height over 5 metres, or shrub or bush cover of over 10% and height less than 5 metres
Other land cover	All other land, including urban and agricultural land, grassland and barren land
Water	Inland water

Validation of the global map with the available material showed its accuracy in this analysis to be about 80% for all the forest classes (FRA 2000). The closed forests could be mapped most accurately and the other wooded lands the least accurately (Table 17.6).

In addition to the global maps of forests, a map of ecological zones was also produced. This was based on the existing national and regional potential vegetation maps, climate data and satellite imagery (FRA 2000). The third type was a map of protected areas, the input for which was collected directly from the countries.

Table 17.6 Validation results for the global map (FAO 2001).

	Global validation dataset						
FAO legend	1	2	3	4	Row total	User's	Standard error
1	65	2	3	8	78	83.33	0.42
2	13	9	3	17	42	21.43	0.64
3	1	2	6	10	19	31.58	1.10
4	3	8	2	160	173	92.49	0.20
Column total	82	21	14	195	312		
Producer's	79.27	42.86	42.86	82.05			
Standard error	0.45	1.10	1.37	0.28			

17.2.5 Forest information database

All the data gathered in the process were placed in the FORIS (Forestry Information System) database, a Web-based system with its main user interface at the FAO Forestry Department web site http://www.fao.org/.

The data are organized by country, subject, species, publication and organizational entity, and the information can be presented in all the FAO's official languages, namely Arabic, Chinese, English, French and Spanish.

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