But there are currently insufficient data and a lack of common reporting methods in many countries to fully integrate NTFP inventories into forest management. Efforts are further constrained by a lack of field skills, time, personnel, and fiscal resources. Until these issues are addressed, the inventory and assessment of NTFRs will remain underutilized in forest management.

See also: **Biodiversity**: Biodiversity in Forests; Plant Diversity in Forests. **Genetics and Genetic Resources**: Forest Management for Conservation. **Harvesting**: Forest Operations in the Tropics, Reduced Impact Logging. **Inventory**: Multipurpose Resource Inventories. **Medicinal, Food and Aromatic Plants**: Edible Products from the Forest; Forest Biodiversity Prospecting; Medicinal and Aromatic Plants: Ethnobotany and Conservation Status; Tribal Medicine and Medicinal Plants. **Mensuration**: Forest Measurements. **Non-wood Products**: Resins, Latex and Palm Oil; Rubber Trees; Seasonal Greenery. Bamboos and their Role in Ecosystem Rehabilitation; Managing for Tropical Non-timber Forest Products. **Sustainable Forest Management**: Definitions, Good Practices and Certification.

Further Reading

Alexiades MN (1996) *Selected Guidelines for Ethnobotanical Research: A Field Manual*. New York: Botanical Garden.

Burkhart HE and Gregoire TG (1994) Forest biometrics. In: Patil GP and Rao CR (eds) *Handbook of Statistics, vol. 12, Environmental Statistics*, pp. 377–407. New York: Botanical Garden.

Cunningham AB (1987) Commercial craftwork: balancing out human needs and resources. *South African Journal of Botany* 53(4): 259–266.

Falconer J (1992) *Non-Timber Forest Products in Southern Ghana: Main Report*. Chatham, UK: Natural Resource Institute.

Jong RJ and Bonnor GM (1995) *Pilot Inventory for Pacific Yew*, Forest Resource Development Agreement Report no. 231. Victoria, BC: Canadian Forest Service and British Columbia Ministry of Forests.

Lund HG (1998) *IUFRO Guidelines for Designing Multipurpose Resource Inventories*, IUFRO World Series vol. 8. Vienna, Austria: International Union of Forest Research Organizations.

Lund HG, Pajari B, and Korhonen M (eds) (1998) *Sustainable development of non-wood goods and benefits from boreal and cold temperate forests*, EFI Proceedings no. 23. Joensuu, Finland: European Forest Institute.

Peters CM (1994) *Sustainable Harvest of Non-Timber Plant Resources in Tropical Moist Forest: An Ecological Primer*. Washington, DC: World Wildlife Fund.

Peters CM (1996) *The Ecology and Management of Non-Timber Forest Resources*, World Bank Technical Paper no. 322. Washington, DC: World Bank.

Pilz D, Fischer C, Molina R, Amaranthus M, and Luoma D (1996) Study 10: Matsutake productivity and ecology plots in Southern Oregon. In: Pilz D and Molina R (eds) *Managing Forest Ecosystems to Conserve Fungus Diversity and Sustain Wild Mushroom Harvests*, General Technical Report no. PNW-GTR-371, pp. 75–77. Portland, OR: US Department of Agriculture Forest Service, Pacific Northwest Research Station.

Salo K (1993) Yields of commercial edible mushrooms in mineral forest soils in forests in Finland, 1985–1986. *Aquilo Ser. Botanica* 31: 115–121.

Wong JLG, Thornber K, and Baker N (2001) *Resource Assessment of Non-Wood Forest Products: Experience and Biometric Principles*. FAO Non-Wood Forest Products Series no. 13. Rome: Food and Agriculture Organization of the United Nations.

Wong JLG (2000) *The Biometrics of Non-Timber Forest Product Resource Assessment: A Review of Current Methodology*. London: UK Department of International Development.

Forest Change

T Krug and J R dos Santos, National Institute for Space Research, São José dos Campos, Brazil

Introduction

Forest inventories constitute the basic documentation containing data (tables, maps) and information relevant to the planning and management of forest practices. Depending on the purpose of the forest inventory, a multitude of different data and information is collected, including, for example, measurements of some tree biophysical characteristics, production assessment, the industrial and economic value of the forest, all of which may be relevant to the efficient use of the forest resources. Different types of inventories, from reconnaissance inventories (a preliminary survey of low intensity that guides the more intensive inventory) to a large area inventories exist. The identification of the areas covered by forests constitutes the first step to initiate the forest inventory.

In order to identify the areas covered by forests, the 'own' definition (see below) of forest (which is necessarily linked to other forest-related definitions, such as deforestation, afforestation, reforestation, forest degradation) needs to be agreed. Unfortunately, there is no universal definition that is used worldwide and for all purposes. An exhaustive compilation of forest definitions has been prepared and includes more than 650 different definitions.

