Forestry Department

Food and Agriculture Organization of the United Nations

FRA 2000

PAN-TROPICAL SURVEY OF FOREST COVER CHANGES 1980-2000

RESULTS AND FINDINGS

Forest Resources Assessment Programme

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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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Table of Contents

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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

4. 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 subregional 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. From them were derived forest area change and forest area change estimates for the reference years and periods. 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.

4.1. Example of 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.

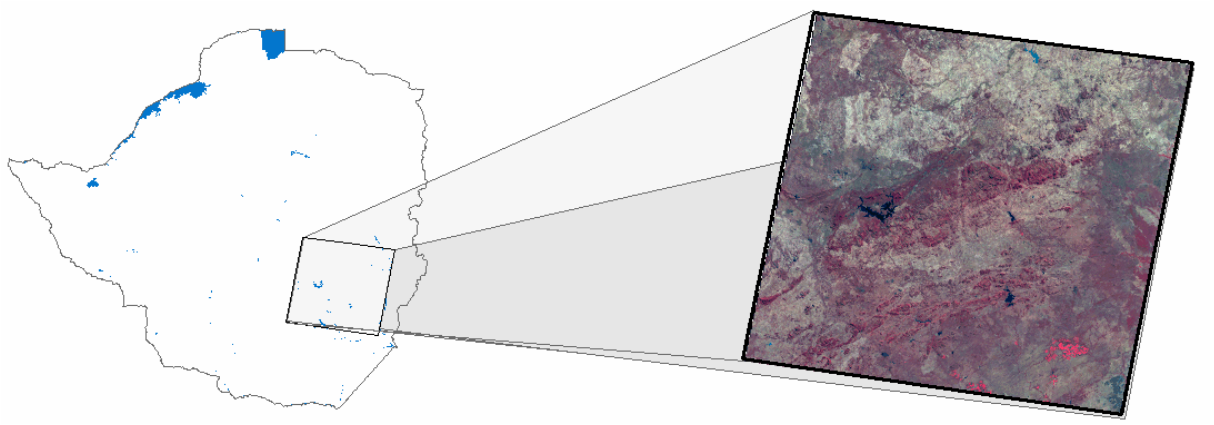
On average the visible area of the T2 image covered 3.1 million ha, which were integrally interpreted. As regards the T1 and T3 images, only the common area with the T2 image was analysed. The size of these common areas varies among the sampling units, mainly due to cloud coverage and shifts in the satellite 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 1). 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 1. Location of the sampling unit 1613 in Zimbabwe and T3 satellite image

