REMOTE SENSING

AND

FOREST MONITORING

IN FRA 2000 AND BEYOND
Forests are crucial for the well-being of humanity. They provide foundations for life on earth through ecological functions, by regulating the climate and water resources, and by serving as habitats for plants and animals. Forests also furnish a wide range of essential goods such as wood, food, fodder and medicines, in addition to opportunities for recreation, spiritual renewal and other services.

Today, forests are under pressure from expanding human populations, which frequently leads to the conversion or degradation of forests into unsustainable forms of land use. When forests are lost or severely degraded, their capacity to function as regulators of the environment is also lost, increasing flood and erosion hazards, reducing soil fertility, and contributing to the loss of plant and animal life. As a result, the sustainable provision of goods and services from forests is jeopardized.

FAO, at the request of the member nations and the world community, regularly monitors the world’s forests through the Forest Resources Assessment Programme. The next report, the Global Forest Resources Assessment 2000 (FRA 2000), will review the forest situation by the end of the millennium. FRA 2000 will include country-level information based on existing forest inventory data, regional investigations of land-cover change processes, and a number of global studies focusing on the interaction between people and forests. The FRA 2000 report will be made public and distributed on the world wide web in the year 2000.

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Paper drafted by Rudi Drigo and presented at the IUFRO Conference "Remote Sensing and Forest Monitoring" June 1 – 3, 1999, Rogow, Poland
Abstract

To fill an evident information gap on land cover change processes associated to tropical deforestation, and to complement the heterogeneous mass of existing country data, FAO carried out, during FRA 1990, the first pan-tropical survey based on high resolution remote sensing data. The survey was based on 117 sampling units covering ten percent of the survey area, each unit composed by multi-date Landsat MSS and TM data representing the period 1980-1990.

In the framework of the remote sensing component of FRA 2000 the 117 sampling units are now being revisited with most recent satellite acquisitions, and following the same methodological approach. This new survey, called Tropical 2000 Update, has the purpose of estimating deforestation rates and studying the land cover change processes of the current decade as well as carrying out an unprecedented assessment of trends comparing current rates and processes to those of the previous decade.

Beyond FRA 2000 and the forthcoming appointment with the millennium, in response to the call for frequent, consistent and thematically deeper information, FAO is developing an expanded survey concept called World Forest Survey. This proposed survey is intended as an extension and intensification of the remote sensing survey currently carried out. Main new features are the extension of the survey to the entire world, the use of a new survey design benefiting from the information produced by the current pan-tropical survey, and the development of a consistent field component for the collection of forestry, environmental and socio-economic parameters.
Introduction

Background

During the years 1991 – 1995, in the framework of the Forest resources Assessment 1990, FAO carried out a pan-tropical survey for an independent assessment of forest cover, deforestation rates and to study the associated processes of change\(^1\). This survey covered, with 10 percent intensity, all tropical forests in wet, moist and dry conditions. The survey was based on a statistical sample composed by multi-temporal satellite images over 117 sampling units (Figure 1). For each unit the study included the analysis of one entire Landsat image close to year 1990 and one (or more) close to year 1980.

The results of this survey confirmed the pan-tropical estimates of forest cover and deforestation rates produced by the complementary component of FRA 1990 that used all reliable forest information produced by countries.

Scope of monitoring

For what purpose has FAO undertaken the remote sensing survey of tropical regions?

The need for an independent survey was felt for the first time during FRA 1990, as a consequence of the experience gained during the collection, harmonization and standardization of existing country data. The global concern on the faith of world’s forests called for new, deeper knowledge on the processes of depletion, but the global synthesis of the heterogeneous mass of existing information could only lead to much needed albeit crude estimates of national forest area and deforestation rate. Statistics that are unable to inform, alone, on the processes and cause-effect mechanisms associated to forest depletion.

