Forestry Department

Food and Agriculture Organization of the United Nations

FRA 2000

PAN-TROPICAL SURVEY OF FOREST COVER CHANGES 1980-2000

Rome, 2002

The Forest Resources Assessment Programme

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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Abbreviations

CATIE	Tropical Agricultural Research and Higher Education Centre
DCW	Digital Chart of the World
ENGREF	Nationale du génie rural des eaux et des forêts
FAO	Food and Agricultural Organization of the United Nations
FRA	Forest Resources Assessment Programme of FAO
FSI	Forest Survey of India
ha	hectare (s)
HRSD	high-resolution satellite data
IBAMA	Instituto Brasileiro do Meio Ambiente
ICIV	Institut pour la cartographie internationale de la végétation, Toulouse
IRS	Infra-red Scanner
JRC	Joint Research Centre
MSS	Multispectral Scanner
NASA	National Aeronautics and Space Administration
SE	standard error of the mean
SPOT	Satellite Pour l'Observation de la Terre
TIFF	Tagged Image File Format
TM	Thematic Mapper
TREES	Tropical Ecosystem Environment Observation by Satellite
WRS	World Reference System of Landsat

1. Introduction

The FRA 2000 estimates of forest area and change are largely based on national statistics and inventory reports, which contain detailed information on the forests of individual countries. However, differences among data sets from the various countries can be great owing to the methods applied, the terms and definitions employed and the currency of the information in the individual inventories. Despite adjustments made to accommodate these differences, uncertainties can still arise when statistics from different countries are compared, especially those relating to forest change.

To bolster FAO's understanding on land-cover change processes in the tropics, especially deforestation, and to complement the country-specific statistics, FAO carried out an independent survey of land cover changes in the tropics. The survey, which emphasized quantifying forest cover change, was based on 117 sampling units covering 10 percent of the survey area. Each sample unit was composed of three multitemporal Landsat satellite images acquired from about 1980 through 2000.

The results of the survey complement the estimates of forest area based on country data and provide unique information on trends in forest change since the 1980s at ten-year intervals. The survey is the first to generate a consistent overview of forest change processes at the pan-tropical, regional and ecological zone levels between two assessment periods. Principal products of the study include change matrices which quantify changes in forests and other land cover classes. From these, several forms of change were identified – deforestation, degradation, fragmentation and shifting cultivation, among others. Analysis in the shifts between classes attributed to these change processes has helped to identify cause-and-effect relationships useful in understanding the complex processes of deforestation. In contrast, the country-based studies were only able to generate single estimates of forest change, without showing how or why the forest area had changed.

The most recent acquisitions of satellite imagery were used in conjunction with the same sample units established for the FRA 1990 pan-tropical survey. Archives from the 1990s containing two multi-date images for the sample units were available for most areas and were complemented by the later image acquisition. The same methodologies and definitions were applied for FRA 2000. The three dates of imagery for each sample unit made it possible to conduct the study over 20 years and to produce statistics at ten-year intervals.

The objectives of the FRA 2000 remote sensing survey were to:

- monitor tropical forest cover state and change for the past 20 years at regional and pan-tropical levels;
- analyse trends in forest cover change between 1980-1990 and 1990-2000;
- study the dynamics of change in forest cover and identify causal mechanisms of deforestation;
- complement existing country information by providing spatially and temporally consistent data on forest state and change.

2. Material and methods

The FRA remote sensing survey consisted in a multi-temporal analysis of sampling units distributed in the pan-tropical area. In the FRA 1990 survey 117 sampling units had been selected and studied with two sequential dates of high-resolution satellite imagery, as close as possible to 1980 and 1990. The same sampling units were revisited for the FRA 2000 survey: a third date, close to 2000, was added to the time-series already studied in FRA 1990, updating the information to the year 2000.

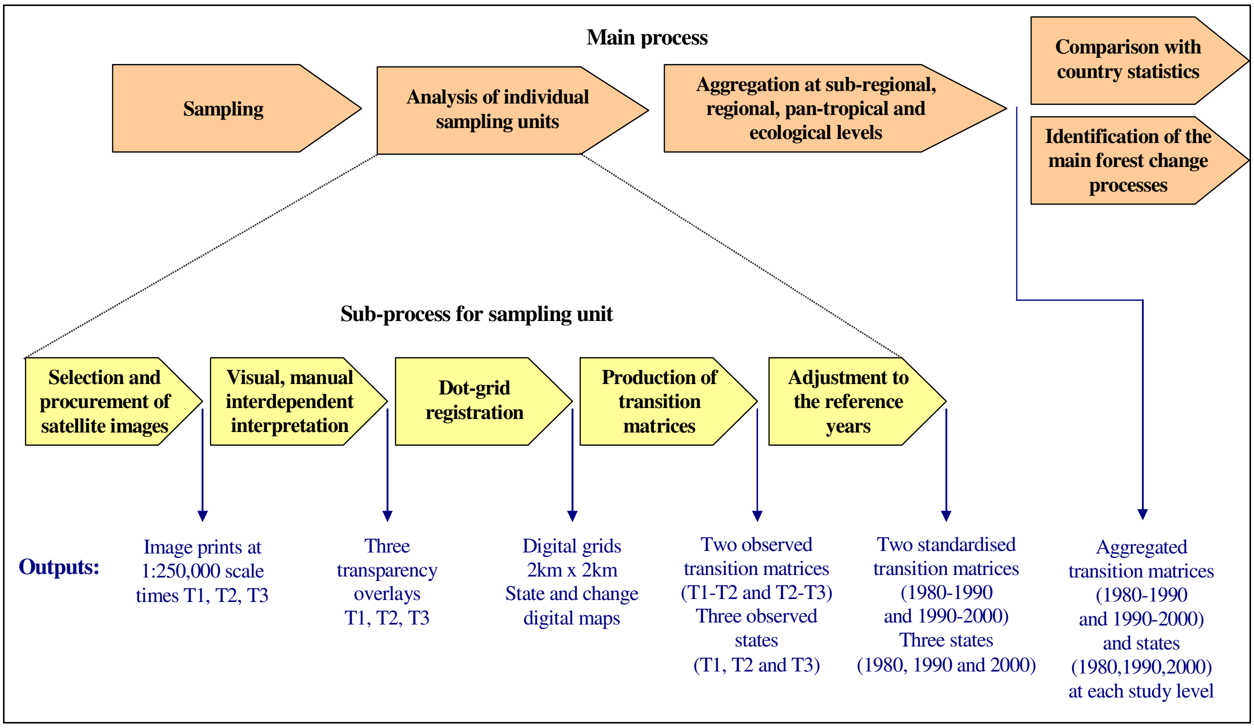
To a large extent the monitoring methodology applied in FRA 2000 survey was the same as for the FRA 1990 survey (FAO, 1991. The sample survey design. FAO FRA 1990 Project document.

FAO, 1996). It was developed to ensure a high level of consistency across the entire data set and among the sampling units by the use of uniform data sources, classification and interpretation techniques. The main features of the survey's methodology were:

- the statistical sampling design;
- a standard classification oriented towards forest assessment;
- an interdependent interpretation procedure;
- the standardization of results to reference years;
- the calculation of aggregated estimates.

Figure 1 illustrates the different steps of the survey processes, further explained below.

Figure 1. FRA 2000 Pan-tropical Remote Sensing Survey processes



The use of a third date of imagery in the time series introduced new elements in the survey. In particular, it brought in some complexity in the calculation of the estimates for the reporting periods (1980-1990 and 1990-2000) and reference years (1980, 1990 and 2000). Then, it made it possible to analyze and calculate changes in land cover over two sequential time periods, and to assess differences in the land cover changes between the two periods. The trend analysis represented a major new component in the survey.

2.1. Sampling design

FRA 2000 employed the same sampling design and revisited the same sampling units as in the FRA 1990 survey (FAO, 1991. The sample survey design. FAO FRA 1990 Project document.

FAO 1996; Czaplewski R.L. 1991. Analyses of alternative sample survey designs. FAO FRA 1990 Project document.

Czaplewski 1994). The main characteristics of the survey design are the following:

- The survey covers all tropical forest types, in wet, moist and dry conditions. Unforested tropical areas (e. g. deserts) were not included. The pan-tropical area is defined as a set of countries and its limits correspond to the country borders. Insular Africa, Oceania and Caribbean Islands were excluded from the survey.
- The World Reference System 2 (WRS 2) for the Landsat satellites was used as the sampling frame. The WRS is a grid of paths and rows overlaid on a map of the Earth, with the paths representing the ground track of the satellite. The intersections of path and row are used to identify Landsat images. The WRS 2 was used from Landsat 4 missions. A sampling unit is defined as a Landsat frame and represented approximately 3.4 million ha (185x185 km^2).
- The sample population consists of 1203 Landsat frames representing all frames where the land area is above one million ha and where the forest cover is above 10 percent, in Latin America and Asia, or where woody vegetation is dominant, in Africa. It represents 51 percent of the total number of frames in the pan-tropical area. According to FRA 1990 national data statistics, 87 percent of the tropical forests are located in the sampled area.
- A two-stage stratified random sampling was adopted. The surveyed area was first divided into three regions (Africa, Asia and Latin America) and ten sub-regions on a geographic basis (Figure 2). Each sub-region was further stratified into a maximum of three sampled strata defined according to forest cover, in Latin America and Asia, or forest dominance, in Africa (Figure 3). The stratification was based on broad continental scale vegetation maps, which have a low resolution and accuracy (maps produced by ICIV, Toulouse).

Figure 2. Division of the pan-tropical area into sub-regions

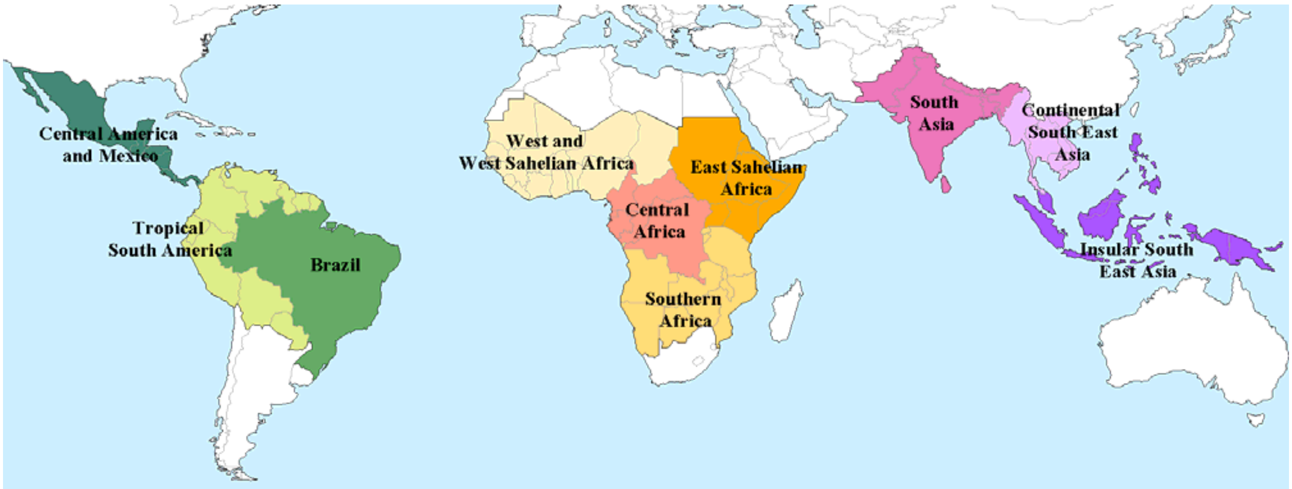
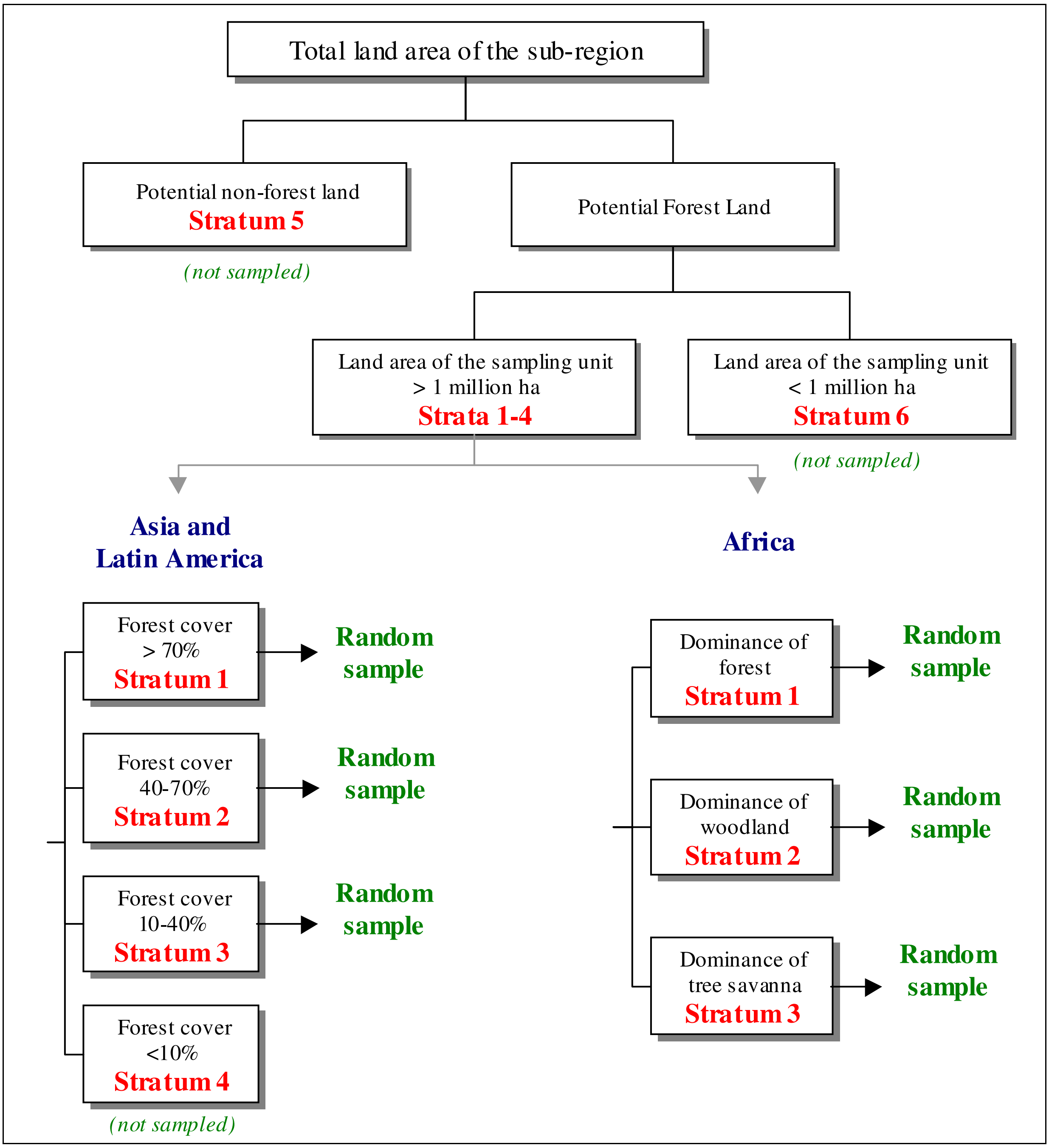


Figure 3. Sample design flowchart for a specific sub-region



- The sample size was fixed at 117 sampling units. The size was determined in function of practical constraints including levels of funding. The allocation of sampling units per sub-region was proportional to the (*a priori*) expected rate of deforestation, which was based on existing information and ecological/socio-economic low-resolution models, built in FRA 1990.

