The FAO Forest Assessment produced in the early 1980s (FAO/UNEP 1981, Lanly 1982) provides a first-order estimate of deforestation rates world-wide. These data produced on a country basis can be used as a baseline land-use rate. A 1990 assessment has been recently published (FAO 1993a), which provides estimates of deforestation rates by country for the period 1981-1990. Thus, some estimates of current and historical rates of deforestation on a country basis can be obtained from these published reports. More detailed information, at the sub-national level, can be obtained by contacting the FAO directly. Deforestation by climatic zone for each tropical country is included in the *Workbook*.

It should be noted, however, that there have been controversies and disagreements regarding FAO estimates of national deforestation rates at times. In some cases where national experts have developed substantially more detailed approaches for their own countries, results have been found to be different from the published FAO estimates. Any internationally provided data should be reviewed carefully by national experts if they are used as a basis for emissions inventory estimates.

Some countries have well-developed estimates of deforestation, based on very good measurements, which provide more detail than is available from the FAO assessments (e.g., Arbhabhirama et al., 1987; INPE, 1992). Where detailed national studies exist for the early 1990s they should be the preferred data source for experts preparing national inventories. FAO data may nonetheless be useful for comparative purposes. The choice of input data is always ultimately a decision of the national experts.

Lack of consistent time-series data at *national level* is considered by FAO staff to be the most critical problem in estimating the deforestation rate. Variation in definitions and measurement techniques from country to country is another problem in making regional and global estimates. FAO has initiated a comprehensive programme for capacity-building in forest resources assessment by mobilising technical and economic co-operation among member countries and among concerned regional and global agencies as follow-up to recommendations of UNCED Agenda 21: Programme Area D.

T5.2 Ongoing Data Efforts

The lack of a comprehensive data set on deforestation rates is a critical problem. The development of such data sets remains one of the priorities for the IPCC process in the coming years (IPCC, 1992). Methods using high resolution remote sensing in conjunction with geographic information systems appear most promising. The International Geosphere-Biosphere Programme's Data Information System (IGBP-DIS) is serving as a central focal point to collect and disseminate information about the various ongoing activities and data sets dealing with land use and changes in land cover. The IGBP-DIS is located in Paris, France (Tel: 33-1-4427-6168, Fax: 33-1-4427-6171).

Experts from around the world have begun to build the scientific, technical, and procedural underpinnings of such a system. The World Forest Watch Meeting held in Sao Jose dos Campos, Brazil (June 1992) provided a high-level international forum for the assessment of current approaches to satellite-based forest monitoring. This meeting also served as a basis for forwarding recommendations from the technical and scientific communities to the policy makers and government leaders at UNCED.

A variety of international participants were represented at the World Forest Watch Conference. The conference concluded that significant technical and methodological advancements have been made in recent years, and they are now sufficient for proceeding with an observation system which could satisfy both scientific and national-level forest management requirements. A priority action now is to establish a fully functional,

permanent monitoring system. The system would support national forest management, global change science, and international policy information needs, such as those of the IPCC.

The current research and development being carried out in laboratories and research centres around the world has shown that it is now feasible to acquire repetitive satellite data sets over very large areas, and that the information derived from such data sets can form the core of a global forest monitoring programme. The International Space Year/World Forest Watch Conference has recently provided illustrations that space observation technology and the community of users are ready for regional and global applications.

Progress made on two forest monitoring projects is worth noting in this respect.

1 The National Institute for Space Research (INPE) of the Secretariat of Science and Technology of the Presidency of the Republic of Brazil has made surveys of the entire Legal Amazon (about 5 million square kilometres) using LANDSAT images. This survey was first conducted in 1978 (with 1977 and 1979 being used to cover areas covered by clouds in the 1978 imagery). The studies were repeated in 1988, 1989, 1990 and 1991. These space-based surveys mapped the extent of gross deforestation (i.e., without accounting for forest regeneration or the establishment of plantations) in the portion of the Legal Amazon covered by forest. The ecosystems ranged from dense tropical forest to thick savannas (cerradao) with a total surface area between 3.9 and 4 million square kilometres. The 1978 survey used 232 Land Sat MSS black and white images based on channels 5 and 7 at a scale of 1:250,000. The more recent studies used 229 LANDSAT TM images annually in a colour composite of channels 3,4 and 5 at a scale of 1:250,000.

2 In 1990 NASA, in conjunction with the United States Environmental Protection Agency and the US Geological Survey, began a prototype procedure for using large amounts of high resolution satellite imagery to map the rate of tropical deforestation. This activity, the LANDSAT Pathfinder Project, builds on experience gained during a proof-of-concept exercise as part of NASA's contribution to the International Space Year/World Forest Watch Project. It focused initially on the Brazilian Amazon, and has now been expanded as part of NASA's Earth Observing System activities to cover other regions of the humid tropical forests.

   This project has succeeded in demonstrating how to develop wall-to-wall maps of forest conversion and regrowth. The project is now in the process of extending its initial proof-of-concept to a large-area experiment across Central Africa, Southeast Asia and the entire Amazon Basin. The project is acquiring several thousand LANDSAT scenes at three points in time - mid 1970s, mid 1980s, and mid 1990s - to compile a comprehensive inventory of deforestation and secondary growth (regrowth of forests on land cleared and subsequently abandoned) to support global carbon cycle models. Methodology and procedures have been identified. Although this exercise is being implemented for most of the tropics, it is not an operational global programme. In principle it will provide an initial large-scale prototype of an operation programme.