In this context, an independent forest/land cover survey was seen as an essential input of \textit{consistent} information over the entire tropical regions to \textit{complement} the country data already produced. \textit{Consistent} in space, all regions analyzed following a standard method and classification scheme, and \textit{consistent} in time, focused on the reliable assessment of land cover changes. The need was not to produce a new estimation of tropical deforestation but rather to describe the processes, inside and outside the forest, associated to deforestation, forest degradation, fragmentation, etc. Monitoring as a tool to understand on-going land cover change processes rather than a pure estimation of deforestation rates.

The main contribution of the remote sensing survey has been the first consistent description of the processes of change, at pan-tropical, regional and ecological level, in form of transition matrices and flux diagrams. From these matrices and diagrams several forms of depletion could be differentiated (deforestation, degradation, fragmentation, shifting cultivation, etc.), and important elements of cause-effect could be disclosed. A step forward toward the understanding of a complex phenomenon rather than a simple estimation of deforestation rates.

\(^1\) This activity was a multi-donor trust fund and a major global cooperative effort coordinated by the Forest Resources Assessment 1990 Project. Methodology, activities and results of the survey are published in Forestry Paper 130 “Forest Resources Assessment 1990 – Survey of Tropical Forest Cover and Study of Change Processes”, FAO, 1996.
In the framework of FRA 2000 the scope of the remote sensing survey has grown in ambition. In fact, by adding one series of new observations the survey will update the 1980-1990 information produced during FRA 1990 to the period 1990-2000 and, through the comparison of the two periods, produce the first assessment of trends. Trends of deforestation, degradation, fragmentation rates as well as trends in the associated/causal processes.

FRA 2000 and beyond

In consideration of FRA 1990 experience and the resulting recommendations, and in view of time and cost implications related to the immediate FRA 2000 needs, a two-phase approach for the implementation of the remote sensing component of FRA Programme have been adopted. This approach takes into consideration the needs of FRA2000, as well as future global assessments. The phases are the following:

1) Tropical 2000 Update

2) World Forest Survey

Since 1996, FAO has worked toward the development of a global continuous monitoring programme, now called World Forest Survey (WFS). This programme follows the same principles of the FRA 1990 survey but it is intended to extend a statistical sample over the entire world following new stratification criteria to improve its efficiency. At present, due to several technical and financial considerations oriented to satisfy both the immediate FRA 2000 requirements as well as the need to meet the global challenge beyond 2000, a phase-in of the long-term World Forest Survey is being envisioned along with the implementation of the 2000 Update for the year 2000 assessment.
Tropical 2000 Update

The strategy for the 2000 Update is to revisit the tropical FRA 1990 sampling units, and update them with a third date of imagery for the reference year 2000. Such a survey will provide up-to-date information on change processes at pan-tropical, regional and ecological level, as well as new and unprecedented insights on deforestation trends over the periods 1980-1990 and 1990-2000.

The new information on deforestation trends will be used to improve the efficiency of the future pan-tropical sample of the World Forest Survey and will represent a unique reference for spot checks and deforestation modeling of existing information.

The 2000 Update is currently implemented with the financial support of the Government of Finland (Project GCP/INT/723/FIN), and of FAO Regular Programme.

The main activities of this project include the refinement of the methodology and the re-visit of the FRA 1990 pan-tropical sampling units by adding recently acquired high resolution data. Along with these technical issues efforts will be made to promote the harmonization of ongoing regional and global programmes and the institutionalization of resource monitoring as an important ingredient to planning and policy formulation at national and international level.

The output of this project will include reliable updated estimates of forest cover state and change, including current trends, and detailed descriptions of the change processes affecting the tropical forest resources by geographical (global, regional) and ecological reporting units. The new data set will complete the FRA 1990 multi-purpose database with recent spatial and statistical data, which can serve to a) improve the deforestation model (through FORIS\(^2\)) and b) provide baseline data for environment oriented studies.