  Within each sub-region, a sample size was distributed for each of the three sampled strata, proportional to the total land area of the stratum. However in Latin America the allocation of sampling units was constant for each stratum to reduce the sampling fraction of the stratum 1 (forest cover > 70%), which included many units but minimal rates of change. For statistical reason a minimum of two sampling units were also fixed per stratum, and the strata where the numbers of Landsat frames were less than ten were merge with the closest stratum (case of the stratum 1 in South Africa sub-region).

Table 1 gives the expected standard errors by region (at 95 percent probability) for forest area estimates calculated during the design phase of the survey, while the distribution of selected sampling units by sub-region and by stratum is presented in Table 2.

Figure 1 shows the distribution of the selected sampling units.

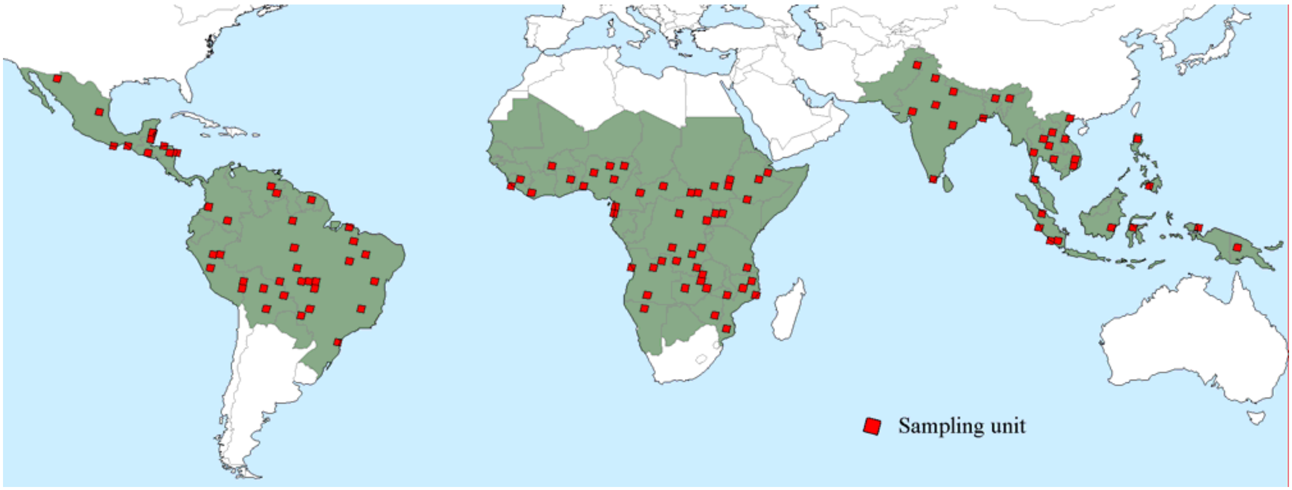
Table 1.Allocation of sampling units by region and expected sampling error for forest area estimates

Region	Population		Estimated sampling error (percent)
	Total number	Sample size	
Africa	461	47	8.0
Latin America	465	40	4.7
Asia	277	30	8.2
TOTAL	**1203**	**117**	**3.9**

Table 2. Allocation of sampling units among sub-regions and strata

Region/Sub-region	Stratum 1	Stratum 2	Stratum 3	Total
East Sahelian Africa	4	-	6	**10**
West Sahelian and West Africa	3	2	5	**10**
Central Africa	8	2	2	**12**
Tropical Southern Africa	-	11	4	**15**
Sub-total Africa	**15**	**15**	**17**	**47**
Mexico and Central America	3	4	3	**10**
Tropical South America	5	4	4	**13**
Brazil	6	5	6	**17**
Sub-total Latin America	**14**	**13**	**13**	**40**
South Asia	-	2	8	**10**
Continental South East Asia	-	5	5	**10**
Insular South East Asia	5	2	3	**10**
Sub-total Asia	**5**	**9**	**16**	**30**
TOTAL	**34**	**37**	**46**	**117**

Figure 4. Distribution of sampling units in the pan-tropical remote sensing survey



Notes: The 117 sampling units of the survey were selected over the entire pan-tropical zone following a two-stage random sampling method based on geographical divisions (regions and sub-regions) and forest cover or forest dominance.

2.2. Land cover classification

A uniform land cover classification was used for all the sampling units to map, gather statistics and describe the vegetation, and in particular woody vegetation.

The classification scheme adopted in the survey was designed with the following objectives:

- to allow a meaningful description of changes, with special attention to forest cover. It should allow describing and measuring changes from forest to non-forest, and vice-versa (e.g. deforestation, amelioration), as well as within the forest (e.g. degradation, amelioration);
- to be simple, based on clear definitions and applicable to all tropical conditions;
- to include classes detectable on high-resolution satellite data, with an acceptable degree of accuracy;
- to correspond as possible to the standard definitions used in FRA.

2.2.1. Land cover classes

The classification was broke down into two levels. The first level includes ten main land cover classes, of which nine visible classes (Table 3). This set of main classes constitutes the minimum common standard and was used for reporting results at pan-tropical and regional and sub-regional levels. The second level consists of twelve additional classes, optional, representing further subdivisions of the main classes. Additional classes were used when pertinent and when they could surely be identified, to allow a more detailed mapping at the sampling unit level.

The classes were defined mainly according to physiognomic criteria but also using contextual elements. Composite classes, - fragmented forest, long fallow and short fallow-, were used where individual elements were below the minimum mapping unit (< 3 x 3 mm).

Table 3. Land cover classification used for the survey (main classes)

	Land cover categories	Land cover classes (main classes)	Brief description
Natural forest	Continuous forest cover	**Closed canopy forest**	Canopy cover > 40 %, average height>5m
		Open canopy forest	Canopy cover 10-40 %, average height > 5 m
		Long Fallow	Forest affected by shifting cultivation Mosaic of mature forest, secondary forest, various stages of natural regrowth and cultivated areas with cultivated areas covering between 5 and 33 % of total area
	Fragmented forest	**Fragmented forest**	Mosaic of forest / non-forest with forest fraction between 10 and 70 % of total area (estimated average 33 %)
Non-forest	Other wooded land	**Shrubs**	Low woody vegetation Average height 1-5 m, canopy coverage > 10 %
		Short fallow	Agricultural areas with short fallow period Mosaic of young secondary forest, various stages of natural regrowth and cultivated areas with cultivated areas covering between 33 and 50 % of total area
	Non-wooded land	**Other land cover**	Includes urban and agricultural area, land with less than 10 % woody vegetation cover
		Water	Sea, lakes, reservoirs, rivers
Human-made woody vegetation		**Plantations**	Forest and agricultural plantations Average height > 1 m
Non-visible		**Non-interpreted**	Clouds, burnt woodland, shadow, outside study area...

Note: classes are grouped as forest/non forest according to the f3 forest definition (see below paragraph).

2.2.2. Forest definitions

The land cover classification contains many different classes of woody vegetation, which may be aggregated relative to various reporting and analysis needs. In the case of forests, three distinct alternative definitions were derived by grouping different classes of woody vegetation:

- the first and most exclusive definition, referred as forest 1 (f1), includes only the closed canopy forest class. This definition excludes all forest fragmentation and degradation stages;
- the second, forest 2 (f2), was constructed to match with the forest definition used in the country reporting in FRA 1990, and comprises the closed and open canopy forest classes, and a fraction (two-ninths) of the fragmented forest class. The reduction factor applied to the fragmented forest class was justified by the facts that, on average only

one third of the area covered by the fragmented forest class is considered as forest, and, in practise, small forest stands were often not included in national statistics;

- the third definition, forest 3 (f3), is the broadest and include all classes representing the forests under various conditions such as grades of density (open and closed canopy forest), spatial and temporal disturbances (fragmented and long fallow classes). A reduction factor of one-third is applied to the fragmented forest class.

2.3. Interpretation of the sampling units and data compilation

2.3.1. Interpretation process

The study of the sampling units was done using manual methods of photo-interpretation of temporal series of high-resolution satellite images. The interpretation was carried out at 1:250,000 scale on transparent overlays over analogue data. The minimum mapping unit was 2 mm width for linear features, and 3 x 3 mm^2 (about 50 ha) for isolated patches.

Each sampling unit was interpreted at three points in time with imagery acquired as close to the reference years 1980, 1990 and 2000 as possible. The designations T1, T2 and T3 were assigned to imagery corresponding to the data sets 1980, 1990 and 2000 respectively.

The T1 and T2 images had been already studied during the FRA 1990 through a technique called “interdependent interpretation” (described in FAO, 1991. The sample survey design. FAO FRA 1990 Project document.

FAO 1996, p.23). The same technique was employed to interpret the T3 images acquired for FRA 2000 (Figure 2-5). This method of interpretation focused on the change detection and required a continuous image-to image comparison with another image of the time series. Each class boundary is based on the analysis of both images, thus eliminating any relative subjectivity in class delineation between the two images. Consequently, the changed areas are treated like other interpreted classes and have not been derived from the difference between two independent interpretations.

Moreover, an important effect of the interdependent interpretation technique is that, all the overlays of the time series are geometrically co-registered. In most cases, analogue images from the time-series presented differing geometric corrections that produced, in spite of their common scale, considerable distortion between the images. In FRA 1990 and FRA 2000 surveys, the T2 image was used as geometric reference and all the overlays were designed to match it perfectly through local registration techniques, as the interpreter progressed in the interpretation. The projection of all the interpretation overlays corresponds to the one of the T2 image.

The interpretation of T1/T3 images was carried out over the entire common area with the T2 image, not only over the changed boundaries. This repetition of all unchanged class boundaries may seem redundant but it has been proved that only a thorough visual analysis permits the detection of all changes. Identifying and drawing the changes only through a visual scanning process tends to produce a systematic underestimation of changes, especially on images with highly fragmented patterns.

Although more time consuming than independent interpretation, this method ensures a high level of consistency in the analysis within the time-series and has been shown to lessen classification errors in both state and change estimates. It substantially reduced errors that would have been caused by geometric offsets in the images, as well as those from differences in satellite scenes due to varying contrast enhancements or seasonal differences in vegetation (Drigo 1991). Spatial correspondence and thematic consistency between interpretations from the time series made it possible to build reliable transition matrices.

A more digital approach based on on-screen interpretation was not chosen since most of the material from FRA 1990 (T1 and T2 images and interpretation) was only available in an analogue format. It would have been too costly and time-consuming to acquire the imagery for the entire time series in a digital format, and to digitise all the interpretation overlays. However a digital approach would have allowed, in particular, a more accurate and automatic co-registration of the satellite data from a time series and avoid interpretation difficulties due to the distortions of the overlays.

The image acquired for the third date added substantially more information to the analysis. Most of the T3 imagery was acquired digitally by FRA and new ancillary information such as vegetation maps had become available since FRA 1990. This new data was used to improve the interpretations of the entire time series. The T1 and T2 interpretations were consequently revised when necessary. This contributed to very slight differences in statistics for the 1980-1990 period, compared to those generated for FRA 1990 for the same period.

2.3.2. Data compilation

The interpreters were responsible for the compilation of the interpretation results so they could verify immediately after the interpretation work the statistics to detect and correct possible errors in interpretation (missing codes or unclosed polygons in the interpretation overlays, inconsistencies...) and data registration (missing or wrong codes entered).

The data compilation method, unsophisticated but robust, was developed to allow all interpreters, in particular those from developing countries, to carry out the analysis with basic hardware and widespread software.

Data capture was achieved by using a dot grid, sized 100 x 100 dots with dots 8 mm distant from each other. The dot density of the grid was selected as a compromise between accuracy and convenience (time and difficulty in the entry).

The interpreted class was registered at each dot for each of the three points in time. The results of the interpretation of the T2 image were first registered, to produce a T2 data grid. Then the T1 or T3 data grids were generated by modifying class codes in the T2 data grid where changes with the T2 image had been reported in the T1 or T3 overlays.

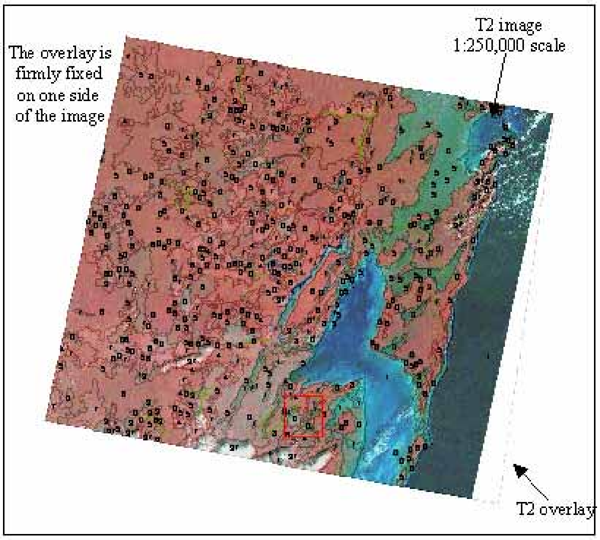
The data registration was carried out in Excel using a customised Excel workbook. For most of the sampling units the data grids corresponding to the T1 and T2 interpretations were already available in a Lotus format from FRA 1990, and were just imported in the Excel workbook and eventually revised if some corrections had been reported on the T1 and T2 interpretation overlays. So the data entry for FRA 2000 survey consisted mainly in entering the changes detected between the T2 and T3 images. The dot grid had to be positioned to match exactly with the data grids available from the FRA 1990 survey. Some macro functions were added in Excel to generate automatically after the data entry raster maps, which helped in the detection of data entry errors.