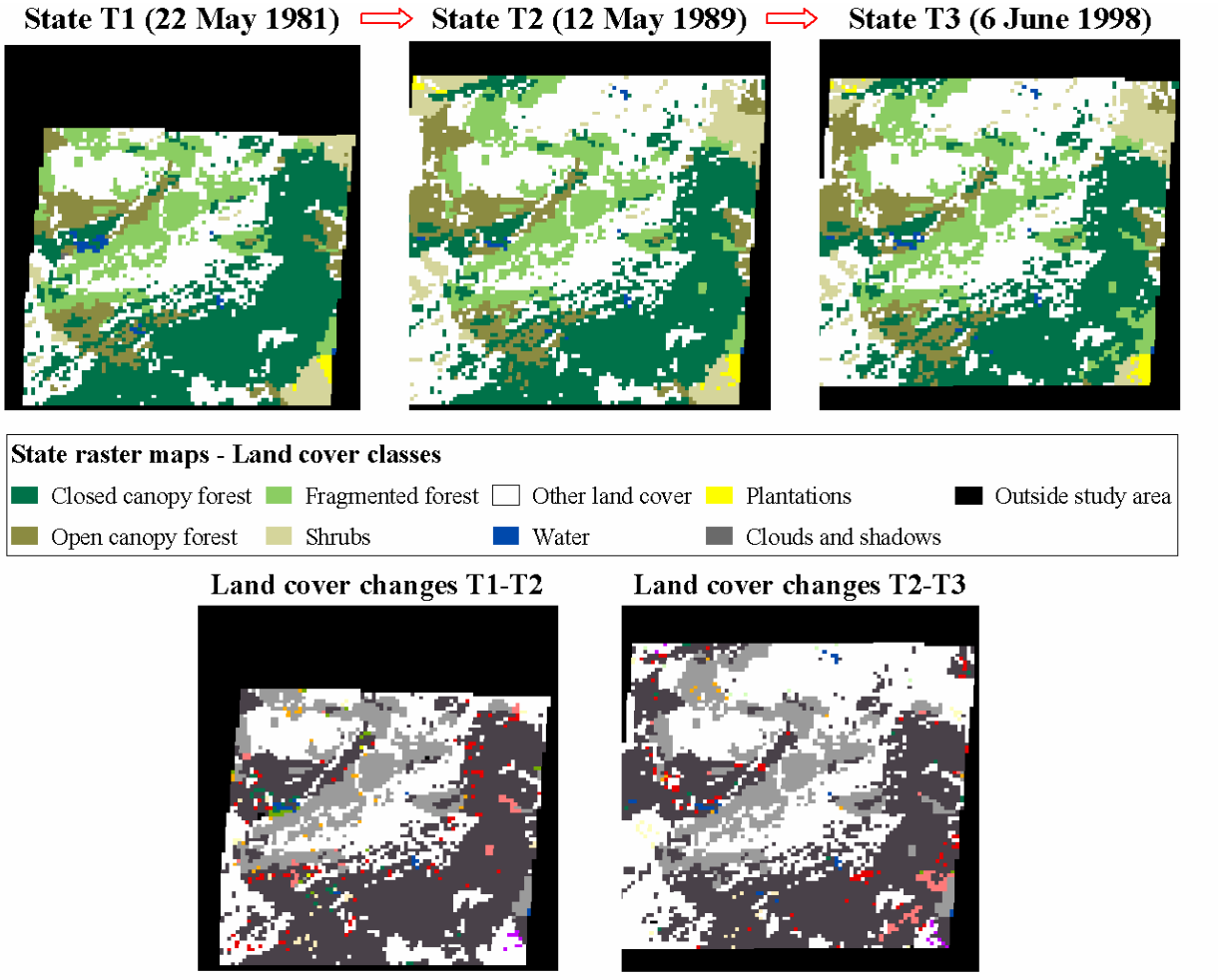


T3 image
Landsat TM 5 Path 169 Row 74
Acquisition date 6 June 1998

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

The *raster* maps shown in the Figure 2 derive 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. The change maps presented are based on the common area between two consecutive images.

Figure 2. Results for a sampling unit (sampling unit code 1613, Zimbabwe). State and change raster maps based on dot grid registrations



4.1.2. Observed transition matrices and states

Transition matrices shown in Table 1 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 1. 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 T1	Land cover classes in 1990: 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 T2	Land cover classes in T3: 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.

Results can also be expressed as relative values, in percentage of the total area where changes were registered in the period (Table 2). The row and column totals give respectively the area changed by classes of origin and destination.

As an example, these matrices show that, in the studied area

- During the first period, the main transition was from the class closed canopy forest to the class other land cover representing 22.8 percent of the total changed area (22 thousand hectares).
- In the second period, this transition decreased to 13.2 thousand while most of the changes (30.3 percent or 21.2 thousand hectares) occurred from the closed canopy forest class to the fragmented forest class. This difference indicates a change in the change processes between the two observed periods.
- During both periods the closed canopy forest class was the most affected by changes (40 percent and 58.3 percent of total change respectively in the periods T1-T2 and T2-T3), while the other land cover class was the most common class of destination

(49.8 percent and 45.7 percent), followed by the fragmented forest class (18.7 percent and 32 percent).