Similar work was carried out for other forest-related terms, such as deforestation, afforestation, and reforestation. An attempt to harmonize the different forest-related definitions to facilitate the country's reporting under different international conventions and processes (such as the United Nations Convention on Biological Diversity, the United Nations Framework Convention on Climate Change, the Forest Resources Assessments, for instance) has been carried out by the Food and Agriculture Organization of the United Nations (FAO). Complications arise in using a country's data in global forest assessments, since each country usually develops and applies its own definition of forest, based on the particular characteristics of its vegetation cover and the application to be given to the data and to the information collected. By 'own' definition it is meant the country's choice of the biophysical parameters of the vegetation cover (minimum height, minimum area cover, crown cover density) or minimum corresponding carbon stock that will be associated with a forest typology.

Most forest definitions include some threshold parameters (usually presented as ranges) associated with biophysical characteristics of the forests (such as minimum height, minimum crown cover) and/or relate to the land use status of the land. Land use refers to the way the land is being used or the intents of use (it is, in general, a political/management decision). Since deforestation, afforestation, and reforestation activities are associated with changes in forest (in particular, changes in forest area), and considering that most of these terms are defined as conversions from one state to another (either forest to nonforest, or vice versa), the implications of the forest definition are multifold.

Part of the definition of forest provided by FAO (and in the Kyoto Protocol to the United Nations Framework Convention on Climate Change) indicates that areas that are normally part of the forest area but which are temporarily unstocked (due to human intervention or natural causes) and which are expected to revert back to forest, are included under forest. The temporarily unstocked condition, if not associated with a land use change but only due to a temporary land cover change, does not characterize a convertion from a forest state into a nonforest state, and hence, deforestation. The status of the land is maintained as forest.

Forest Inventories

Forest inventories may be carried out at country, regional, or global level. The methodologies used to develop the inventories vary widely. Even at the country level, a full coverage of all the forest area is seldom carried out. Some parameters to be estimated entail destructive sampling to generate mean values that are used as representative values for certain forest components. In general, two approaches are used (either jointly or separately) in forest inventories: (1) remotely sensed data (aerial photographs, satellite imagery), and (2) statistical sampling techniques. Although some information can be provided via remote sensing, the main share of data is usually obtained through field measurements, hence the need to rely on sampling techniques.

Aerial photographs and satellite imagery may be useful to stratify the forest area into vegetation types, or even tree species, depending on the scale of the aerial photographs or the spatial resolution of the sensor on board the satellite. Through stratification, a number of strata containing relatively homogenous elements is defined. Then sampling can be applied in each stratum, ensuring that all the classes of interest (vegetation types or tree species, for instance) are included. Multistage stratification can also be applied. First, the broad classes of forest types are stratified, and then each stratum is further stratified according to tree species, height, age, wood volume, or productivity, for instance.

One common practice for stratifying the forest area according to different forest types (broad categories) is to integrate fine spatial resolution satellite data (around 30 meters) with available national vegetation maps in a geographical information system (GIS). Satellite data can be used to update the vegetation maps and, on the other hand, the existing vegetation maps may be useful in providing the spectral characteristics of broad vegetation types, improving the thematic classification (digital or based on visual analysis).

Despite the relevance of remotely sensed data to the forest inventory process, they are not adequate to provide data or information on the full range of forest parameters that may be included in a comprehensive inventory. Even very high resolution satellite data, such as the 1-m spatial resolution data from Ikonos or Quick Bird are not suitable for providing accurate data on the diameter (or the circumference at breast height) of trees which is used in several allometric equations to estimate forest biomass.

Forest Change

Changes in forest are normally associated with the variations in the biophysical characteristics of the trees (due to natural growth or decay) and/or to total or partial structural changes due to natural causes (such as pest attack, wildfires) or anthropogenic activities (such as selective logging, pruning). In general, these changes are not related to changes in the forest area, depending on the definition of forest used. Structural changes due to wildfires, for instance, may cause part or all of the forest area to be temporarily unstocked, but if land use does not change, the unstocked area is still regarded as forest, according to the FAO definition of forest. For several purposes, the estimation of the change in forest area is critical. These changes can be either positive (through reforestation, afforestation, or natural expansion) or negative (through deforestation). All these changes (biophysical, structural, and area change) are directly connected to other forest-related changes, such as change in biomass and in carbon stocks. Changes in the soil carbon may also result from the conversion of forest into pasture or agriculture. Changes in forest may also be associated with changes in the products and services (social and economic, aesthetic, cultural, or historical values) provided by the forests.

Some forests can also undergo periodic changes that are not directly human-induced, but result from a natural phenomena related to the climate region where the forest is located. This is the case of the so-called deciduous or semideciduous tropical (or subtropical) forests, where 20–50% of the tree species composition is characterized by a complete or partial loss of foliage. This loss occurs during the biological driest period, and does not promote a structural change in the forest. The ecological concept related to this type of vegetation involves two climatic aspects: (1) tropical, characterized by high levels of pluviometry in the summer, followed by a persistent drought period (4–6 months); and (2) subtropical, which does not have a dry period, but goes through a physiological drought resulting from an intense cold (mean temperature of 15°C for 3 months) during the winter.