The resulting data grids were used to determine the states (i.e. the areas for the various land cover classes at each of the three points in time), and to estimate the class-to-class changes during the two time periods. The changes within a sampling unit between two dates were compressed into a single area transition matrix, which quantifies the various shifts between the classes. Area calculations were made considering that every dot of the dot grid or cell of the data grid represented 400 ha, considering that the scale of interpretation was of 1:250,000.

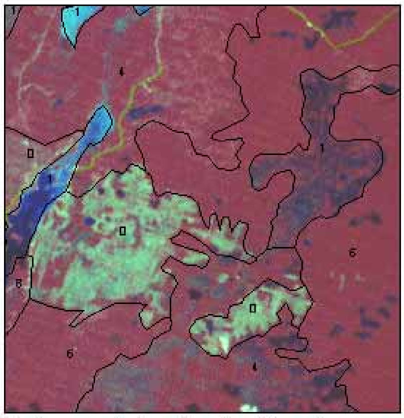
The information set for each sampling unit consists of three observed states (at the time T1, T2 and T3) and two area transition matrices (periods T1-T2 and T2-T3).

Figure 2-5. Interdependent interpretation procedure

1. Interpretation of the T2 image on a transparent film overlay (T2 overlay)

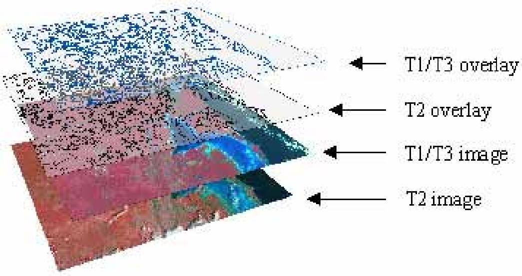


The T2 overlay is placed on the top of the T2 image.



The interpretation includes the delineation of land cover classes (black lines) and control features (green lines). Land cover class codes are written in every polygon.

2. Insertion of the T1/T3 image between the T2 image and the T2 overlay.



A new overlay (T1/T3 overlay) is fixed on the top of the T2 overlay.

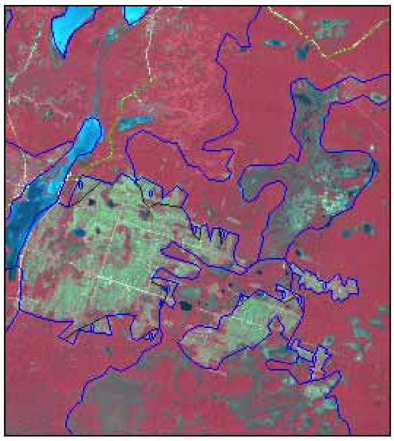
T1/T3 image are not fixed, to adjust it locally to the T2 overlay

3. Interpretation of the T1/T3 image.

The interpretation of the T1/T3 image is carried out on the T1/T3 overlay with continuous reference to the T2 overlay.
Only the common area with the T2 image is interpreted, through continuous comparison of the two images.

When the class boundary of the T2 overlay fits the T1/T3 image, it means that there is no change and the same lines are repeated.

When the features of the T2 overlay does not fit the T1/T3 image, it means that there is a difference (not necessarily in land cover).
Then, the two images are compared directly from each other. Two outcomes are possible:
- there are no real changes in land cover. The line on the T2 overlay was wrong and is therefore corrected and the same line is drawn on the T1/T3 overlay.
- there is a real change in land cover. A new class boundary is drawn on the T1/T3 overly according to the feature of T1/T3 image.



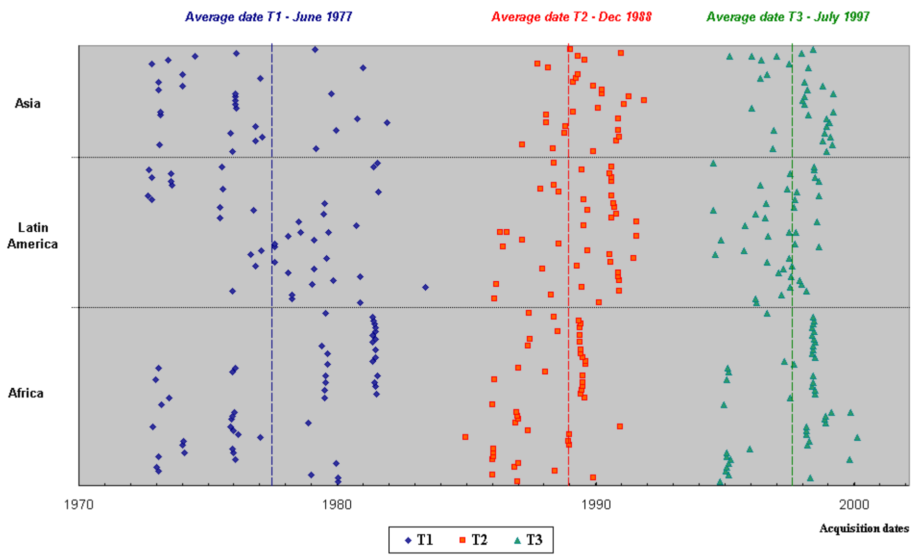
The delineation on the T2 overlay is used as the reference.
Polygons are designed in blue on the new overlay.
Land cover codes are written only where changes with the T2 images are detected.

The position of the T1/T3 image is continuously checked and adjusted thanks to the control features reported on the T2 overlay.

2.4. Standardisation of the transition matrices to the reference years 1980, 1990, 2000

While the images were selected to be as close as possible to the reference years 1980, 1990 and 2000, they rarely corresponded exactly to the reference years and varied considerably between sampling units (Figure 2-6).

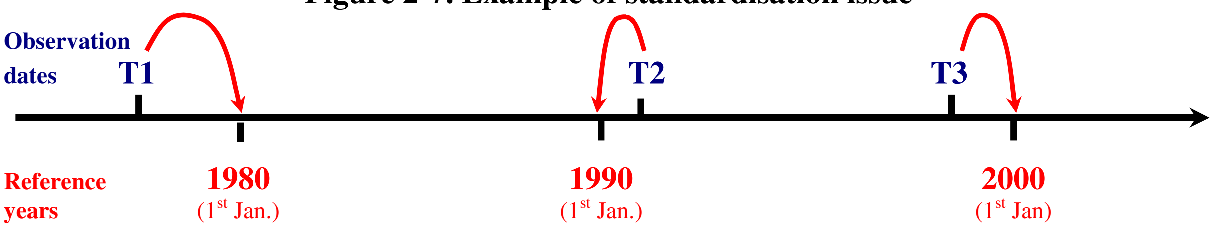
Figure 2-6. Temporal distribution of satellite images used for the survey



Each dot corresponds to an image used during the survey. T1 corresponds to the first observed image of the time series, T2 to the second, T3 to the third. The average dates for T1, T2 and T3 images are mid-1977, end-1988 and mid-1997.

Before making estimates at the various aggregate levels, data from the sampling units had to be standardised to the reference years 1980, 1990 and 2000. The processes involved were to either extrapolate or interpolate the statistics from the sampling units (states and transition matrices) starting from the original date of acquisition of the imagery (T1, T2 and T3) to the various reference years (Figure 2-7).

Figure 2-7. Example of standardisation issue



Notes: The figure presents an example of the time standardisation problem. The observed matrices for the period T1-T2 and T2-T3 (and corresponding states T1, T2, T3) must be either extrapolated or interpolated to represent the periods 1980-1990 and 1990-2000.

The results from the standardisation was standardized matrices (1980-1990 and 1990-2000) and states (1980,1990, 2000) for the common area to the entire time series, for each sampling unit.

3. Results and findings

The results from the FRA 2000 Remote Sensing Survey cover most of pan-tropical forests under a wide range of ecological conditions, from tropical rainforests to dry forests. Estimates were calculated at different levels: at sampling unit, stratum, sub-regional, regional, pan-tropical levels and at ecological zones level. The reliability of the estimates differs according to the study level. The survey was mainly designed for generating information with an acceptable statistical precision at the regional and pan-tropical levels. Estimates at the sub-regional level have a relatively low precision but give valuable indications on forest changes processes.

For each level of analysis the major findings consist of transition matrices which summarize all change information registered during two consecutive periods. These matrices constitute an interesting source of information for studying land use dynamics and understanding the processes of changes involved. Forest area change and forest area change estimates for the reference years and periods were generated from the matrices. The survey is the first assessment tool to provide consistent and comparable information over two reporting periods (1980-1990 and 1990-2000), allowing the calculation of both changes and the change in changes between the two periods. Past assessments have not been able to provide such information on trends owing to various inconsistencies in information between subsequent FRA reports.

Moreover, the consistency of the survey over the whole pan-tropical area makes it a good tool for comparing statistics between regions and calibrating results from national statistics on a regional basis.

3.1. Results at sampling unit level

Among the 117 sampling units selected for the survey, 113 were analysed and mapped at three points in time (T1, T2 and T3). The four remaining samples could not be completely studied due to a lack of suitable images available, and were only interpreted at two points in time. Two of them are located in the Congo Basin, one in Venezuela, the other one in Papua New Guinea.

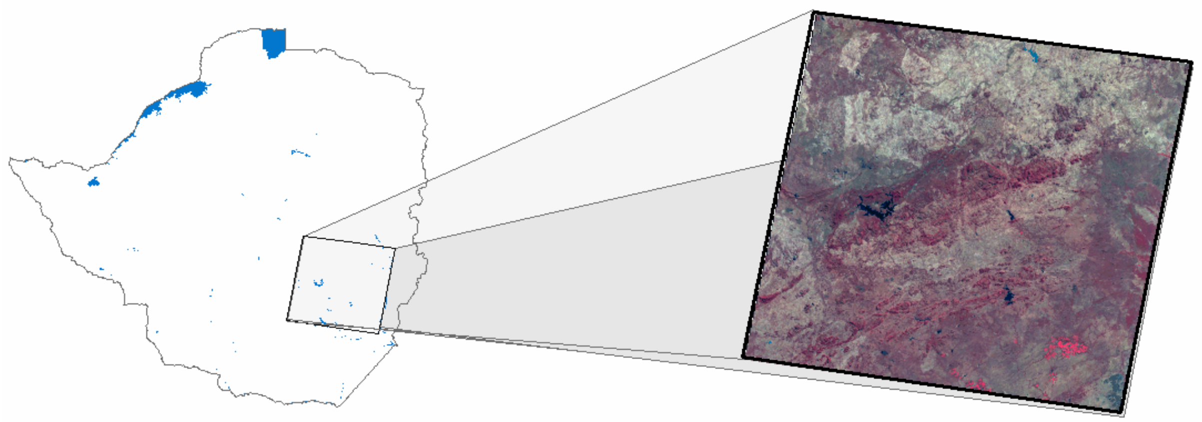
On average the visible area of the T2 image covered 3.1 million ha, which were integrally interpreted. As regards the T1 and T3 images, only the common area with the T2 image was analysed. The size of these common areas varies among the sampling units, mainly due to cloud coverage and shifts in the satellite track. The interpreted visible common area between the T1 and T2 images represented a mean of 2.2 million ha, while the common area between the T2 and T3 images amounted about 2.6 million ha. The common visible part to all three images of the time series measured on average 2 million ha. In total, the visible area interpreted covered 982 million hectares (T1, T2 and T3 images). Excluding the permanent water the common area to all three dates represent a total land area of 225 millions over all the sampling units or 7.4 percent of the total surveyed area.

The resulting maps represent primary spatial information that could be used for a number of analyses in particular at local level, which pursue other objectives than the actual remote sensing survey. Geo-referenced maps derived from the import of the data grids into a Geographic Information System (GIS) as well as the maps derived from the scanning process of the interpretation overlays constitutes an important spatial data set.

For every sampling unit, estimates of the land cover state (area covered by each land cover classes) at the three times of observation and at the reference years, as well as area change matrices for the observed and reference periods were produced. Forest cover estimates and forest cover change estimates were also calculated for the different forest definitions adopted.

An example of results from the interpretation is given for a sampling unit located in Zimbabwe (sampling unit code 1613, WRS2 path/row 169/74, see Figure 8). The T1 image, a Landsat Multispectral scanner (MSS) scene, was acquired on May 1981; the T2 image, also a Landsat MSS image, was dated May 1989; the T3 image used was a Landsat Thematic Mapper (TM) scene from June 1998.

Figure 8. Location of the sampling unit 1613 in Zimbabwe and T3 satellite image



T3 image
Landsat TM 5 Path 169 Row 74
Acquisition date 6 June 1998

3.1.1. State and change raster maps based on dot grid registrations

Maps were produced from the interpretation of the three date time series of images. They represent the states at the times T1, T2 and T3 (above) and the distribution of changes during the periods T1-T2 and T2-T3 (below). The pixel size (smallest unit of the map), in relationship with the dot grid specifications used for the data registration, is 2 x 2 km^2.

3.1.2. Observed transition matrices and states

Transition matrices shown in Table 4 summarise all the changes in land cover classes observed and reported in the interpretation overlays of the sampling unit during the studied periods (T1-T2 and T2-T3).

The matrices presented refer only to the common part to all three images of the time series. This restriction of the studied area allows comparing matrices from both periods. Similar matrices describing the changes observed in the common area to two consecutive images were also produced.

The row and columns sums of the matrices give the area of each classes, or states, at the times T1, T2 and T3.

Table 4. Observed area transition matrices for the periods T1-T2 and T2-T3, for the sampling unit 1613, Zimbabwe (thousand ha).