   The use of geographic information system technology is crucial to the project, as it provides the overall framework upon which the raw satellite data can be synthesised with other cartographic, numerical and geographical data for scientific research and national forestry management. As its name implies, this project is exploratory, but it could readily be expanded to form the nucleus of a global scale operational programme.

These two projects demonstrate the feasibility of developing a global tropical forest information system to support an operational tropical forest monitoring programme. High resolution satellite data from LANDSAT or Spot satellites are being used to provide digital maps of deforestation.

High resolution data from the LANDSAT series of earth observation satellites can be employed to make regular measurements of deforestation. Large amounts of these data exist in national and foreign archives, dating back approximately 20 years. This satellite data system has been perfected over years of development (5 satellites have been launched) and it is expected to be an operational system into the next century (LANDSAT 7 and 8 are being designed[33]). This system is complemented by the French SPOT satellites. Thus, a continuous and consistent source of data is available upon which a high resolution, fine-scale (1:250,000 scale mapping) information system could be developed.

An operational forest monitoring using high resolution data such as that provided by LANDSAT and SPOT could provide wall-to-wall mapping for the entire humid tropical zone. The approach would be as follows:

- An initial mapping effort would define where and how much deforestation exists in the tropical forests (a baseline assessment). The stratification of forest types and critical regions could be enhanced by the use of coarse resolution information from AVHRR.
- Acquisition of LANDSAT and/or SPOT imagery can be co-ordinated regularly every 3-5 years to obtain cloud-free coverage systematically throughout the tropics. The best way to achieve this is to rely heavily on the foreign ground stations. For example, from the LANDSAT routine and complete coverage for the Amazon Basin and Southeast Asia is possible from several foreign ground receiving stations in these regions. As a rule these stations regularly collect data from every orbital pass within the line-of-sight radius of their antenna. For regions, such as central Africa where no ground station exits, programmed acquisitions from the satellite are possible.
- The imagery is analysed for deforestation using a methodology analogous to that developed by the LANDSAT Pathfinder Project, where a simple delineation of the boundary between intact forest and cleared areas is recorded into a geographic information system. Areas of secondary growth would also be delineated. Subsequent years are compared to the baseline and the increment of new deforestation and secondary growth is recorded. The resulting data set provides a 1:250,000 to 1:500,000 scale map of deforestation at a regular repeat interval, and from this a rate of deforestation is derived.
- These geographically-referenced measurements can directly support the implementation of the IPCC national inventory methodology, which requires a time series of historical forest clearing data, and would require updating at periodic intervals. The proposed accurate and precise deforestation data set would be an important asset to national experts working to implement the IPCC methodology for national emissions and removals from land-use change.
- An accuracy assessment effort will need to be put into place to define and track the measurement variance and error (e.g., ground truthing) This component will need to determine accuracy with respect to: (a) variance due to positional accuracy (i.e., the mapping precision) and (b) the variance associated with image interpretation.

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[33] Landsat 6 crashed, soon after it was launched.

- An effort focused on establishing in-country co-operation will be necessary. Such co-operation fulfils several ancillary but vital objectives: (a) it builds a process of national acceptance of the methods and results through active involvement, (b) it provides a mechanism for technology transfer and training for eventual implementation of national inventories based on remote sensing, (c) it facilitates logistical co-ordination of the field component, (d) it provides direct co-operation at various foreign ground stations, and (e) it enables co-operation with national and regional experts in the interpretation of imagery.

T5.3 Summary

Tropical deforestation and carbon emissions are important components of both science and policy. Yet, in spite of the growing need for precise estimates of deforestation to support both international policy and basic research, an operational programme of measurement, monitoring and mapping has yet to be developed. Comprehensive and systematic information on the extent of forest and forest loss is not available on a global basis. IPCC (1990), for example, considers the rate of tropical deforestation to be one of the key unknowns in global climate change assessment. Any lasting and effective implementation of a global system of national emission inventories to support the IPCC and other international processes will require a new, concerted effort to measure and map tropical deforestation, and develop the data base necessary for other important components of the calculations. These measurements of deforestation from high resolution satellite remote sensing can also support the UN/FAO Forest Assessment by providing quantitative and spatially comprehensive measures of changes in forest cover for the tropics.

This Technical Appendix summarises the most comprehensive current data sources for tropical deforestation information, and discusses ongoing efforts to improve on this data via analysis of remote sensing images. Ideally, each country would like to have data on their land-use changes and associated trace gas emissions and uptake over the past 40 to 50 years so that their estimates of current annual net emissions would include delayed and continuous emissions and uptake due to activities that occurred in prior years. Since this is not the case for many countries, the methodology described has made simplifying assumptions in order to treat the effects of past land-use activities on current emissions. This appendix provides some perspective on the available international sources for dealing with one key data gap – data on rates of forest clearing over time.

In future editions of the *Guidelines*, it may be possible to include more information on data available to assist national experts as a result of some of the ongoing efforts described in this version. It may also be possible and desirable to provide similar discussion of a range of other international data collection efforts which may assist national experts in refining other key data driven uncertainties in the national estimates of emissions and removals from land-use change and forestry.

In the meantime, it is recommended that countries continue efforts to collect historical records of land-use change and develop systems of tracking land use through time so that as the methodology is further refined, the land-use change time series needed to account better for emissions and uptake of CO_2 and other trace gases are available.

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