Many efforts exist to identify the determinants of forest change, which are fundamental for the development of models to predict the rate and trend of change. However, the ability of these models to reliably predict the new fronts of deforestation and the rates of change is most commonly not very good. The traditional determinants are usually related to demographic factors (such as density, population movement), economic factors, governmental incentives, agriculture expansion, agrarian reform, infrastructure (road building), and technology (improved seeds). However, they seem insufficient to provide good predictions of where and how the changes in forest will occur (see **Figure 1**). The definition of deforestation adopted to generate the rates in **Figure 1** refers to the conversion of areas of primary forest physiognomy by anthropogenic activities, for the development of agriculture and cattle raising, detected from orbital platforms. Gross deforestation indicates that the areas in process of secondary

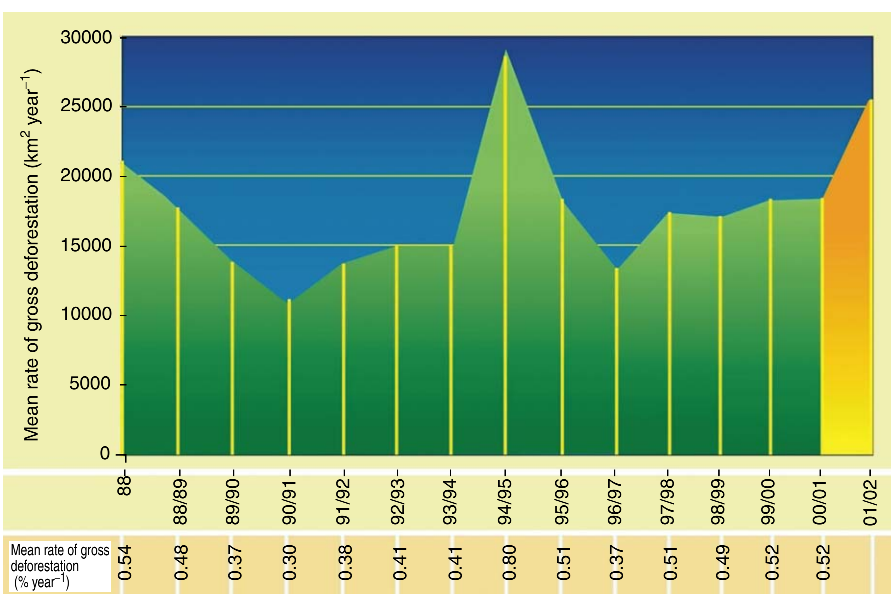


Figure 1 Evolution of the mean rate of gross deforestation in Brazilian Amazonia (km^2 year^{-1}). This illustrates the variation in the annual rate of gross deforestation from the period 1988–2001, and provides an estimate, based on a sample of 50 images, of the rate of gross deforestation from 2001 to 2002. Mean rate of gross forestation (percent per year) is given relative to the area of remaining forest. Data from 1993 and 1994 refer to an estimate of the mean rate of gross deforestation for the period 1992–1994. The mean rate gross deforestation for 2002 was based on the analysis of 50 TM Landsat images from that year.

succession or forest recovery are not subtracted in the calculation of the extent and the rate.

Forest changes can be estimated at various levels (global, regional, country, tree stand). In general, global estimates of change are provided for forest cover, forest volume, and biomass, using a range of methods from information provided by each individual country, through their national forest inventories (usually carried out at every 10 years) and/or the use of remote sensing. The advent of satellite imagery in the mid-1970s motivated the use of data from sensors on board earth observation and meteorological satellites for global assessments purposes. From the practical point of view, data from coarse spatial resolution satellite systems, such as those from the 1.1-km spatial resolution Advanced Very High Resolution Radiometer (AVHRR) sensor on board the National Oceanic and Atmospheric Administration (NOAA) series of satellites (1.1-km spatial resolution) seemed appropriate to map the extensive areas and to detect changes in forest cover. However, with this coarse spatial resolution, it was only expected that major changes in the vegetation cover would be detected. The advantage of the NOAA satellites, however, relates to their daily coverage of large areas at very low acquisition and processing costs.

At the country level (or smaller administrative units), forest assessments or estimates of forest change are usually developed from field observations, existing surveys and maps, in addition to high spatial resolution satellite data (around 30 m). This spatial resolution has demonstrated to be very appropriate for mapping land cover and to detect land-cover or land-use changes. However, the temporal resolution of these orbital systems (Landsat, SPOT, CBERS) ranges at present from 16 to 28 days, and most are based on optical sensors, which present mapping limitations over cloud-covered areas. For regional assessments, an intermediary spatial resolution of approximately 250 m is normally adequate. One difficulty associated with estimating forest cover or forest cover changes relates to the accuracy of the estimates. Field data collection and classification of remotely sensed data (digital or by visual analysis) are subject to errors of different nature. The accuracy of the satellite-derived forest estimates depends on the spatial resolution of the system and the classification process. The accuracy can be estimated from existing or sampled ground data, aerial photographs, and/or data from very high resolution satellite systems.