Area transition matrix T1-T2 (1981-1989)

(Thousand hectares) — Land cover classes in 1990

Land cover classes in T1	Closed canopy forest	Open canopy forest	Long fallow	Fragmented forest	Shrubs	Short fallow	Other land cover	Water	Plantations	State T1	*% of total land area*
Closed canopy forest	842.4	8.8		6.8	0.8		22.0	0.4		881.2	*38.3*
Open canopy forest	0.8	202.8		9.6			10.4			223.6	*9.7*
Long fallow											
Fragmented forest	2.0	4.8		368.8			10.4			386.0	*16.8*
Shrubs					65.2		2.8		2.8	70.8	*3.1*
Short fallow											
Other land cover	0.8	4.4		0.8			708.0			714.0	*31.1*
Water	2.0	2.8		0.8			2.4	7.6		15.6	*0.7*
Plantations									8.0	8.0	*0.3*
State T2 →	848.0	223.6		386.8	66.0		756.0	8.0	10.8	2 299.2	
% of total land area →	*0.4*	*0.1*		*0.2*	*0.0*		*32.9*	*0.0*	*0.0*		

Area transition matrix T2-T3 (1989-1998)

(Thousand hectares) — Land cover classes in T3

Land cover classes in T2	Closed canopy forest	Open canopy forest	Long fallow	Fragmented forest	Shrubs	Short fallow	Other land cover	Water	Plantations	State T2	*% of total land area*
Closed canopy forest	807.2	4.4		21.2	0.8		13.2	1.2		848.0	*36.9*
Open canopy forest		212.8		0.4			10.0	0.4		223.6	*9.7*
Long fallow											
Fragmented forest				382.8			3.6	0.4		386.8	*16.8*
Shrubs					58.0		4.8		3.2	66.0	*2.9*
Short fallow											
Other land cover	2.4	0.8		0.8	0.8		750.0	1.2		756.0	*32.9*
Water								8.0		8.0	*0.3*
Plantations							0.4		10.4	10.8	*0.5*
State T3 →	809.6	218.0		405.2	59.6		782.0	11.2	13.6	2 299.2	
% of total land area →	*35.2*	*9.5*		*17.6*	*2.6*		*34.0*	*0.5*	*0.6*		

Notes: The diagonals of the matrices contain areas where no change was identified between two consecutive dates. The other elements represent areas that changed from a class (row class) to another (column class) during the studied period. The land cover classes are ordered according to decreasing indicative woody biomass content, with the exception of the plantation class, so negative changes (from higher to lower biomass) correspond to the values above the diagonal while positive changes are below.

3.1.3. Standardised transition matrices 1980-1990 and 1990-2000

The matrices presented in Table 5 show the results of the standardisation procedure to the reference years 1980,1990 and 2000 presented in section 2.4. The main interest of these matrices is the calculation of estimates at aggregated levels such as regional, pan-tropical or ecological levels. They can also be used for comparing the matrices between sampling units.

Diagrams of comparison of standardised vs. observed states, as presented in Figure 9, were used for verifying the solutions of the standardisation process. They also give a picture of the trend of each class inside the sampling unit.

Table 5. Standardised area transition matrices for the periods 1980-1990 and 1990-2000 for the sampling unit 1613, Zimbabwe (thousand ha)

Area transition matrix 1980-1990

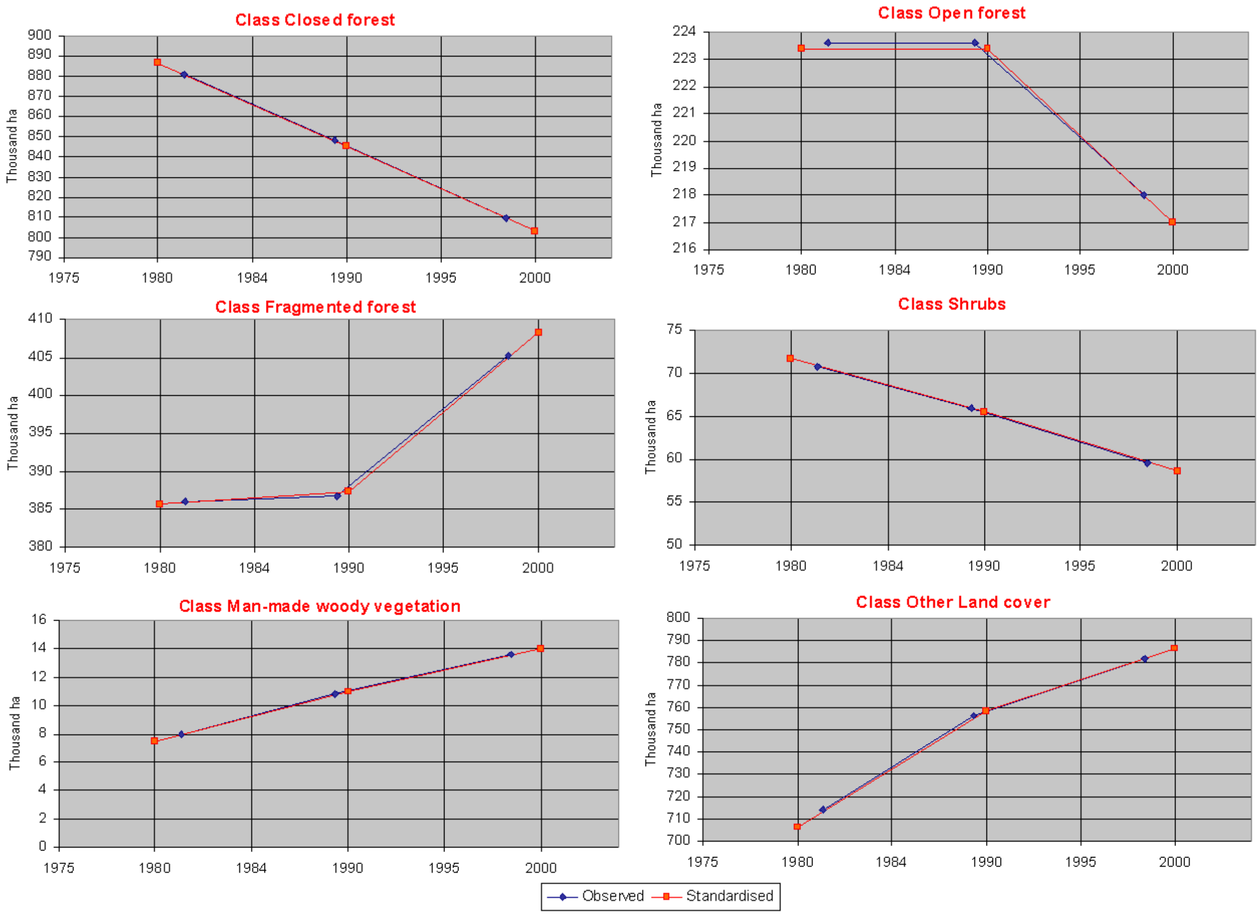
(Thousand hectares)	Land cover classes in 1990										
Land cover classes in 1980	Closed canopy forest	Open canopy forest	Long fallow	Fragmented forest	Shrubs	Short fallow	Other Land Cover	Water	Plantations	**State 1980**	*% of total land area*
Closed canopy forest	838.4	10.8		9.0	1.0		27.3	0.5		**887.0**	*38.6*
Open canopy forest	1.0	198.1		11.5			12.8			**223.4**	*9.7*
Long fallow											
Fragmented forest	2.4	5.7		364.9			12.7			**385.7**	*16.8*
Shrubs					64.6		3.6		3.5	**71.7**	*3.1*
Short fallow											
Other land cover	1.0	5.3		1.0			699.0			**706.3**	*30.7*
Water	2.5	3.5		1.0			3.1	7.3		**17.4**	*0.8*
Plantations									7.5	**7.5**	*0.3*
State 1990 →	**845.3**	**223.4**		**387.4**	**65.6**		**758.5**	**7.8**	**11.0**	2 299	
% of total land area →	*36.8*	*9.7*		*16.9*	*2.9*		*33.0*	*0.3*	*0.5*		

Area transition matrix 1990-2000

(Thousand hectares)	Land cover classes in 2000										
Land cover classes in 1990	Closed canopy forest	Open canopy forest	Long fallow	Fragmented forest	Shrubs	Short fallow	Other Land Cover	Water	Plantations	**State 1990**	*% of total land area*
Closed canopy forest	800.6	4.6		23.8	0.9		14.1	1.3		**845.3**	*36.8*
Open canopy forest		212.0					10.9	0.5		**223.4**	*9.7*
Long fallow											
Fragmented forest	- 0.1	- 0.2		383.6			3.7	0.5		**387.4**	*16.9*
Shrubs					56.8		5.3		3.5	**65.6**	*2.9*
Short fallow											
Other land cover	2.7	0.7		0.9	0.9		752.0	1.4		**758.5**	*33.0*
Water	- 0.1	- 0.1					- 0.1	8.1		**7.8**	*0.3*
Plantations							0.5		10.5	**11.0**	*0.5*
State 2000 →	**803.1**	**217.0**		**408.3**	**58.6**		**786.4**	**11.8**	**14.0**	2 299	
% of total land area →	*34.9*	*9.4*		*17.8*	*2.5*		*34.2*	*0.5*	*0.6*		

Notes: see Table 4. The small negative values produced by the mathematical routines, unrealistic, were removed before the aggregation process.

Figure 9. Diagrams of comparison between standardised and observed states. Sampling unit 1613, Zimbabwe. Thousand ha.



Notes: The observed dots (in blue) represent the area effectively measured at the time T1, T2 and T3, while the standardised dots (in red) are calculated area generated from the standardisation at the year 1980, 1990 and 2000 procedure through a number of assumptions. In the above case, the results were extrapolated to the years 1980 and 2000.

3.2. States and changes for the periods 1980-1990 and 1990-2000 at pan-tropical, regional and ecological zones levels

The aggregated area transition matrices for the 1980-1990 and 1990-2000 periods, estimated for the two reference periods at pan-tropical and regional levels and for ecological zones, constitute the overall and more interesting results of the remote sensing survey. They are based on the standardized matrices of 113 of the 117 selected sampling units. These matrices, presented in the following paragraphs, describe in details the land cover changes from 1980 (classes in row) to 1990 (classes in columns), and from 1990 (classes in row) to 2000 (classes in column) for the surveyed land area. Standard errors and 95% confidence intervals of the elements of the matrices were also calculated.

To facilitate the analysis, different results directly generated from the area transition matrices are shown in the Appendix:

- Summaries of net changes by class for the two periods 1980-1990 and 1990-2000 were produced to describe the area lost and gained for each class during the two studied periods. They were obtained directly from the matrices by calculating the difference between two consecutive states (row and column sums of the matrices).

- Elements of the transition matrices were also expressed as percentage of the total area change estimated for a given period. This presentation of the results focuses on the analysis of change and allows identifying the major transitions and the main classes of destination and of origin.

Although the results are presented hereby for the two periods, the analysis focuses on the period 1990-2000. The comparison with the decade 1980-1990 will be presented in the section 3.3 where the significance of the differences between the estimates from the two periods is studied.

3.2.1. Area transition matrices and net changes by land cover classes at pan-tropical and regional levels

3.2.1.1. Pan-tropical level

For the 1990-2000 reporting period, at the pan-tropical level, the survey revealed that closed canopy forest was the class most subject to loss (see Figure 15 and Table 12, in Appendix): a mean of 70 million hectares disappeared (45 percent of the total area change). At the opposite, the other land cover class, which includes sparsely vegetated areas such as grassland, agriculture and urban areas, showed the greatest increase in area across the tropics (54 percent). The main area transition at the pan-tropical level, estimated at 43 million ha (26 percent of all changes), was the conversion of closed canopy forests to other land cover (Table 11, in Appendix). Also noticeable during that decade were the transitions from fragmented forest, shrubs and short fallow classes to the other land cover class, and from closed canopy forest to fragmented forest and short fallow classes.

3.2.1.2. Regional level

The summaries of net changes by region (Figure 16, Figure 17 and Figure 18) show also that in all the regions the closed canopy forest was the main class affected by loss in the period 1990-2000 while the “other land cover” class presented the major increase. However, results at regional level varied somewhat.

Forest change in Latin America (Table 17 and Figure 18, in Appendix), during the 1990s, was characterized by a marked large transition from closed canopy forests into other land cover (32 millions hectares or 41 percent of total change), which was about twice as great as the total area in the other two regions. Substantial areas of shrubs were also converted into other land cover class in Latin America, but not in Asia or Africa. The other land cover class expanded considerably and gained an estimated area covering almost 40 million ha (67 percent of total changes in the region).

While the findings were similar in Asia (Table 15 and Figure 17, in Appendix), showing that the greatest transition was from closed canopy forests class into “other land cover” (32 percent of total area change), that region also had large areas of closed canopy forest that were transformed into both long and short fallow. Changes from other land cover and closed canopy forests to plantations (human-made woody vegetation) were also notably observed in Asia. The plantation area expanded notably. Meanwhile, the area covered by the long fallow class in Asia reduced.

In Africa (Table 13, in Appendix) the amount of closed canopy forest converted into other land cover was relatively low in comparison with other regions (only 5 percent of all the changes). Large portions of both closed and open canopy forests were converted into fragmented forest and short fallow classes in the region. Significant areas of fragmented forest were also converted into other land cover. The open canopy forest in Africa sustained greater losses than in the other regions (minus 10 million hectares or 25 percent of total area change).

Positive transitions are those in which the woody content of the area increased. While they were not common during the 1990s, some positive changes were observed when other land cover recuperated into short fallow and shrubs in Latin America. Shifts from other land cover to fragmented forest were more uniformly distributed throughout the tropics, while changes from short fallow to long fallow were observed mostly in Asia.

3.2.2. Forest area and forest area change at pan-tropical and regional level

3.2.2.1. Forest Area

Estimates of forest area and area change, including error estimates, were calculated by grouping the relevant classes constituting the forest definitions adopted (see section 2.2.2 for the forest definitions).

Table 6 reports the forest area estimates for the year 2000 according to all three definitions of forest adopted. Considering the forest definition f3, the forest area for the surveyed area in 2000 was estimated at 1.6 billion hectares, or about 50 percent of the surveyed land area. Half of this area was in Latin America.