Methodology

The methodology followed for the 2000 Update is strongly linked to the one followed for FRA 1990. In view of the paramount importance of methodological consistency within time series for a reliable estimation of changes, the analysis of the recent “2000” images must be done coherently to the format of the pre-existing 1980 and 1990 data sets.

This methodological approach presents practical and conceptual aspects.

It is practical to continue with visual interpretation of analogue data since that was the approach followed in the past. At this point, changing from the analogue to the digital approach would mean purchasing and processing of digital data for all historical images and repeating all analyses.

It is conceptually essential to continue with the interdependent interpretation approach developed and followed during FRA 1990 since this is the only one that ensures high consistency in the estimation of changes through the elimination of error propagation.

\(^2\) FORIS (FOrest Resources Information System) is a statistical database which stores national/sub-national forest resources data (forest area, functions, growing stock, volume) developed under FAO's FRA 1990 project.
interdependent interpretation procedure is now applied to the three dates using the intermediate 1990 image \( (T_2) \) as “pivot”. It’s not the simple interpretation of one additional image but rather the addition of new evidence into a three-date reference system. The contribution of the third date \( (T_3) \) in this case is not only used for the estimation of the changes between \( T_2 \) and \( T_3 \) but also to improve the reliability and consistency of the entire \( T_1-T_2-T_3 \) series. In fact, in addition to providing evidence of the changes recently occurred, \( T_3 \) often contributes to a better understanding of the terrain condition, vegetation types and land-uses. This new knowledge is therefore inserted into \( T_2 \) and \( T_3 \) interpretations, which are revised to improve the assessment of state as well as change. The consistency within the entire time series is extremely important if we want to achieve the challenging objective of reliably measuring not only recent change rates but overall trends.

**Expected 2000 Update Results**

As example of an individual sampling unit of the 2000 Update study, Annex 1 shows the images and the results produced for a location in Mato Grosso, Brazil. The statistical results reported include the sequential transition matrices for the periods 1972-1989 and 1989-1997, the periodic and annual deforestation rates and the deforestation trend estimated as the percent variation of annual rates. The information contained in the transition matrices is also represented in form of biomass flux diagrams, which help to visualize and compare the processes of change observed over the two periods. In addition to clearly displaying the quantity of change, the analysis of sequential diagrams indicate if the process have changed over time highlighting, perhaps, changes in the cause-effect mechanisms.

The results aggregated at pan-tropical, regional and ecological level will represent the main contribution of the survey. The reporting units will be the same of Forestry Paper 130, which reports the results of the 1990 survey. The thematic content, however will be new in view of the new period observed and the unprecedented analysis of trends.

As preliminary example of trend analysis, the graph in Figure 2 shows the scattergram of pre-and post-90 annual deforestation rates observed on a subset of the South America sample. The subset here represented is composed by 12 sampling units that were recently re-visited in the framework of a cooperative FAO FRA/JRC TREES activity.

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3 Project GCP/INT/131/EC “Estimation of Recent Deforestation Rate in South America”
Figure 2: Analysis of deforestation trend based on a sub-set of the South America sample. Deforestation rates refer to F3 definition of forest. Input data is shown in Annex 2.

![Deforestation Trends Graph](image)

Figure 3: Biomass flux diagram 1980 – 1990. Based on FRA 1990 standardized transition matrices of the re-visited sampling units.

![Biomass Flux Diagram](image)
Figure 4: Biomass flux diagram 1990 – 1996. Based on aggregation of transition matrices of the re-visited sampling units

The results displayed in Figures 2, 3 and 4 are not statistically representative of South America, since they are based on a small number of units. Nonetheless, the results reveal interesting new information on the distribution of current deforestation and its trend. In the graph in Figure 2 the trend is estimated as the percent ratio of the annual deforestation rate of the second period over that of the first period (input data is tabulated in Annex 2). The distribution of data points shows that there is a wide variation between the deforestation rates observed in the two periods. It is quite evident however, that the negative trend (increment of deforestation) is mainly shown by the units which already had a high deforestation rate. From this limited number of sampling units it appears that the areas with low pre-’90 deforestation rates present an even lower rate after 1990, while the areas with high pre-’90 deforestation present an even higher post-’90 rate. The trend appears clearly negative, with a coefficient of 1.52, which means some 52 percent increase in annual deforestation rate. There is also a very clear geographic distribution of rates and trends. The sampling units located in the Brasilian States of Mato grosso and Rondonia show the highest deforestation rates and a consistent negative trend.