Forest-related estimates can also be developed from data collected in a sample selected according to a specific sampling design, the most common one being the stratified sampling design. The stratified sampling design aims at subdividing the population into a number of strata so that the variance within each one of them is smaller than the overall variance of the population. If ancillary data are available to support the stratification of the population, then it is expected that stratified sampling will increase the sampling efficiency. However, regardless of the method used, there are uncertainties associated with the estimates. How close is an estimate based on sampling from the true population parameter being estimated? This uncertainty is usually expressed by coupling the point estimate with the maximum error of the estimative, to a given probability. The question then becomes: what is the probability that the sample estimate deviates from the true value by a given amount? Ideally, this amount would be small. However, it is closely linked to the number of samples to be observed which, in turn, is a function of the variance of the population or area unit to be sampled.

In addition to identifying the occurrence of changes in the forests, whenever there is land use change, it may be important also to identify the new land associated to the previously forest area (e.g., annual and perennial agriculture, pasture, settlements). The most common approach is to make use of transition matrices, which indicate, for a sequence of time periods, through sampling or complete analysis of fine spatial resolution satellite data, how much of the original forest was converted to other land uses, and vice versa. Markov chain models may also be used to provide the likelihood of transition from one land cover or land use to another. Transition sequences can be obtained from the observation of fine spatial resolution satellite imagery at different points in time. The use of coarse spatial resolution data is only justified if only the transitions between very broad classes are of interest.

Global Forest Area and Area Change Estimates

The best-known effort to inventory the state of the forests around the world and their change (including area and stock) is carried out by the FAO through its Forest Resources Assessments (the latest one being Forest Resources Assessment 2000) (*see* **Resource Assessment**: Regional and Global Forest Resource Assessments). In addition to estimating the area and stock of the world forests, estimates of the rate of change, what triggers the changes, and what are their economic, environmental, and social impacts are also addressed.

Data on forest area and forest area change are provided by FAO by country, and at regional and global levels. This task is carried out using, wherever available, data provided by the countries (in general surveys of national forest inventories and mapping reports) and remotely sensed data. Since many countries lack data on forest area and/or a consistent time series to allow forest change to be estimated, it is important to evaluate the uncertainties associated with any global mapping or estimates. This, in general, is not an easy task, particularly when different methods are used to generate the maps or the estimates.

The estimates provided in the FRA Forest Resources Assessment 2000 report for the area covered by forests in the world was around 3.9 billion ha, which corresponds to approximately 30% of the world's land area. About 95% of the forest cover was in natural forest and 5% in forest plantations. Natural forests, in this context, refers to forest stands predominantly composed of self-sown native trees (trees which have germinated and grown from spontaneous seedfall, either wholly naturally or influenced by various silvicultural activities).

The net change of the forest area (the difference between the area deforested and the expansion of natural forest and forest plantation) was approximately 9.4 million ha year^{-1}, from 1990 to 2000. Presently, the largest changes in forest area occur in the tropics and are mostly due to deforestation activities (approximately 14.2 million ha year^{-1} in the period 1990–2000, against 0.4 million ha outside the tropics). Increases in forest area are estimated to be on the order of 3.3 million ha in the nontropics and 1.9 million ha in the tropics, totaling an annual increase of 5.2 million ha (1.6 million ha from afforestation and 3.6 million ha from natural expansion of forests (natural succession on to previously nonforested lands). All these figures represent annual estimates for the period 1990–2000. The remote sensing survey in Forest Resources Assessment 2000 revealed that the deforestation process in the tropics is dominated by direct conversion of forests to agriculture.

Of the total forest area, 47% is concentrated in the tropics, 33% in the boreal zone, 11% in the temperate areas, and 9% in the subtropics. The distribution of the forest area by region is presented in **Table 1**.