Table 6. Estimates of forest area by region and at the pan-tropical level in 2000

	Relative forest area *(million ha)*		**Relative forest area** *(percent)*	
	Mean	*SE*	*Mean*	*SE*
Africa	519	37	42	3
Latin America	780	49	63	4
Asia	272	23	45	4
Pan-tropical	1571	66	51	2

Notes: The figures are related to the surveyed area, representing about 90 percent of the total forest land in the pan-tropical region. The estimates refer to the f3 definition of forest (cf. part 1, section 2.2.2). SE=Standard error of the mean.

3.2.2.2. Forest area change

Deforestation was defined as the sum of all area transition from forest to non–forest classes. The net forest area change was estimated as the difference of the transitions resulting from non-forest into forest classes minus the deforestation. The deforestation rate was estimated at 0.52 percent per year, corresponding to an annual deforestation of 9.2 million hectares per year, for the pan-tropical zone for the time period 1990-2000 (f3 definition of forest). The net forest area change was of -8.6 million hectares per year during the period (Table 7). Standard errors at the regional levels were relatively high and differences of deforestation rates between geographical regions were not statistically significant at the 5 percent level.

Table 7. Annual deforestation and net forest area changes during the period 1990-2000 by region and at pan-tropical level

	Annual deforestation *(million ha/year)*	**Annual net forest area change** *(million ha/year)*		**Forest area change rate** *(percent/year)*	
	Mean	*Mean*	SE	*Mean*	*SE*
Africa	2.3	-2.1	0.4	0.38	0.06
Asia	2.5	-2.3	0.6	0.79	0.20
Latin America	4.4	-4.2	1.1	0.51	0.15
Pan-tropical	9.2	-8.6	1.3	0.52	0.08

3.2.3. Results at ecological level

In order to identify which types of forest were changing, reporting on forests through the remote sensing survey was classified according to ecological zones by grouping classes from the FRA 2000 global Ecological Zone map (FAO 2001) to obtain three aggregate zones:

- Tropical rain forest. Contains the global ecological zone *Tropical rain forest* (wet: high rainfall, no or short dry season).
- Tropical moist deciduous forest. Corresponds to the global ecological zone Tropical moist deciduous forest (subhumid, wet/dry: three to five months dry);
- Tropical dry forest and shrubland. Covers the global ecological zones tropical dry forest (dry/wet, five to height months dry) and tropical shrubland (semi-arid: evaporation > precipitation).

Only the tropical domain was considered (all months without frost: in marine areas over 18°C). The grouping of the ecological zones (tropical dry forest and tropical shrubland) was justified by the necessity of having a minimum number of sampling units in each zone.

To aggregate the statistics for the ecological zone of interest, the sampling units were classified according to their location relative to the ecological zone covering most of the sampling unit area, since zones transected some of the sampling units. A GIS was used to overlay the common area to the T1, T2 and T3 data grids with the global ecological zone maps.

The sampling units mainly in the Tropical Mountain systems ecological zone (near > 1000 m altitude), were classified considering:

- the second major tropical ecological zone
- detailed local ecological maps used to build the global ecological zone map
- the spatial distribution of the forests since the forest was completely sometimes present in only one tropical ecological zone due to the altitude factor.

Then, one sampling unit belonging entirely to the temperate domain according to the global ecological zone map was excluded from the analysis (sampling unit 3105, Mexico North).

The ecological zone classification used in FRA 2000 differs from the one used in the FRA 1990 survey. It lead to relatively high differences with the results at ecological zone level for the period 1980-1990 as reported in FRA 1990 (FAO, 1991. The sample survey design. FAO FRA 1990 Project document.

FAO 1996, pp 61-66).

Detailed results such as transition matrices and corresponding standard errors and confidence intervals, summary of net change by land cover classes by ecological zones were also generated.

The distribution of forests by ecological zones, as given in Figure 10 showed that the surveyed forests are mainly in the tropical rain forest ecological zone. Deforestation estimates by ecological zone (Table 8) show that the forest loss is also concentrated in the rain forest ecological zone.

Figure 10. Distribution of the forest by ecological zone in 2000 (f3 definition)

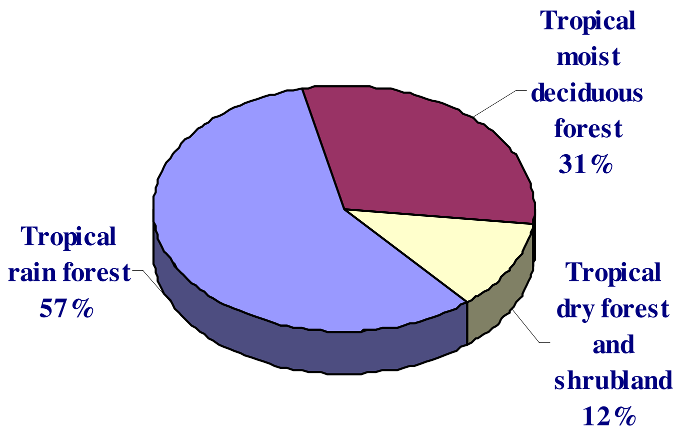


Table 8. Annual deforestation and net forest area change during the period 1990-2000 by ecological zone

	Annual deforestation *(million ha/year)*	Annual net forest area change *(million ha/year)*		Annual deforestation rate *(percent/year)*	
	Mean	*Mean*	SE	*Mean*	*SE*
Tropical rain forest	6.0	-5.7	1.2	0.59	0.14
Tropical moist deciduous forest	2.4	-2.2	0.4	0.43	0.07
Tropical dry forest and shrubland	0.8	-0.7	0.3	0.38	0.13

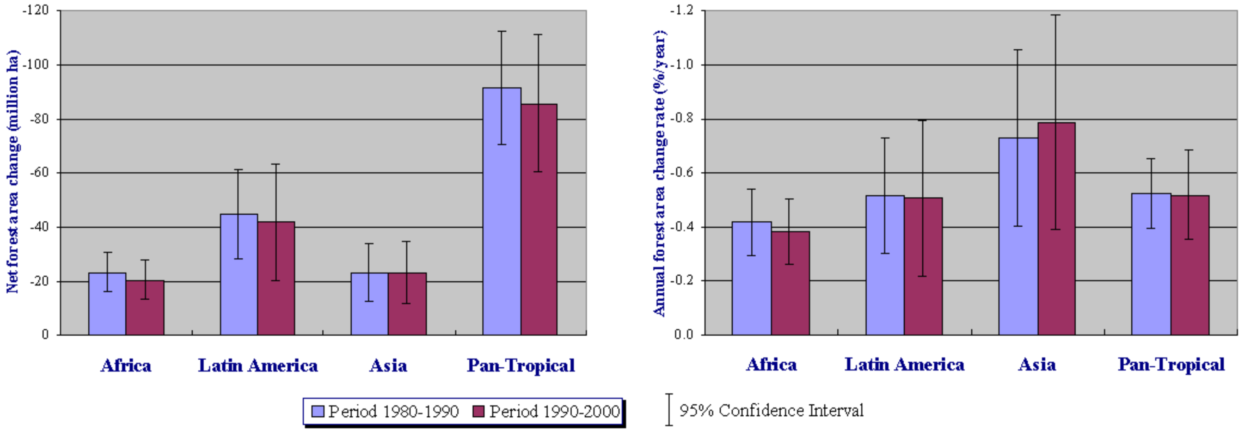
3.3. Trend analysis: comparison of the forest changes 1980-1990 and 1990-2000

3.3.1. Comparison of the forest area change estimates

Statistical tests were used to assess if the differences between estimates from the two studied periods were significant and thus to detect a possible break in the trend.

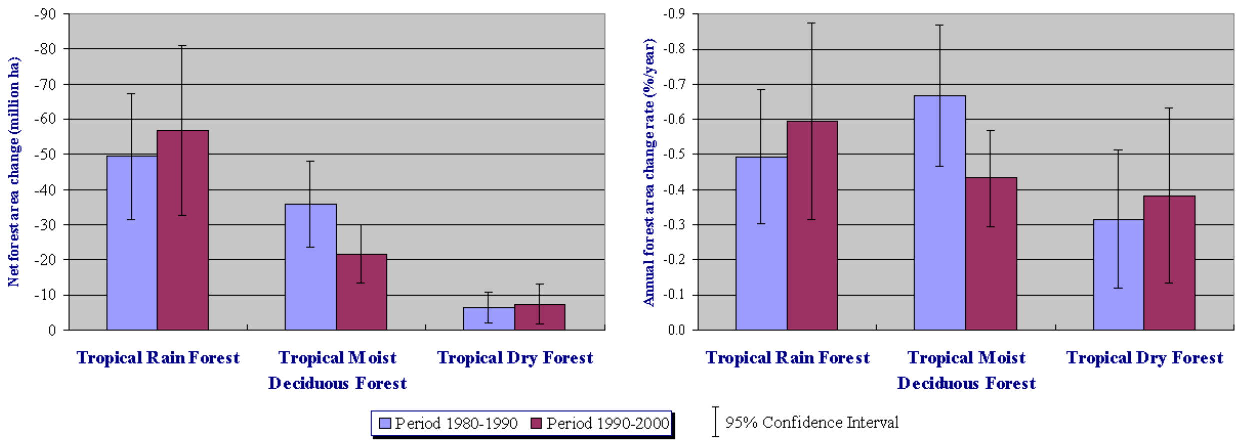
Figure 11 compares the absolute and relative changes of forest area between the two periods, with a 95 percent confidence interval indicated. Results showed that there was no significant difference in the estimates of deforestation at the 5 percent level of significance for the two study periods (1980-1990 and 1990-2000) at either regional or pan-tropical level.

Figure 11. Net forest area change by region and at pan-tropical level 1980-1990 and 1990-2000 (left); annual deforestation rate by region and at pan-tropical level 1980-1990 and 1990-2000 (right).



At ecological zone level, deforestation in the tropical moist deciduous forest zone was found to be significantly different between the two study periods (1980-1990 and 1990-2000). In this zone, both the net forest area change and the deforestation rate decreased significantly at the 5 percent level of significance (Figure 12). For the other ecological zones, differences in the net forest area change and annual deforestation rate was not significant.

Figure 12. Net forest area change by ecological zone, 1980-1990 and 1990-2000 (left); Annual deforestation rate by ecological zone, 1980-1990 and 1990-2000 (right).



3.3.2. Difference in the transition estimates

The following tables (Table 9) gives by geographical units the class-to-class transitions for which it was possible to detect a significant difference between the periods 1980-1990 and 1990-2000. This analysis considers the estimates of the proportion of one class going to another one (transition probability) during a period.

Table 9. Comparison of the transition probability estimates, 1980-1990 with 1990-2000 by region and at pan-tropical level

	Transitions with significant difference between the periods		Increase/ Decrease
Africa	Closed canopy forest	► Open canopy forest	Decrease
	Open canopy forest	► Other land cover	Decrease
Asia	Closed canopy forest	► Open canopy forest	Decrease
	Other land cover	► Plantations	Increase
Latin America	Closed canopy forest	► Open canopy forest	Decrease
Pan-tropical	Closed canopy forest	► Open canopy forest	Decrease
	Open canopy forest	► Other land cover	Decrease
	Closed canopy forest	► Long Fallow	Decrease
	Closed canopy forest	► Short fallow	Decrease
	Other land cover	► Open canopy forest	Decrease

Notes: The table shows the transition estimates statistically different between the periods 1980-1990 and 1990-200 at a 5 percent level of significance. Differences were calculated on the proportion estimates (probability of a class to change to another during the period). Only the transitions with an estimate above 1 million hectares for one of the two periods were considered. An increase indicates that the class-to-class transition was meaningfully superior during the period 1990-2000 than during the period 1980-1990.

Several conclusions can be underlined from the table above. There is a general decrease of the degradation of closed canopy forest into open canopy forest, observable in all the regions and at pan-tropical level. At pan-tropical level changes from closed canopy forest to the shifting cultivation classes (long and short fallow) decreased in the second decade compare to the period 1980-1990. An increase of the conversion of the other land cover into plantation is also noticeable in Asia: while most of the plantations were in the first period mainly established to the detriment of forest area, the new planted area during the second period were both in previously forested and non-forested zones.

3.4. Main forest change processes by region

Standardized transition matrices were used to depict major forest change processes and to quantify their relative importance at the pan-tropical and regional levels.

Change processes can be identified according to a selection of criteria adopted: extent and intensity of degradation of the forest cover, rapidity of the change process, the size of the activity contributing to the deforestation, main driving forces involved in the change process, type of land use involved...

In the study the main criteria selected were the scale of the change process and the rapidity of the processes.

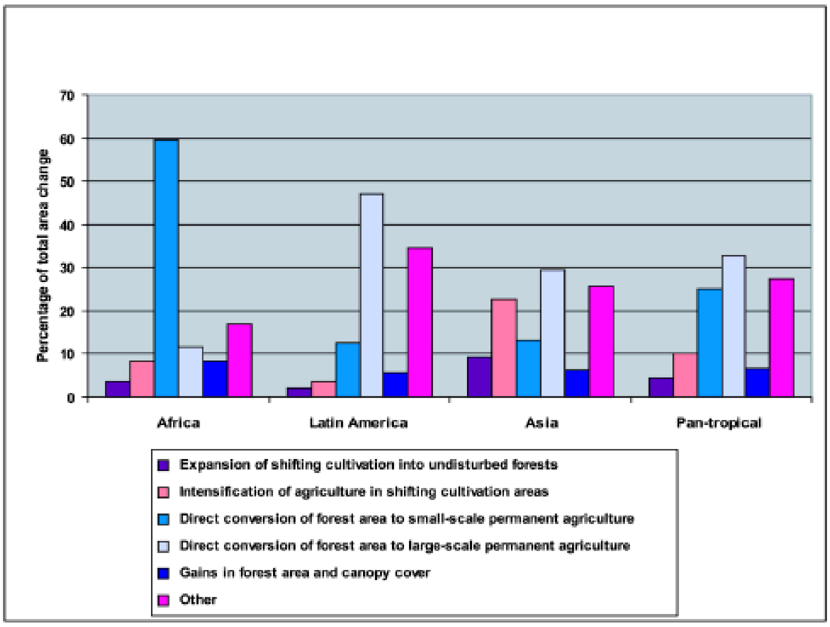
According to these criteria four deforestation processes were differentiated:

- **Expansion of shifting cultivation into undisturbed areas.** This process occurred in forests where shifting cultivation or degradation began after 1980. The impact on the forests was moderate and gradual, as the shifting cultivation incrementally expanded into them. This process was denoted by transitions from closed and open canopy forest classes to the long fallow class, and from closed canopy forest to open canopy forest.