In addition to the quantitative estimation of deforestation trends, (change of deforestation rates) it is interesting to analyze the variations occurring to the change processes before and after 1990, which we may call process trends. This analysis helps to understand how the causes and mechanisms associated to deforestation, degradation, etc. are changing in time.

In order to compare the change processes of the two periods, (which are based on different lengths of time), the analysis is based on the percentages of each period’s change.
A comparison of the two diagrams indicates that the dominance of the transition from closed forest to other land cover, for the 1990-1996 study period, is greater than that of the 1980-1990 period. Expansion of large-scale cattle ranching and, to a lesser degree, permanent agriculture, are becoming the dominant cause of deforestation for these study sites. Subsistence farming associated to re-settlement programmes, indicated by the transition closed forest to short fallow, that represented a significant share of the total change in the pre-'90 period, is now almost absent. This could be the effect of changes in Brazilian policies regarding resettlement programs.
Development options

Monitoring world’s resources has rapidly become a permanent necessity. Information on the dynamics affecting bio-physical resources are demanded at decreasing intervals and increasing thematic depth.

In a time frame beyond the 2000 appointment, there are a number of ideas and suggestions on how to improve and extend the scope of the FRA remote sensing survey. Survey that must be seen and designed as a permanent source of information and not constrained to specific events, such as the onset of the new millennium. Several indications and recommendations for improvement came from the last Kotka meeting, others are a direct consequence of the knowledge base created by the FORIS component and the first FRA survey, others more came with technological advances and with increasing definition of thematic requirements. These improved features embody a survey concept currently under development called World Forest Survey (WFS).

These improved survey features can be classified into two main groups: (a) technical/methodological improvements, and (b) extended scope of the survey as summarized below:

A. Technical/methodological improvements

Improved stratification and sampling intensity

Make use of current knowledge as auxiliary variables for the stratification and more efficient sample allocation. In recent years the tropical regions have been covered by a number of large-scale studies, carried out by FAO and others, that considerably improved our knowledge on forest cover and on the broad spatial distribution of deforestation risk. Since deforestation, or forest change, is certainly the key parameter to be measured, a stratification on deforestation risk, as currently applied by TREES Project, is possible and highly recommended, notwithstanding an adequate coverage of the entire population. This will likely improve the precision of forest change estimates, which normally present a comparatively high sampling error.

Preliminary studies on sampling intensities based on the FRA 1990 results indicate that, along with more efficient stratification criteria, a slightly higher intensity would also be required. The number of sampling units over tropical regions has been thus estimated at some 150, as compared to the 117 currently studied.

Improved digital processing and cartographic output

In the analysis of future sample sites the interdependent interpretation will remain the core element of the monitoring methodology, in order to ensure the temporal consistency, but the use of digital data will be predominant. Unlike the analogue approach followed so far, a digital approach will enable the production of time series spatially and radiometrically co-registered, which will facilitate the interpretation. A digital approach will produce digital cartographic output without additional GIS work. Procedures have been developed for the interpretation on
screen of multi-date digital images that allow for the fast viewing through the time series (CORINE Update⁴), which is essential to the interdependent approach. Other, more sophisticated processing systems allow, through the analysis of radiometric correlation between multi-date data sets, the automated detection of potential land cover changes (change vector analysis⁵).

In all cases, however, is up to the human interpreter to decide if variations within the time series are true land cover changes or simple changes in appearance due to seasonal variations, atmospheric disturbance, etc.