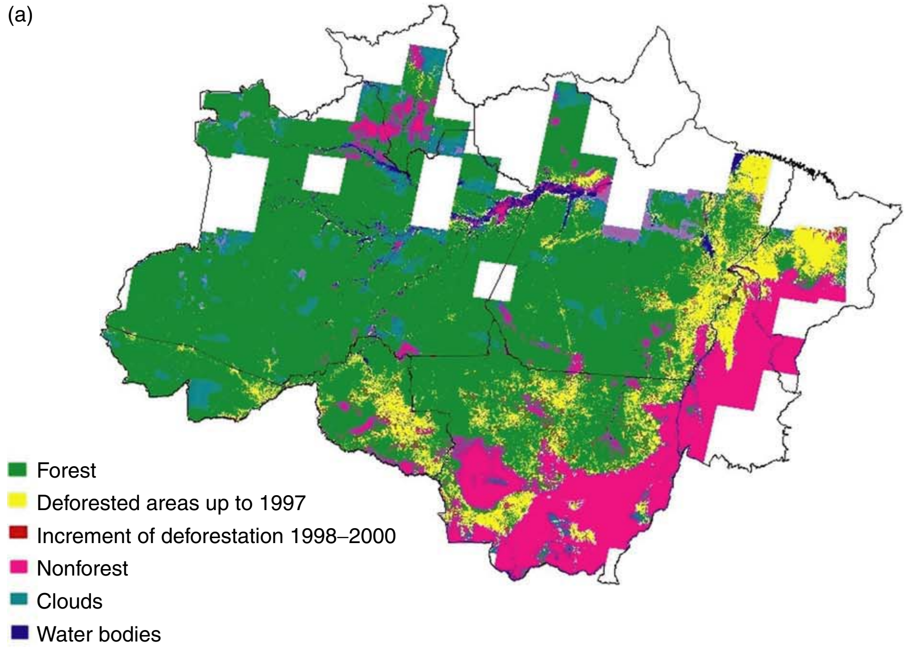
Another initiative at global level, focusing on the tropical forests of the world, was carried out by the Joint Research Centre and was known as the TREES (Tropical Ecosystem Environment Observations by Satellites) project. As the name indicates, the main sources of relevant data to detect changes in forest cover were fine or coarse spatial resolution satellite data. Methods such as image differencing, spectral bands ratios, and regression models are normally used to detect changes from images collected at two different points in time. If images acquired at several different time periods are available, it is possible to identify deforestation 'hot spots' areas which, with the help of local forest experts to adjust for possible inconsistencies, can be of significant value. The TREES project provided maps of 'hot spot' areas for southeast Asia, west and central Africa, and south and central America. 'Hot spot' areas, in the context of the TREES project, was defined as 'an area where major changes of the forest cover are going on at present (past 5 years) or are expected to take place in the near future (next 5 years).'

The knowledge of the deforestation 'hot spot' areas guides the selection of statistical samples to estimate the annual rate of deforestation, for instance. In the Brazilian Amazonia basin, this annual rate is estimated through the analysis of data from approximately 50 TM Landsat images selected in the so-called 'arc of deforestation' (**Figure 2a**) which accounts for nearly 75% of the total rate of gross deforestation in the region (covered by 229 TM Landsat images). The difference between the estimated and observed (analysis of all the images) rates has demonstrated that the estimates were off by at most 5%.

Table 1 Forest area by region (FAO Global Forest Resource Assessment, 2000)

Region	*Land area ($ha \times 10^6$)*	*Total forest (natural forests and forest plantations)*				*Natural forests ($ha \times 10^6$)*	*Forest plantations ($ha \times 10^6$)*
		Area ($ha \times 10^6$)	*% of land area*	*% of all forests*	*Net change*		
Africa	2978	650	22	17	−5.3	642	8
Asia	3085	548	18	14	−0.4	432	116
Europe	2260	1039	46	27	0.9	1007	32
North and Central America	2137	549	26	14	−0.6	532	18
Oceania	849	198	23	5	−0.4	194	3
South America	1755	886	51	23	−3.7	875	10
World total	13064	3869	30	100	−9.4	3682	187

(a)



(b)