- **Intensification of agriculture in shifting cultivation areas.** This process occurred in forests already impacted by shifting agriculture practices in 1980. It also occurred where shifting cultivation had become more intense (where fallow period decreased) or where a complete transition from shifting to permanent agriculture had occurred from the 1980s to the 1990s. For this study, it included the transitions from the long fallow class to fragmented forest and short fallow, and from the short fallow class to other land cover.
- **Direct conversion of forests to small-scale permanent agriculture.** In this process, small areas of forest (less than 25 ha) were converted to agriculture. For this study, the transitions were represented in changes from closed and open forest to fragmented forest and short fallow, and from fragmented forest to either short fallow or other land cover.
- **Direct conversion of forest area to large-scale agriculture.** In this process, large areas (greater than 25 ha) of closed canopy forest, open canopy forest and long fallow were converted to other land cover. (This could also be represented by the more or less simultaneous conversion of smaller adjoining areas which, when aggregated, occupied an area of more than 25 ha. Such areas were indistinguishable in satellite imagery from large uniformly converted areas of forests.)

The elements of the matrices were grouped to estimate the area involved in each processes at the different levels.

Figure 13. Percentage of total area change by individual processes at regional and pan-tropical level for the period 1990-2000



Notes: The figure represents the proportion of the total area change during the period 1980-2000 divided by the identified processes. The positive changes includes comprises transitions from non-forest classes to forest classes and positive changes within forest classes).

At the pan-tropical level, deforestation in undisturbed forests was prevalent and evenly distributed between large- and small-scale conversions to agriculture. Regional variations in change processes are summarized as follows (Figure 13).

- **Africa.** The major process of deforestation was due to the conversion of forest for the establishment of small-scale permanent agriculture.
- **Latin America.** Deforestation due to conversion to large-scale permanent agriculture was the predominant process.
- **Asia.** The major process was the direct conversion of forest to large-scale agriculture, with other processes contributing substantially to deforestation as well.

3.5. Comparison with FRA 2000 statistics from countries

FRA 2000 included a separate assessment of forest state and change using existing information from countries. The results of the two studies were compared to analyse the relationships between the two and to find ways of using the two data sets together to obtain an integrated estimate at the worldwide level.

It was observed that the two assessment components differed in several respects (resolution, definitions, geographic coverage, measurement techniques, and currency of information). Variations between the two information sets could contribute to differences in the respective estimates; consequently a direct comparison between the two was impossible. However, because the remote sensing survey was conducted under relatively controlled conditions, using a consistent method among all subregions and regions, and employed the application of statistical sampling, it was used as a calibration tool at the regional level to improve some of the overall findings for the tropics.

Comparisons between the country-based findings and the remote sensing survey estimates were limited to the 73 countries that were covered by the remote sensing survey. Sixty of these countries were covered by at least a part of one sampling unit (Table 10). Only results at the subregional, regional and pan-tropical levels were examined (as the remote sensing survey was not used for generating national level results) using the f2 definition of forests (since it corresponds most closely to the definition used for the country statistical data).

Forest area estimates from the remote sensing survey were in general lower than estimates from the country data in the tropics, throughout the regions, and in most subregions. Nevertheless, there is a good correlation between the country data and the remote sensing estimates, observable at the subregional and regional levels (Figure 14).

The forest area change estimates from the two information sets were comparable for Asia and Latin America. However, the data for Africa were not comparable and consequently the correlation at the pan-tropical level was also low. The subregions contributing most to the disparity of the two data sets were East Africa and southern Africa. The disparity could be attributed primarily to two causes.

- **Seasonality and ecological conditions.** In dry areas, difficulties are commonly encountered in the use of satellite imagery to classify and interpret vegetation and to detect change. Leaf cover in such forests is low, exception during the short rainy season.

When leaves are green the forests show up well in the imagery, but when they are absent it is difficult to detect and interpret the vegetation.

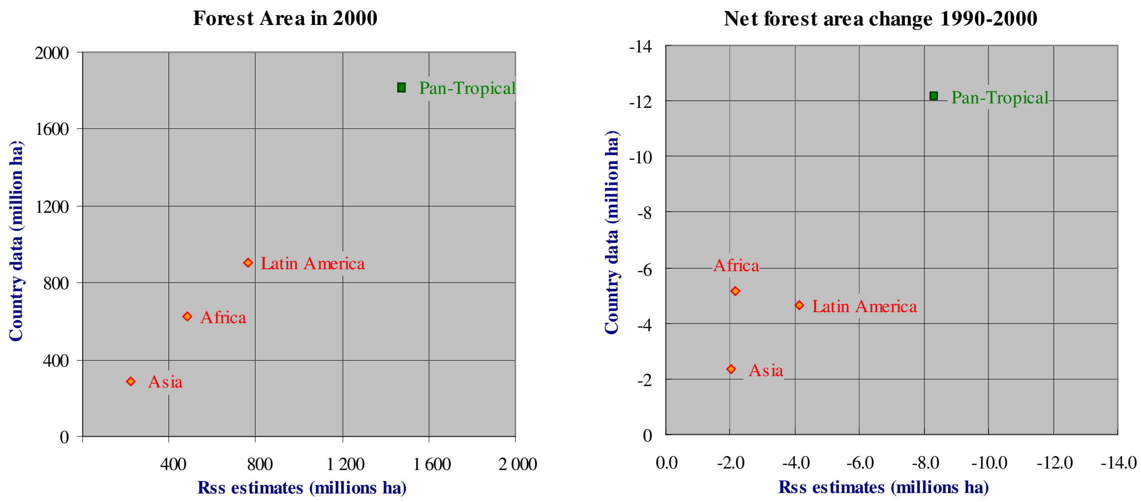
- **Inconsistencies in specific countries.** Country data from a few countries – the People's Democratic Republic of the Congo, the Sudan and Zambia – contributed to the high deforestation rate in Africa. Deforestation rates for the sampling units in the Sudan and Zambia were much lower than those calculated from the country data. This is not unexpected, as sampling units were not designed to provide representative national statistics and may have been located in areas that had lower deforestation rates within the countries. It is also possible that the country data from the Sudan and Zambia overestimated deforestation. For example, the baseline data for Zambia were from 1978, and the data for the Sudan from 1990 covered only one-third (the gum belt) of the country. Moreover, the change estimates were based on expert opinion or on estimates from surrounding countries owing to the absence of comparable time series of information for both countries.

Table 10. Comparison forest area and forest area change estimates from the Remote Sensing Survey with country data

	Forest Area 2000 *(million ha)*			Annual net forest area change *(million ha/year)*			Annual deforestation rate *(%/year)*		
	Country data	**Remote sensing Survey**	**Significant difference**	**Country data**	**Remote sensing survey**	**Significant difference**	**Country data**	**Remote sensing Survey**	**Significant difference**
Africa	622	484	**	-5.2	-2.2	***	0.77	0.43	***
Asia	289	224	**	-2.4	-2.0	n.s.	0.78	0.84	n.s.
Latin America	892	767	**	-4.4	-4.1	n.s	0.45	0.51	n.s.
Pan-tropical	1 803	1 475	***	-12.0	-8.3	**	0.62	0.54	n.s.

*Notes: Only the results from the countries included in the remote sensing survey were compiled to obtain the country data given in the table. The remote sensing estimates refer to the F2 definition of forest.The hypothesis tested in the table is that the country data value is the true value of the sampled population of the remote sensing survey. The level of significance of the difference between country data and remote sensing estimates: *** = 0.01 percent level of significance, ** = 1 percent level of significance, * = 5 percent level of significance, n.s = not significant at the 5 percent level.*

Figure 14. Forest area in 2000 (left) and net forest area change (right) - comparison between country data and remote sensing survey estimates (million hectares)



Conclusions

The remote sensing fulfilled its objectives by providing a detailed set of information describing the state and change of tropical forest at different aggregation levels for the periods 1980-1990 and 1990-2000. One major accomplishment of the survey was to produce a comparable set of information on forest change in the tropics spanning two decades.

In precision the results are consistent with the FRA 1990 findings, and correspond with expected levels. Improvements in future designs could increase the precision of the forest area change estimates and the comparison between two periods.

In the current survey are as follows the net forest area change was estimated at -8.6 million hectares annually for the 1990-2000 period. No significant difference in deforestation could be identified between the two periods at the pan-tropical or regional levels, although the decrease in the rate of deforestation in the 1990s in tropical moist deciduous forests was significantly less than in the period 1980-1990. The survey revealed that the main deforestation process was the direct conversion of forests to permanent agriculture and the comparison with FRA 2000 country data showed a high and statistically significant difference in the forest area change estimates for Africa for the period 1990-2000.

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Appendix. Area transition matrices and net changes by land cover classes at pan-tropical and regional levels – Tables and figures

Table 11. Area transition matrices for the periods 1980-1990 and 1990-2000 at pan-tropical level (million ha)

Area transition matrix 1980-1990

(million ha)

Land cover classes in 1980	Closed canopy forest	Open canopy forest	Long fallow	Fragmented forest	Shrubs	Short fallow	Other land cover	Water	Plantations	State 1980	*% of total land area*
	Land cover classes in 1990										
Closed canopy forest	1 200.4	6.3	9.5	11.3	1.7	15.1	35.5	2.1	2.7	**1 284.6**	*41.9*
Open canopy forest	0.7	295.9	0.6	5.9	1.3	2.3	10.0	0.6	0.2	**317.4**	*10.3*
Long fallow	1.1	0.1	62.3	0.3	0.3	6.8	2.2	0.1	ε	**73.0**	*2.4*
Fragmented forest	0.7	0.8	0.2	197.5	0.8	3.9	14.8	0.4	0.2	**219.4**	*7.2*
Shrubs	0.2	0.1	0.2	0.1	149.9	0.3	19.2	0.6	0.3	**170.9**	*5.6*
Short fallow	1.1	0.4	1.3	0.7	0.3	109.2	7.2	0.2	0.2	**120.5**	*3.9*
Other land cover	0.8	1.0	0.3	1.6	1.6	1.2	853.6	1.4	0.9	**862.2**	*28.1*
Water	0.1	0.1	ε	0.1	ε	0.1	1.0	2.5	ε	**4.0**	*0.1*
Plantations	0.1	ε	ε	ε	ε	0.2	0.9	ε	14.8	**16.1**	*0.5*
State 1990 →	**1 205.1**	**304.5**	**74.4**	**217.5**	**155.9**	**139.0**	**944.4**	**7.8**	**19.3**	**3 068**	
% of total land area →	*39.3*	*9.9*	*2.4*	*7.1*	*5.1*	*4.5*	*30.8*	*0.3*	*0.6*		

Area transition matrix 1990-2000

(million ha)

Land cover classes in 1990	Closed canopy forest	Open canopy forest	Long fallow	Fragmented forest	Shrubs	Short fallow	Other land cover	Water	Plantations	State 1990	*% of total land area*
	Land cover classes in 2000										
Closed canopy forest	1131.6	1.2	5.7	9.4	1.3	9.8	43.1	1.1	1.9	**1 205.1**	*39.3*
Open canopy forest	0.2	287.3	0.5	6.8	0.7	2.2	6.6	0.1	ε	**304.5**	*9.9*
Long fallow	1.1	0.1	63.2	0.2	ε	4.8	4.7	ε	0.2	**74.4**	*2.4*
Fragmented forest	0.5	0.4	0.2	202.1	0.5	2.2	11.2	0.1	0.2	**217.5**	*7.1*
Shrubs	0.1	0.1	ε	0.1	143.5	0.6	9.7	1.8	0.1	**155.9**	*5.1*
Short fallow	1.0	0.3	1.2	1.5	0.2	122.7	11.6	0.2	0.4	**139.0**	*4.5*
Other land cover	0.6	0.5	0.5	2.3	3.7	4.9	928.4	1.3	2.3	**944.4**	*30.8*
Water	0.2	ε	ε	ε	0.8	ε	1.2	5.6		**7.8**	*0.3*
Plantations	ε			ε	ε	ε	1.1		18.0	**19.3**	*0.6*
State 2000 →	**1 135.2**	**290.0**	**71.5**	**222.5**	**150.6**	**147.3**	**1 017.6**	**10.2**	**23.2**	**3 068**	
% of total land area →	*37.0*	*9.5*	*2.3*	*7.3*	*4.9*	*4.8*	*33.2*	*0.3*	*0.8*		

Notes: See Table 4. The symbol ε indicates values below the displayed decimal point. The matrices are based on the common visible area between all the images of the three date time-series. Stable water was excluded from the matrices. For the comparison between periods see section 3.3.