Another important consideration vis-à-vis technological features is that the essential expertise required for the interpretation will remain on the object of the study, i.e. land cover, vegetation, land use, and not on the tool used to estimate it.

B. Extension of scope

From pan-tropical to global

In order to produce a complete and coherent picture of the status and changes of world’s forests the survey should be extended outside the tropics to cover the entire world. This extension of coverage to include temperate and boreal regions was recommended by Kotka III⁶ experts on the basis of the results obtained from the FRA 1990 pan-tropical survey. In fact, the information on forest change from these regions is often contradictory, as in the case of Russia, or so heterogeneous to prevent global syntheses with adequate thematic depth.

The expansion of the survey to the entire world presents some new methodological issues ranging from the land cover classification in temperate and boreal regions, which cannot be equal to that applied for the tropics, to the sampling design and stratification criteria. These issues have been addressed in a number of pilot studies and technical discussions among experts from the US Forest Service, the Joint research Center and FAO. The conclusions from these consultations are summarized in a proposal presented in 1998 to the North America Forest Commission⁷.

A total number of some 300 sampling units, half over tropical and half over temperate and boreal regions, is preliminarily considered adequate for a world-wide survey.

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⁴ "Technical and Methodological Guide for Updating Corine Land Cover Data Base”, V. Perdigão, A. Annoni, SAI, JRC.
⁶ “Expert Consultation on Global Forest Resources Assessment 2000” (Kotka III) held in Kotka, Finland in 1996
**Field sampling**

WFS should address increasingly complex information requirements on the dynamics of interesting world’s forests. This challenging task would require, in addition to land cover change measurements, information on forestry parameters as well as on social, economic and environmental aspects.

Although the remote sensing component will remain the backbone of the survey, the collection of these important parameters will impose a terrain approach inclusive of field sampling for forestry and environmental data, socio-economic investigations, etc. The survey would be designed in a multi-phase structure where global maps such as forest cover and deforestation risk (the latter limited to tropical regions) would represent the first phase, the high resolution sample would represent the second phase and the field sample would represent the third, and subsequent, phases.

The field sampling will be the most demanding part of the survey, presenting complex logistic, administrative and statistical problems and requiring extensive financial resources.

In fact, the terrain phase will require a considerable R&D component where series of pilot studies will be carried out to test alternative statistical and operational approaches in varying ecological and socio-economic conditions.

**Link to national inventories and to international initiatives**

It is evident that such an ambitious programme can only succeed if it benefits from the partnership and terrain knowledge of national institutions. The direct link with national inventory and planning institutions will be of mutual benefit. National institutions will benefit from methodology development and internationally accepted standards, while the WFS will benefit from the location-specific data, terrain knowledge and logistic support particularly during the field phase.

In line with FAO underlying objectives in the forestry sector, which focus on supporting member countries in the sustainable management of forests, the survey must be designed to produce technical solutions that are applicable at national level and that are suitable to address national planning issues.

As per other international and regional initiatives, all possible efforts will be made to harmonize and integrate with on-going large-scale studies to the extent that this will be beneficial to meet survey’s objectives and in member countries’ interest. Such integration will be achieved through the harmonization of technical solutions aimed at valorizing the work already done and avoiding redundancy and repetition.

**Conclusions**

FAO intends to support member countries to improve the management of forests. Remote sensing is one technique that is essential for achieving this. However, it must be acknowledged that remote sensing alone cannot provide all the information needed. Remote sensing is irreplaceable for (a) visualizing geographic patterns, i.e. mapping, and measuring changes over time, and (b) to facilitate efficient and controlled field sampling. At FRA, the need for
extensive field sampling is currently emphasized, to complement and enrich the remote sensing surveys of the world’s forests.
References


Expert Consultation on Global Forest Resources Assessment 2000. (Kotka III) held in Kotka, Finland in 1996


Annex 1: Example of Sampling Unit level data and results

The images, statistical results and flux diagrams shown below exemplify one sampling unit of the 2000 Update study. The Unit represented is located in the State of Mato Grosso, Brazil, path 241, row 69 of the Landsat World Reference System. The images used, reproduced below, were acquired on 22 October 1972 (T1), 7 July 1989 (T2), and 13 July 1997 (T3). The T1 image shows a standard false color composite (forest in red), produced by Eros Data Center, USA, while the other two images present the current standard INPE band combination displaying the forest in green.