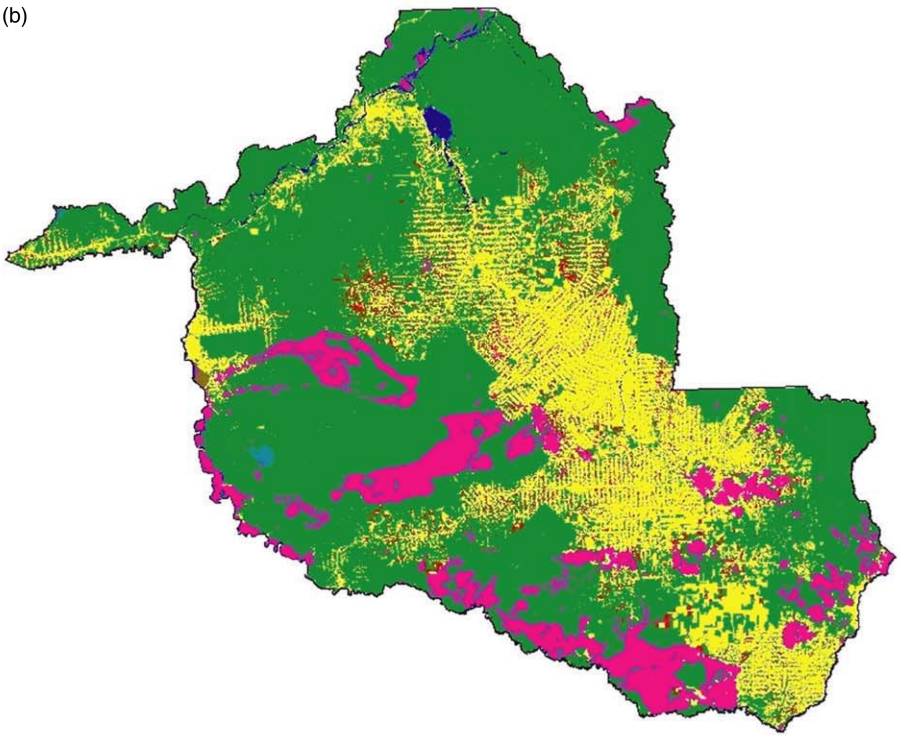


Figure 2 Mosaic derived from digital classification of TM Landsat imagery containing the deforested areas up to year 1997 and increments of deforestation from 1998 to 2000, (a) in the Brazilian Amazonia; (b) Zoom in Rondonia State.

Estimating the Rate of Deforestation

One key issue in the forestry sector concerns the estimation of rates of change. In particular, the rate of deforestation is of special interest, for many reasons. The contribution of land use, land-use change, and the forestry sector to climate change (through the increase of the concentration of some greenhouse gases in the atmosphere) is of particular interest, since the largest contribution from the nonindustrialized countries is associated with deforestation activities.

Reliable estimates of the rate of deforestation in the tropics can be generated from the analysis of high spatial resolution satellite data (approximately 30 m), which provide spatially explicit observations of changes in the forest cover. The Brazilian Ministry of Science and Technology, through its National Institute for Space Research (INPE) conducts annual estimates of the gross deforestation rates of Brazilian Amazonia, whose original forest cover was 4 million km^2 (400 million ha), corresponding to approximately 60% of the tropical rainforest in South America (cerrado vegetation not included). The estimates are based on the visual analysis of all 229 TM Landsat imagery (30 m spatial resolution) that cover the region (the so-called 'wall-to-wall' coverage).

Since the estimates are generated on an annual basis and is based on the visual interpretation of satellite imagery, the spatial distribution of the gross deforestation can be displayed and, through use of GIS, integrated with other database such as vegetation maps. This particular integration allows the identification of the forest types affected by deforestation activities. This information is relevant in estimating the carbon stock change associated to the deforestation activity. The visualization of the annual spatial distribution of deforestation helps to identify the deforestation 'hot spot' areas. In the case of the Brazilian Amazonia, approximately 75% of the annual gross deforestation concentrates on 50 out of the 229 images that cover the region. Estimates of the rate of deforestation can be made from the analysis of these 50 images, since the deforestation activities do not shift significantly from one place to another each year. Thus, changes in forest area can be estimated with 'reasonable' accuracy from a sample of images selected from the set of images that concentrate the images covering 'hot spot' areas.

Figure 2 presents the spatial distribution of the deforestation detected up to 1997 in the Brazilian Amazonia, the aggregated deforestation from the period 1997–2000, and the increments of deforestation 2000–2001. The use of GIS to integrate georeferenced databases allows the identification of the vegetation physiognomies affected by the deforestation activities each year. **Figure 3** presents the distribution of the main vegetation types in