Figure 15. Summary of net changes during the periods 1980-1990 and 1990-2000 by land cover classes at pan-tropical level (million ha)

(million ha)	**1980-1990**	**1990-2000**
Closed canopy forest	- 79.5	- 69.9
Open canopy forest	- 12.9	- 14.6
Long fallow	1.4	- 2.9
Fragmented forest	- 1.9	5.0
Shrubs	- 15.0	- 5.3
Short fallow	18.6	8.2
Other land cover	82.2	73.2
Water	3.8	2.4
Plantations	3.2	3.9

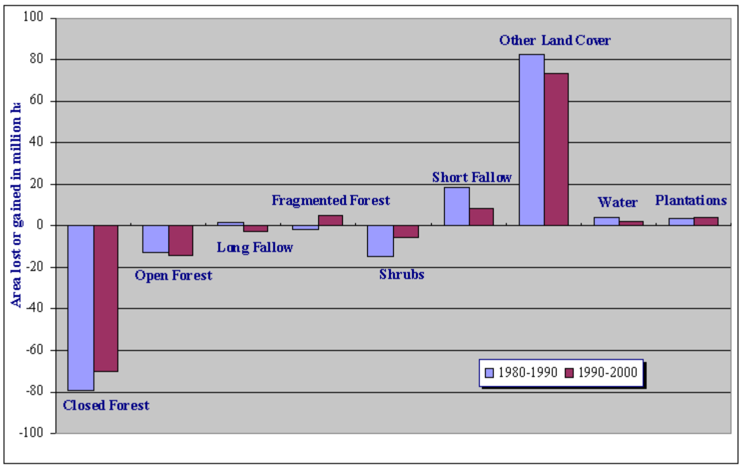

Table 12. Analysis of change for the periods 1980-1990 and 1990-2000 at pan-tropical level (percentages of the total area change)

Period 1: 1980-1990

% of total change

Land cover classes in 1980	Land cover classes in 1990: Closed canopy forest	Open canopy forest	Long fallow	Fragmented forest	Shrubs	Short fallow	Other land cover	Water	Plantations	Total change by class of origin: ha	%
Closed canopy forest		3.4	5.2	6.2	0.9	8.3	19.5	1.2	1.5	**84.2**	*46.3*
Open canopy forest	0.4		0.3	3.3	0.7	1.3	5.5	0.3	0.1	**21.5**	*11.8*
Long fallow	0.6	ε		0.1	0.1	3.7	1.2	ε	ε	**10.7**	*5.8*
Fragmented forest	0.4	0.4	0.1		0.4	2.2	8.1	0.2	0.1	**21.9**	*12.0*
Shrubs	0.1	ε	0.1	0.1		0.2	10.6	0.3	0.1	**21.0**	*11.5*
Short fallow	0.6	0.2	0.7	0.4	0.2		4.0	0.1	0.1	**11.3**	*6.2*
Other land cover	0.4	0.5	0.2	0.9	0.9	0.7		0.8	0.5	**8.7**	*4.8*
Water	0.1	ε	ε	ε	ε	ε	0.6		ε	**1.4**	*0.6*
Plantations	0.1	ε	ε	ε	ε	0.1	0.5	ε		**1.3**	*0.7*
Total change by class of destination ha	**4.7**	**8.7**	**12.2**	**19.9**	**6.0**	**29.9**	**90.9**	**5.3**	**4.5**	**181.9**	
%	*2.6*	*4.6*	*6.7*	*10.9*	*3.3*	*16.4*	*49.9*	*2.9*	*2.4*		*100*

Period 2: 1990-2000

% of total change

Land cover classes in 1990	Land cover classes in 2000: Closed canopy forest	Open canopy forest	Long fallow	Fragmented forest	Shrubs	Short fallow	Other land cover	Water	Plantations	Total change by class of origin: ha	%
Closed canopy forest		0.7	3.5	5.7	0.8	5.9	26.0	0.7	1.1	**73.6**	*44.4*
Open canopy forest	0.1		0.3	4.1	0.4	1.3	4.0	ε	ε	**17.2**	*10.3*
Long fallow	0.6	0.1		0.1	ε	2.9	2.8	ε	0.1	**11.2**	*6.7*
Fragmented forest	0.3	0.3	0.2		0.3	1.3	6.7	0.1	0.1	**15.3**	*9.3*
Shrubs	0.1	ε	ε	ε		0.3	5.9	1.1	ε	**12.4**	*7.4*
Short fallow	0.6	0.2	0.8	0.9	0.1		7.0	0.1	0.2	**16.3**	*9.9*
Other land cover	0.4	0.3	0.3	1.4	2.2	3.0		0.8	1.4	**16.0**	*9.7*
Water	0.1	ε	ε	ε	0.5	ε	0.7			**2.2**	*1.3*
Plantations	ε			ε	ε	ε	0.7			**1.2**	*0.7*
Total change by class of destination ha	**3.7**	**2.6**	**8.3**	**20.3**	**7.1**	**24.5**	**89.3**	**4.6**	**5.1**	**165.5**	
%	*2.2*	*1.5*	*5.0*	*12.2*	*4.3*	*14.8*	*53.9*	*2.7*	*3.0*		*100*

Notes: The elements of the above matrices represent the transition as percentages of the total area that underwent change (sum of all values of the area transition matrices above and below the diagonal). The row totals give the area and the percentage of total change by class of origin; the column totals give the area and percentages by class of destination.

Table 13. Area transition matrices for the periods 1980-1990 and 1990-2000 in Africa (million ha)

Area transition matrix 1980-1990

(million ha)

Land cover classes in 1980 \ Land cover classes in 1990	Closed canopy forest	Open canopy forest	Long fallow	Fragmented forest	Shrubs	Short fallow	Other land cover	Water	Plantations	State 1980	*% of total land area*
Closed canopy forest	273.9	2.7	0.9	4.6	0.1	7.2	2.5	ε	0.1	**292.0**	*23.9*
Open canopy forest	0.2	192.7	0.3	5.2	0.1	1.6	4.7	ε	ε	**204.9**	*16.7*
Long fallow	0.1	ε	15.8	0.2	ε	0.8	0.3			**17.2**	*1.4*
Fragmented forest	0.5	0.6	0.1	136.5	0.2	2.2	5.8	ε	ε	**145.8**	*11.9*
Shrubs	ε	ε	ε	0.1	44.2	0.2	1.2		ε	**45.8**	*3.7*
Short fallow	0.5	0.2	0.1	0.5	0.1	58.2	1.6	ε	0.1	**61.3**	*5.0*
Other land cover	0.3	0.7	ε	1.2	0.3	0.4	452.2	0.2	0.2	**455.5**	*37.2*
Water	ε	ε		ε	ε	0.1	0.4	0.1		**0.6**	*0.1*
Plantations	ε					ε	ε		0.8	**0.9**	*0.1*
State 1990 →	**275.6**	**197.0**	**17.2**	**148.2**	**44.9**	**70.7**	**468.7**	**0.4**	**1.3**	**1 224**	
% of total land area →	*22.5*	*16.1*	*1.4*	*12.1*	*3.7*	*5.8*	*38.3*	*0.0*	*0.1*		

Area transition matrix 1990-2000

(million ha)

Land cover classes in 1990 \ Land cover classes in 2000	Closed canopy forest	Open canopy forest	Long fallow	Fragmented forest	Shrubs	Short fallow	Other land cover	Water	Plantations	State 1990	*% of total land area*
Closed canopy forest	261.4	0.6	0.7	5.7	ε	5.0	2.0	ε	0.1	**275.6**	*22.5*
Open canopy forest	ε	186.1	0.2	5.8	0.1	1.8	2.9	ε	ε	**197.0**	*16.1*
Long fallow	ε	0.1	16.3	0.1	ε	0.5	0.2			**17.2**	*1.4*
Fragmented forest	0.2	0.2	ε	139.8	0.1	1.8	6.0	ε	ε	**148.2**	*12.1*
Shrubs	ε	ε	ε	ε	42.9	0.3	1.5		ε	**44.9**	*3.7*
Short fallow	0.8	0.2	0.3	0.9	0.2	65.3	2.9	0.1		**70.7**	*5.8*
Other land cover	0.1	0.2	ε	0.4	0.2	0.4	467.0	0.3	0.1	**468.7**	*38.3*
Water						ε	0.2	0.2		**0.4**	*0.0*
Plantations	ε			ε		ε	0.1		1.2	**1.3**	*0.1*
State 2000 →	**262.6**	**187.4**	**17.6**	**152.8**	**43.5**	**75.1**	**483.0**	**0.6**	**1.4**	**1 224**	
% of total land area →	*21.5*	*15.3*	*1.4*	*12.5*	*3.6*	*6.1*	*39.5*	*0.0*	*0.1*		

Notes: See notes Table 11

Figure 16. Summary of net changes during the periods 1980-1990 and 1990-2000 by land cover classes in Africa (million ha)

(million ha)	1980-1990	1990-2000
Closed canopy forest	- 16.5	- 13.0
Open canopy forest	- 7.9	- 9.6
Long fallow	0.1	0.3
Fragmented forest	2.4	4.7
Shrubs	- 0.9	- 1.4
Short fallow	9.4	4.4
Other land cover	13.2	14.3
Water	- 0.3	0.2
Plantations	0.5	0.1

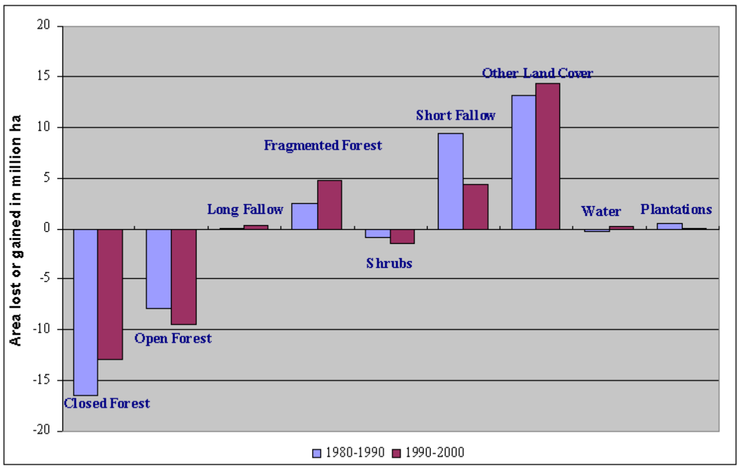

Table 14. Analysis of change for the periods 1980-1990 and 1990-2000 in Africa (percentage of total change)

Period 1: 1980-1990

% of total change

Land cover classes in 1980		Land cover classes in 1990: Closed canopy forest	Open canopy forest	Long fallow	Fragmented forest	Shrubs	Short fallow	Other land cover	Water	Plantations	Total change by class of origin: ha	%
Closed canopy forest			5.4	1.8	9.3	0.2	14.5	5.1	0.1	0.2	18.2	36.5
Open canopy forest		0.5		0.6	10.5	0.1	3.2	9.5	ε	0.1	12.2	24.6
Long fallow		0.2	ε		0.4	0.1	1.6	0.5			1.4	2.7
Fragmented forest		0.9	1.3	0.2		0.4	4.4	11.6	ε	ε	9.3	18.7
Shrubs		0.1	ε	ε	0.1		0.5	2.5		0.1	1.6	3.2
Short fallow		1.0	0.5	0.3	1.0	0.1		3.2	0.1	0.1	3.1	6.2
Other land cover		0.7	1.5	0.1	2.3	0.5	0.8		0.3	0.5	3.4	6.7
Water		0.1	0.1		ε	ε	0.1	0.7			0.5	1.0
Plantations		ε					ε	0.1			0.1	0.1
Total change by	ha	**1.7**	**4.3**	**1.4**	**11.7**	**0.7**	**12.5**	**16.5**	**0.2**	**0.5**	**49.7**	
class of destination	%	*3.4*	*8.7*	*2.9*	*23.6*	*1.4*	*25.1*	*33.3*	*0.5*	*1.1*		*100*

Period 2: 1990-2000

% of total change

Land cover classes in 1990		Land cover classes in 2000: Closed canopy forest	Open canopy forest	Long fallow	Fragmented forest	Shrubs	Short fallow	Other land cover	Water	Plantations	Total change by class of origin: ha	%
Closed canopy forest			1.4	1.6	12.9	0.1	11.4	4.6	0.1	0.2	14.1	32.2
Open canopy forest		0.1		0.5	13.3	0.3	4.0	6.6	ε	ε	11.0	24.9
Long fallow		0.1	0.1		0.3	ε	1.2	0.5			1.0	2.2
Fragmented forest		0.4	0.5	0.1		0.1	4.2	13.7	ε	ε	8.4	19.0
Shrubs		0.1	ε	ε	0.1		0.7	3.5		0.1	2.0	4.5
Short fallow		1.8	0.5	0.7	2.2	0.4		6.7	0.1		5.4	12.3
Other land cover		0.2	0.5	0.1	0.9	0.4	0.9		0.7	0.2	1.7	3.9
Water							ε	0.5			0.2	0.5
Plantations		ε			ε		ε	0.3			0.2	0.3
Total change by	ha	**1.2**	**1.4**	**1.3**	**13.1**	**0.6**	**9.8**	**15.9**	**0.4**	**0.2**	**43.9**	
class of destination	%	*2.6*	*3.1*	*3.0*	*29.7*	*1.3*	*22.3*	*36.3*	*0.9*	*0.5*		*100*

Notes: See notes Table 12.

Table 15. Area transition matrices for the periods 1980-1990 and 1990-2000 in Asia (million ha)

Area transition matrix 1980-1990

(million ha)

Land cover classes in 1980 \ Land cover classes in 1990	Closed canopy forest	Open canopy forest	Long fallow	Fragmented forest	Shrubs	Short fallow	Other Land Cover	Water	Plantations	State 1980	*% of total land area*
Closed canopy forest	210.8	1.8	5.4	1.2	0.3	4.4	7.4	0.4	2.5	**234.3**	*38.4*
Open canopy forest	0.3	24.6	0.1	0.2	0.3	0.1	1.0	0.1	0.1	**26.8**	*4.4*
Long fallow	0.8	ε	42.4	0.1	0.2	5.5	1.9	0.1	ε	**50.9**	*8.3*
Fragmented forest	0.1	0.1	0.1	17.1	0.4	0.2	2.1	ε	0.1	**20.1**	*3.3*
Shrubs	0.1	0.1	0.1	0.1	8.0	ε	1.2	ε	0.1	**9.6**	*1.6*
Short fallow	0.5	0.1	1.0	0.1	0.2	38.4	3.8	ε	0.1	**44.3**	*7.3*
Other land cover	0.2	0.2	0.2	0.2	0.3	0.1	208.1	0.3	0.4	**210.0**	*34.4*
Water	ε	ε		ε	ε		0.1	0.5	ε	**0.7**	*0.1*
Plantations	0.1	ε	ε	ε	ε	0.1	0.8	ε	12.7	**13.8**	*2.3*
State 1990 →	**213.0**	**26.8**	**49.3**	**19.0**	**9.7**	**49.0**	**226.3**	**1.4**	**16.0**	**611**	
% of total land area →	*34.9*	*4.4*	*8.1*	*3.1*	*1.6*	*8.0*	*37.1*	*0.2*	*2.6*		

Area transition matrix 1990-2000

(million ha)

Land cover classes in 1990 \ Land cover classes in 2000	Closed canopy forest	Open canopy forest	Long fallow	Fragmented forest	Shrubs	Short fallow	Other Land Cover	Water	Plantations	State 1990	*% of total land area*
Closed canopy forest	193.0	0.4	3.6	0.7	0.1	3.2	9.4	0.7	1.8	**213.0**	*34.9*
Open canopy forest	0.2	24.7	0.2	0.2	0.2	0.3	1.1	ε	ε	**26.8**	*4.4*
Long fallow	0.5	ε	41.7	ε	ε	3.9	2.8	ε	0.2	**49.3**	*8.1*
Fragmented forest	0.1	ε	0.2	16.8	0.2	0.2	1.3	ε	0.1	**19.0**	*3.1*
Shrubs	ε	ε	ε	ε	8.6	0.2	0.8	ε	ε	**9.7**	*1.6*
Short fallow	0.1	ε	0.7	ε	ε	41.3	6.3	0.1	0.4	**49.0**	*8.0*
Other land cover	0.2	0.2	0.2	0.4	0.2	0.3	222.7	0.3	2.0	**226.3**	*37.1*
Water	ε			ε	ε		0.1	1.2		**1.4**	*0.2*
Plantations	ε			ε		ε	0.7		15.3	**16.0**	*2.6*
State 2000 →	**194.2**	**25.3**	**46.6**	**18.3**	**9.3**	**49.5**	**245.1**	**2.5**	**19.8**	**611**	
% of total land area →	*31.8*	*4.2*	*7.6*	*3.0*	*1.5*	*8.1*	*40.1*	*0.4*	*3.2*		

Notes: See notes Table 11.