The table below shows part of the statistical results produced for the sampling unit 3507, located in the State of Mato Grosso, Brazil. The results here shown refer to the sequential matrices based on the area visible at all three dates, which is, in this case, 2,959,200 hectares. The sequential matrices should be read starting from the left side of the upper matrix, through the total T2 values between the two matrices, and ending at the left side of the lower matrix which shows the totals at T3.
In the lower section of the table the forest-related land cover classes are aggregated in various groupings to form three different definitions of forest, for the three dates.

The definitions of forest vary between F1 which includes only the class Closed Forest, to F3 which includes all land cover classes that present forest characteristics, no matter how degraded or fragmented. F2 is an intermediate definition which best corresponds to the FAO standard definition of forest applied in the approach based on existing country data (FORIS).

The annual change rates are then calculated for each definition of forest and for each period. The trend is then calculated as the percent variation of the annual change rate of the second period over that of the first period. The trends estimated for this sampling unit are very negative, ranging between 300.4 and 381.2 percent depending on the definition adopted. This means that in this area the mean annual rate of deforestation has increased three to four times.
T3 image

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Definitions of Forest:

F1 = Closed Forest

F2 = Closed Forest + Open Forest + 1/3 Fragmented Forest (best match with FORIS definition)

F3 = Closed Forest + Open Forest + Fragmented Forest + Long Fallow
While the transition matrices allow for a quantitative estimation of change rates (deforestation, degradation, etc.) they hardly provide a perceivable description of the associated processes. These can be obtained through the diagrams that relate the class-to-class transitions to estimated biomass values for the land cover classes involved. Although the biomass values, and consequent biomass fluxes, are often only indicative, nevertheless the diagrams clearly express the dynamics involved and allow for an inference of causes and typologies. Accompanied by knowledge of socio-economic setting, these results represent excellent objective tools for the understanding of the man-resource interaction and for the formulation of remedial policies.

The diagrams below show the processes of change during the two periods. The comparable scale allow to perceive the dramatic increment of deforestation rate, specially considering that the second diagram refers to a period (1989-1997) which is half of that covered by the first diagram.
Annex 2: Summary of results from the revisit of 12 South America sampling units

Deforestation trends by definition of forest

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Results of the JRC/FAO cooperative Project GCP/INT/131/EC “Estimation of Recent Deforestation Rate in South America”
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</tbody>
</table>

Deforestation trend = \( \frac{\text{Annual defo. rate (post'90)}}{\text{annual defo. rate (pre'90)}} \times 100 \)
FRA Working Papers

1998

1. FRA 2000 Terms and Definitions (18 pp. - E/F/S/P)

2. FRA 2000 Guidelines for assessments in tropical and sub-tropical countries (43 pp. - E/F/S/P)

1999

3. The status of the forest resources assessment in the South-Asian sub-region and the country capacity building needs. Proceedings of the GCP/RAS/162/JPN regional workshop held in Dehradun 8-12 June 1998. (186 pp. - E)

4. Volume/Biomass Special Study: georeferenced forest volume data for Latin America (93 pp. - E)

5. Volume/Biomass Special Study: georeferenced forest volume data for Asia and Tropical Oceania (102 pp. - E)

6. Country Maps for the Forestry Department website (21 pp. - E)

7. Forest Resources Information System (FORIS) – Concepts and Status Report (20 pp. - E)


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