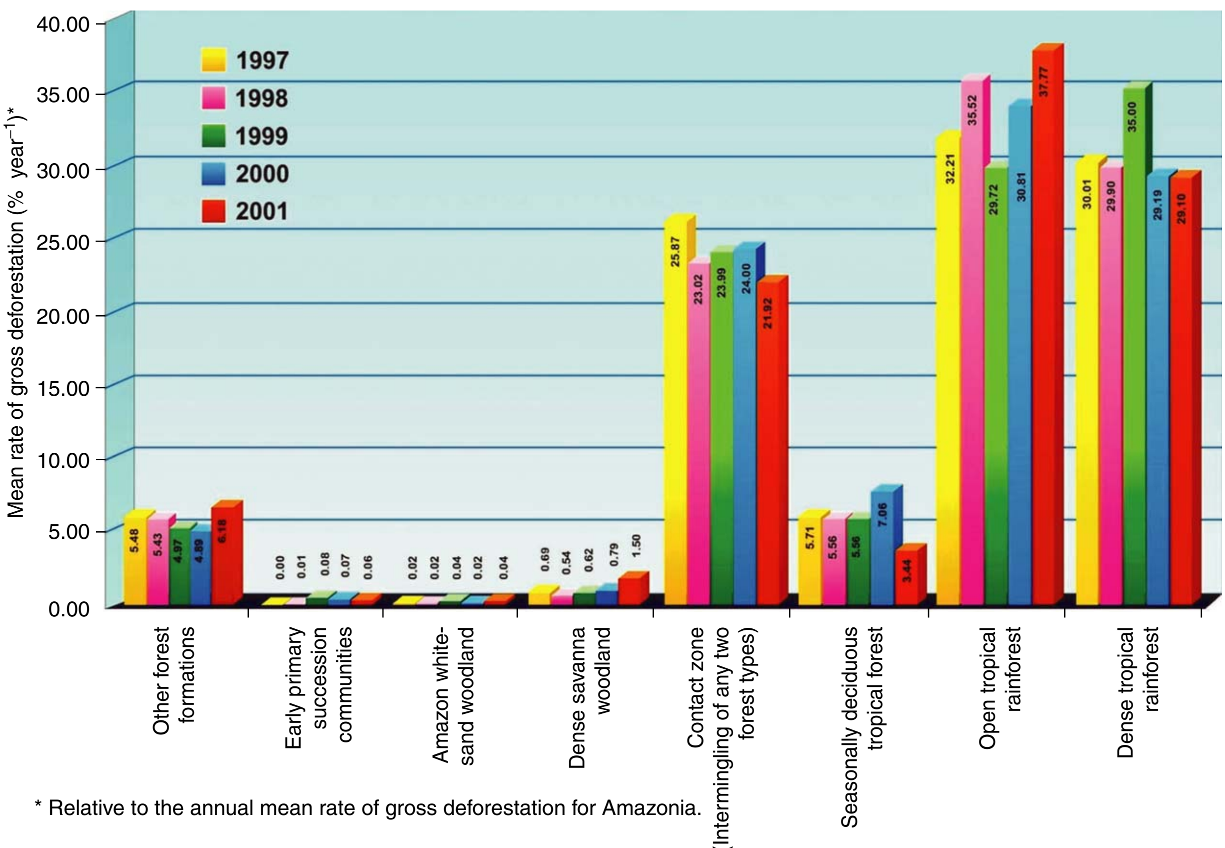


Figure 3 Distribution of the mean rate of gross deforestation (percent per year) (relative to the annual mean rate of gross deforestation for Amazonia) by forest physiognomy from 1997 until 2001.

Amazonia and the percent amount of deforestation affecting each of the vegetation physiognomies.

Biomass and Related Changes

Biomass, from the forest point of view, is defined as the total amount of aboveground living organic matter in trees expressed as oven-dry tonnes per unit area (tree, hectare, region, or country). The term biomass density is used when the biomass is presented as mass per unit area. The product between the estimated forest biomass density and the corresponding forest area gives the total biomass. The total biomass for a country or region, when different forest types exist, is estimated from the sum of the individual total biomass for each type.

Many methods exist to estimate biomass density, and these can be found in the related literature. These methods are provided for individual trees, plantations, and forest stands. The already existing data (from national forest inventories, for instance) may prove to be not always useful, since they may have been developed for other purposes and may lack the necessary information to generate reliable estimates. The estimates of the changes in the forest area, if provided by broad vegetation types, can be coupled with estimates of biomass density of these types to generate estimates of the changes in the total biomass. This approach may be satisfactory for generating changes in total biomass at regional or global levels. However, the statistical reliability of the estimates, at country level, is in general low.

The use of radar remotely sensed data to estimate biomass and to detect changes in aboveground stocks is an ongoing line of research. The main problem with the existing radar systems (the Canadian RADARSAT or the European Union ERS-2, for example) is that their signal saturates at low biomass levels. Hence, above this saturation level, the differences in biomass are no longer captured. There are many orbital radar systems available, but none has yet succeeded in providing reliable estimates of biomass, unless for low biomass content forests (regrowing forest areas, for example). Simulated P-band SAR (synthetic aperture radar) data from aircraft-based radar sensors indicated the potential use of these data to detect biomass in forests up to 200 tonnes ha^{-1} (dry aboveground biomass), which represent substantial improvements when compared to the available C or L band radar systems. However, there are no space-borne systems presently operating in this frequency. P-band sensors operate in the range 30–100 cm of the electromagnetic spectrum, whereas C and L bands operate in the ranges of 3.75–7.5 cm and 15–30 cm, respectively.

The contribution of the different components of the biomass (stem, branches, leaves, understory vegetation) to the total biomass depends on the type of the forest (natural or planted, closed or open). Studies in the Brazilian Amazonia indicate that approximately 65% of the total aboveground live biomass corresponds to trunks, and 35% to the canopy, where leaves account for approximately 12%.

The average annual change in biomass stocks for a given forest type can be estimated from the ratio between the difference of total biomass estimated at two different points in time (t_1 and t_2) and the number of years that separate the estimates ($t_2 - t_1$). Another method is based on the annual growth rate of the forest, the annual change of forest area, and the annual loss of biomass (due to commercial harvest, natural mortality, pruning, pest attack, etc. For the estimation of the annual growth rate, which is defined as the annual increase on aboveground and belowground living biomass, equations are available and usually rely on the use of biomass expansion factors. The annual total biomass loss is in general computed as the sum of biomass losses due to harvesting, fuelwood gathering, and natural or anthropogenic disturbances.