Figure 17. Summary of net changes during the periods 1980-1990 and 1990-2000 by land cover classes in Asia (million ha).

(million ha)	**1980-1990**	**1990-2000**
Closed canopy forest	- 21.3	- 18.8
Open canopy forest	0.0	- 1.5
Long fallow	- 1.6	- 2.7
Fragmented forest	- 1.2	- 0.7
Shrubs	0.2	- 0.4
Short fallow	4.7	0.5
Other land cover	16.3	18.8
Water	0.7	1.1
Plantations	2.2	3.8

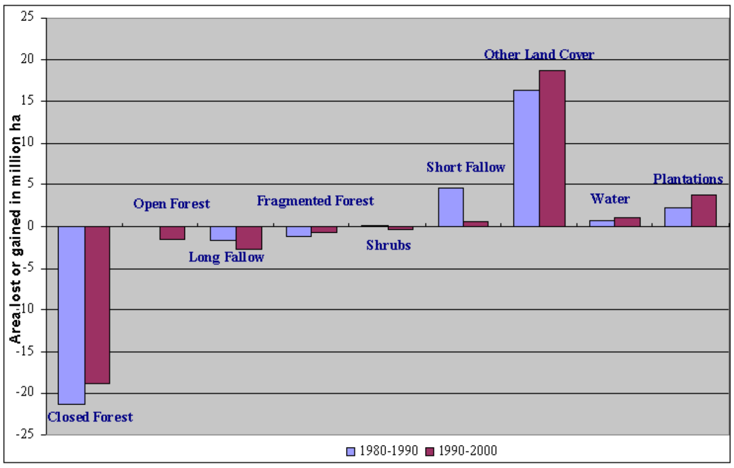

Table 16. Analysis of change for the periods 1980-1990 and 1990-2000 in Asia (percentage of total change)

Period 1: 1980-1990

% of total change

Land cover classes in 1980	Land cover classes in 1990: Closed canopy forest	Open canopy forest	Long fallow	Fragmented forest	Shrubs	Short fallow	Other Land Cover	Water	Plantations	Total change by class of origin: ha	%
Closed canopy forest		3.7	11.2	2.6	0.6	9.3	15.5	0.8	5.3	**23.4**	*48.9*
Open canopy forest	0.6		0.3	0.4	0.6	0.2	2.2	0.1	0.1	**2.2**	*4.7*
Long fallow	1.8	ε		0.1	0.4	11.5	3.9	0.1	ε	**8.6**	*17.8*
Fragmented forest	0.2	0.2	0.3		0.7	0.4	4.3	0.1	0.2	**3.1**	*6.4*
Shrubs	0.1	0.1	0.1	0.1		ε	2.4	0.1	0.1	**1.5**	*3.2*
Short fallow	1.0	0.1	2.1	0.2	0.5		7.9	0.1	0.2	**5.8**	*12.2*
Other land cover	0.4	0.5	0.5	0.4	0.7	0.2		0.6	0.8	**1.9**	*4.0*
Water	0.1	ε		ε	ε		0.2		ε	**0.2**	*0.3*
Plantations	0.2	ε	ε	ε	ε	0.3	1.7	ε		**1.1**	*2.2*
Total change by class of destination ha	**2.1**	**2.3**	**7.0**	**1.9**	**1.7**	**10.5**	**18.2**	**0.9**	**3.3**	**47.9**	
%	*4.5*	*4.7*	*14.5*	*3.9*	*3.6*	*21.9*	*38.1*	*1.9*	*6.7*		*100*

Period 2: 1990-2000

% of total change

Land cover classes in 1990	Land cover classes in 2000: Closed canopy forest	Open canopy forest	Long fallow	Fragmented forest	Shrubs	Short fallow	Other Land Cover	Water	Plantations	Total change by class of origin: ha	%
Closed canopy forest		0.9	8.0	1.6	0.3	7.0	20.8	1.7	4.0	**19.9**	*44.2*
Open canopy forest	0.4		0.4	0.5	0.4	0.6	2.4	0.1	ε	**2.1**	*4.7*
Long fallow	1.2	ε		0.1	ε	8.7	6.3	0.1	0.5	**7.6**	*16.9*
Fragmented forest	0.2	0.1	0.4		0.5	0.5	2.8	0.1	0.1	**2.1**	*4.7*
Shrubs	0.1	ε	ε	ε		0.5	1.7	0.1	ε	**1.1**	*2.4*
Short fallow	0.3	ε	1.6	0.1	ε		13.9	0.2	0.9	**7.6**	*16.9*
Other land cover	0.3	0.4	0.4	0.8	0.4	0.7		0.7	4.4	**3.7**	*8.1*
Water	ε			ε	ε		0.3			**0.2**	*0.3*
Plantations	0.0			0.0		0.1	1.5			**0.7**	*1.6*
Total change by class of destination ha	**1.1**	**0.6**	**4.9**	**1.4**	**0.7**	**8.1**	**22.4**	**1.3**	**4.5**	**45.1**	
%	*2.4*	*1.4*	*10.8*	*3.1*	*1.6*	*18.1*	*49.7*	*2.8*	*9.9*		*100*

Notes: See notes Table 12.

Table 17. Area transition matrices for the periods 1980-1990 and 1990-2000 in Latin America (million ha)

Area transition matrix 1980-1990

(million ha)

Land cover classes in 1980	Land cover classes in 1990: Closed canopy forest	Open canopy forest	Long fallow	Fragmented forest	Shrubs	Short fallow	Other Land Cover	Water	Plantations	State 1980	*% of total land area*
Closed canopy forest	715.7	1.8	3.3	5.4	1.4	3.4	25.5	1.7	ε	758.3	*61.5*
Open canopy forest	0.1	78.6	0.1	0.5	1.0	0.6	4.2	0.5	0.1	85.7	*6.9*
Long fallow	0.1	ε	4.1	ε	ε	0.5	0.1	ε		4.9	*0.4*
Fragmented forest	0.1	ε	ε	44.0	0.3	1.6	7.0	0.3	0.1	53.5	*4.3*
Shrubs	0.1	ε	0.2	ε	97.7	0.1	16.8	0.5	0.2	115.5	*9.4*
Short fallow	0.1	0.1	0.2	0.1	ε	12.6	1.8	0.1		14.9	*1.2*
Other land cover	0.2	ε	ε	0.2	0.9	0.7	193.3	1.0	0.3	196.7	*15.9*
Water	0.1	ε	ε	0.1	ε	ε	0.6	1.9		2.7	*0.2*
Plantations				ε			0.1		1.3	1.4	*0.1*
State 1990 →	716.6	80.7	7.9	50.3	101.3	19.4	249.3	6.0	1.9	1 234	
% of total land area →	*58.1*	*6.5*	*0.6*	*4.1*	*8.2*	*1.6*	*20.2*	*0.5*	*0.2*		

Area transition matrix 1990-2000

(million ha)

Land cover classes in 1990	Land cover classes in 2000: Closed canopy forest	Open canopy forest	Long fallow	Fragmented forest	Shrubs	Short fallow	Other Land Cover	Water	Plantations	State 1990	*% of total land area*
Closed canopy forest	677.1	0.2	1.4	3.0	1.1	1.7	31.7	0.3	ε	716.6	*58.1*
Open canopy forest	ε	76.6	0.1	0.8	0.3	0.1	2.7	ε	ε	80.7	*6.5*
Long fallow	0.5	0.1	5.3	0.1	ε	0.3	1.6	ε		7.9	*0.6*
Fragmented forest	0.2	0.2	ε	45.5	0.2	0.1	3.9	0.1	0.1	50.3	*4.1*
Shrubs	ε	0.1	ε	ε	92.0	ε	7.4	1.7	ε	101.3	*8.2*
Short fallow	0.1	0.1	0.2	0.5	ε	16.1	2.4	ε		19.4	*1.6*
Other land cover	0.4	0.1	0.3	1.5	3.3	4.2	238.7	0.7	0.2	249.3	*20.2*
Water	0.1	ε	ε	ε	0.8	ε	0.9	4.1		6.0	*0.5*
Plantations				ε	ε		0.3		1.6	1.9	*0.2*
State 2000 →	678.5	77.2	7.4	51.4	97.7	22.7	289.6	7.0	2.0	1 234	
% of total land area →	*55.0*	*6.3*	*0.6*	*4.2*	*7.9*	*1.8*	*23.5*	*0.6*	*0.2*		

Notes: See notes Table 11.

Figure 18. Summary of net changes during the periods 1980-1990 and 1990-2000 by land cover classes in Latin America (million ha)

(million ha)	**1980-1990**	**1990-2000**
Closed canopy forest	- 41.7	- 38.1
Open canopy forest	- 5.0	- 3.5
Long fallow	3.0	- 0.5
Fragmented forest	- 3.1	1.0
Shrubs	- 14.2	- 3.5
Short fallow	4.5	3.3
Other land cover	52.7	40.2
Water	3.4	1.0
Plantations	0.6	0.1

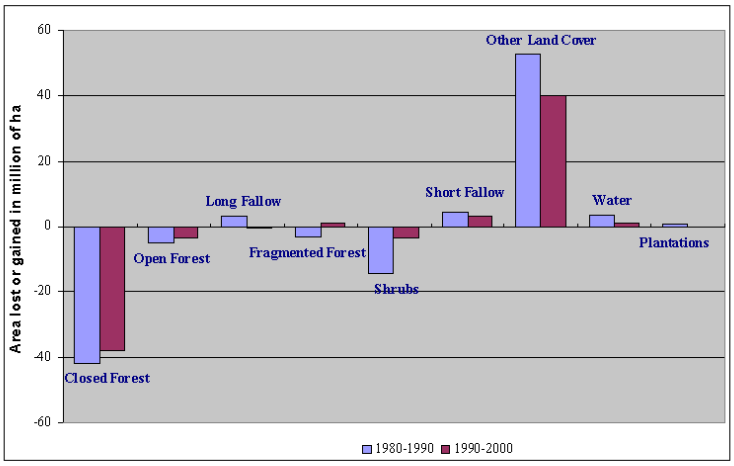

Table 18. Analysis of change for the periods 1980-1990 and 1990-2000 in Latin America (percentage of total change)

Period 1: 1980-1990

% of total change

Land cover classes in 1980		Land cover classes in 1990: Closed canopy forest	Open canopy forest	Long fallow	Fragmented forest	Shrubs	Short fallow	Other Land Cover	Water	Plantations	Total change by class of origin: ha	%
Closed canopy forest			2.2	3.9	6.5	1.6	4.0	30.3	2.0	ε	**42.6**	*50.4*
Open canopy forest		0.1		0.1	0.6	1.1	0.7	5.0	0.6	0.1	**7.1**	*8.4*
Long fallow		0.2	ε		ε	ε	0.6	0.1	ε		**0.8**	*0.9*
Fragmented forest		0.2	0.1	ε		0.3	1.9	8.2	0.4	0.2	**9.5**	*11.2*
Shrubs		0.1	ε	0.2	ε		0.1	19.9	0.6	0.2	**17.8**	*21.1*
Short fallow		0.1	0.1	0.2	0.1	ε		2.2	0.1		**2.3**	*2.8*
Other land cover		0.3	ε	ε	0.3	1.1	0.9		1.1	0.3	**3.4**	*4.0*
Water		0.1	ε	ε	0.1	ε	ε	0.7			**0.8**	*0.8*
Plantations					ε			0.1			**0.1**	*0.1*
Total change by class of destination	ha	**0.9**	**2.0**	**3.8**	**6.3**	**3.6**	**6.9**	**56.1**	**4.1**	**0.7**	**84.3**	
	%	*1.0*	*2.3*	*4.4*	*7.5*	*4.2*	*8.1*	*66.5*	*4.9*	*0.8*		*100*

Period 2: 1990-2000

% of total change

Land cover classes in 1990		Land cover classes in 2000: Closed canopy forest	Open canopy forest	Long fallow	Fragmented forest	Shrubs	Short fallow	Other Land Cover	Water	Plantations	Total change by class of origin: ha	%
Closed canopy forest			0.2	1.8	3.9	1.5	2.2	41.5	0.5	ε	**39.5**	*51.6*
Open canopy forest		ε		0.2	1.0	0.4	0.2	3.5	ε	ε	**4.1**	*5.3*
Long fallow		0.6	0.1		0.1	ε	0.4	2.1	ε		**2.6**	*3.4*
Fragmented forest		0.3	0.2	0.1		0.2	0.2	5.1	0.1	0.2	**4.8**	*6.3*
Shrubs		ε	0.1	ε	ε		ε	9.7	2.3	ε	**9.3**	*12.0*
Short fallow		0.1	0.1	0.3	0.6	ε		3.1	ε		**3.3**	*4.3*
Other land cover		0.5	0.1	0.4	1.9	4.4	5.5		0.9	0.2	**10.7**	*14.0*
Water		0.2	ε	ε	0.1	1.0	0.1	1.1			**1.9**	*2.4*
Plantations					ε	ε		0.4			**0.3**	*0.4*
Total change by class of destination	ha	**1.4**	**0.6**	**2.1**	**5.9**	**5.8**	**6.6**	**50.9**	**2.9**	**0.4**	**76.5**	
	%	*1.8*	*0.7*	*2.7*	*7.7*	*7.5*	*8.5*	*66.5*	*3.7*	*0.4*		*100*

Notes: See notes Table 12.