Another approach to estimate biomass change is based on field observations: permanent sample plots are established in areas representative of the vegetation types of interest, and are monitored. In this respect, high resolution satellite imagery can be useful. Measurements collected on at least two points in time are necessary to estimate change. From the biomass changes observed in the permanent sample plots for each vegetation type and the changes in their corresponding area, and estimate of the total biomass change can be derived. Since the variance of the biomass change in the permanent plots, as well as the variance in area change, the uncertainty related to the change in total biomass can be provided (area change and biomass change can be considered independent variables; in this case, the variance of the total biomass change is simply the sum of the two variances).

Modeling is another approach that can be used to estimate total biomass change. However, these models rely on the understanding of the relationship between biomass density and factors that influence its change, in particular those associated directly or indirectly with humans, such as population density and movement, socioeconomic aspects, forest fragmentation, establishment of infrastructure such as roads and railways, etc. This approach, at present, is still in its early stages. The potential use of these models will depend on the ability to understand better how humans intervene in the process and how to account for these interventions.

Changes in Forest Carbon Stocks

Trees are composed of carbon that results from the photosynthesis process. Their growth results from the removal of carbon dioxide from the atmosphere (through respiration), justifying the label of forests as carbon sinks. Carbon from trees can also be emitted to the atmosphere through, for instance, the decomposition of wood, stumps, and leaves from deforestation. In this case, the trees are referred to as carbon sources. Trees stock carbon not only above ground (stem, branches, foliage, and understory vegetation) but also below ground (all living biomass of live roots). Carbon pools also include dead organic wood (nonliving woody biomass), litter, and soil organic matter (including organic carbon in mineral and organic soils). Anthropogenic changes in carbon stock normally result from changes in land use, such as conversion of natural ecosystems (such as forests) to cropland, grazing land, or pasture or abandonment of croplands; and activities such as harvesting of timber and establishment of tree plantations. Estimating forest carbon stocks and their changes is not a trivial task and the associated uncertainties are very high. Some changes cannot be reliably estimated in small intervals of time, as is the case with soil carbon. The estimation of carbon stock changes from the land use, land use change, and forestry sector is one of the components in the national greenhouse gas inventory that countries have to calculate annually. A very comprehensive report on methodologies for estimating changes in carbon stocks in all these pools has recently been published by the Institute for Global Environmental Strategies (IGES) for the Intergovernmental Panel on Climate Change (IPCC) and should be available in 2004.

See also: **Inventory**: Large-scale Forest Inventory and Scenario Modeling. **Resource Assessment**: Forest Resources; GIS and Remote Sensing; Regional and Global Forest Resource Assessments.

Further Reading

Brown S (1997) *Estimating Biomass and Biomass Change of Tropical Forests: A Primer.* FAO Forestry Paper no. 134. Rome: Food and Agriculture Organization.

FAO (2002) *Proceedings of the Second Expert Meeting on Harmonizing Forest-Related Definitions for Use by Various Stakeholders*. Rome: Food and Agriculture Organization.

Fearnside PM (1997) Wood density for estimating forest biomass in Brazilian Amazonia. *Forest Ecology and Management* 90: 59–87.

INPE (National Institute for Space Research) (2003) Monitoring of the Brazilian Amazonian Forest by Satellite: 2001–2002. Available online at www.grid.inpe.br

IPCC (Intergovernmental Panel on Climate Change) (2004) *Good Practice Guidance for Land Use, Land-Use Change and Forestry.* New York: Cambridge University Press.

Joint Research Centre (JRC) of the European Commission (2003) *Land Use Change Monitoring in the Framework of the UNFCCC and its Kyoto Protocol: Report on Current Capabilities of Satellite Remote Sensing Technology.* Ispra, Italy: JRC EU.

Kleinn C (2002) New technologies and methodologies for national forest inventories. *Unasylva 210* 53: 10–15.

Lund HG (coord.) (2003) *Definitions of Forest, Deforestation, Afforestation, and Reforestation*. Available online at http://home.att.net/~gklund/DEFpaper.htm.

Schoene D (2002) Assessing and reporting forest carbon stock changes: a concerted effort? *Unasylva 210* 53: 76–81.

TREES (Tropical Ecosystem Environment Observations by Satellite) (1998) *Identification of Deforestation Hot Spot Areas in the Humid Tropics*. TREES publication series B, Research Report no. 4, 104 pp. Global Vegetation Monitoring Unit, Ispra, Italy: Space Applications Institute.

GIS and Remote Sensing

M A Wulder, Canadian Forest Service, Victoria, BC, Canada

Introduction

Forest inventory data are the primary information source for forest management. Forest inventories are undertaken to provide a survey of the location, composition, and distribution of the forest resource and their relative amounts over a given area. Forest inventories are required to derive the information for resource evaluation enabling management decisions at a variety of levels, such as harvest plans through to the development of provincial or state level strategies. The production of a forest inventory data set follows a series of stages, the ultimate being the development of a digital spatial database. Forest inventory, stored and manipulated in a geographic information system (GIS), is a key information source for operational-level planning and strategic-level planning and management. Operational-level forest inventories are often calibrated with field-sampled measurements and are used to develop location-specific information required for harvest