Table 2. Analysis of change for the periods T1-T2 and T2-T3 in the sampling unit 1613, Zimbabwe (percentage of total change)

PERIOD 1: T1-T2 (1981-1989)

% of total change		Land cover classes in T2								Total change by class of origin	
Land cover classes in T1		Closed canopy forest	Open canopy forest	Long fallow	Fragmented forest	Shrubs	Short fallow	Other land cover	Water	Plantations	ha	%
Closed canopy forest			9.1		7.1	0.8		22.8	0.4		**38.8**	*40.2*
Open canopy forest		0.8			10.0			10.8			**20.8**	*21.6*
Long fallow												
Fragmented forest		2.1	5.0					10.8			**17.2**	*17.8*
Shrubs								2.9		2.9	**5.6**	*5.8*
Short fallow												
Other land cover		0.8	4.6		0.8						**6.0**	*6.2*
Water		2.1	2.9		0.8			2.5			**8.0**	*8.3*
Plantations												
Total change by class of destination	ha	**5.6**	**20.8**		**18**	**0.8**		**48**	**0.4**	**2.8**	**96.4**	
	%	*5.8*	*21.6*		*18.7*	*0.8*		*49.8*	*0.4*	*2.9*		*100.0*

PERIOD 2: T2-T3 (1989-1998)

% of total change		Land cover classes in T3								Total change by class of origin	
Land cover classes in T2		Closed canopy forest	Open canopy forest	Long fallow	Fragmented forest	Shrubs	Short fallow	Other land cover	Water	Plantations	ha	%
Closed canopy forest			6.3		30.3	1.1		18.9	1.7		**40.8**	*58.3*
Open canopy forest					0.6			14.3	0.6		**10.8**	*15.4*
Long fallow												
Fragmented forest								5.1	0.6		**4.0**	*5.7*
Shrubs								6.9		4.6	**8.0**	*11.4*
Short fallow												
Other land cover		3.4	1.1		1.1	1.1			1.7		**6.0**	*8.6*
Water												
Plantations								0.6			**0.4**	*0.6*
Total change by class of destination	ha	**2.4**	**5.2**		**22.4**	**1.6**		**32**	**3.2**	**3.2**	**70.0**	
	%	*3.4*	*7.4*		*32.0*	*2.3*		*45.7*	*4.6*	*4.6*		*100.0*

4.1.3. Forest cover and forest cover change estimates

Estimates of forest cover and forest area change were calculated by grouping different land cover classes according to the different definitions of forest adopted (Table 3). The definitions are presented in section 2.2.2.

Table 3. Forest area estimates for the sampling unit 1613 (Zimbabwe), according to different definitions of forest (thousand ha)

	Forest definition **f1**	Forest definition **f2**	Forest definition **f3**
T1	881.2	1 190.6	1 233.5
T2	848.0	1 157.6	1 200.5
T3	809.6	1 117.6	1 162.7

Table 4. Forest area change estimates for the sampling units 1613 (Zimbabwe), for the different forest definition (thousand ha)

		Annual deforestation *(thousand ha/year)*	**Net annual forest area change** *(thousand ha/year)*	**Deforestation rate** *(%/year)*
Forest definition f1	**Period T1-T2**	4.9	- 4.2	0.48
	Period T2-T3	4.5	- 4.2	0.51
Forest definition f2	**Period T1-T2**	6.1	- 4.1	0.35
	Period T2-T3	5.4	- 5.0	0.39
Forest definition f3	**Period T1-T2**	6.0	- 4.1	0.34
	Period T2-T3	5.2	-4.7	0.35

Notes: deforestation represents the gross forest loss (all transitions from forest to non-forest classes according to the selected definition); net forest area change is the net forest gain or loss (transitions from non-forest to forest classes minus deforestation).

4.1.4. 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 3, 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 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	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*		

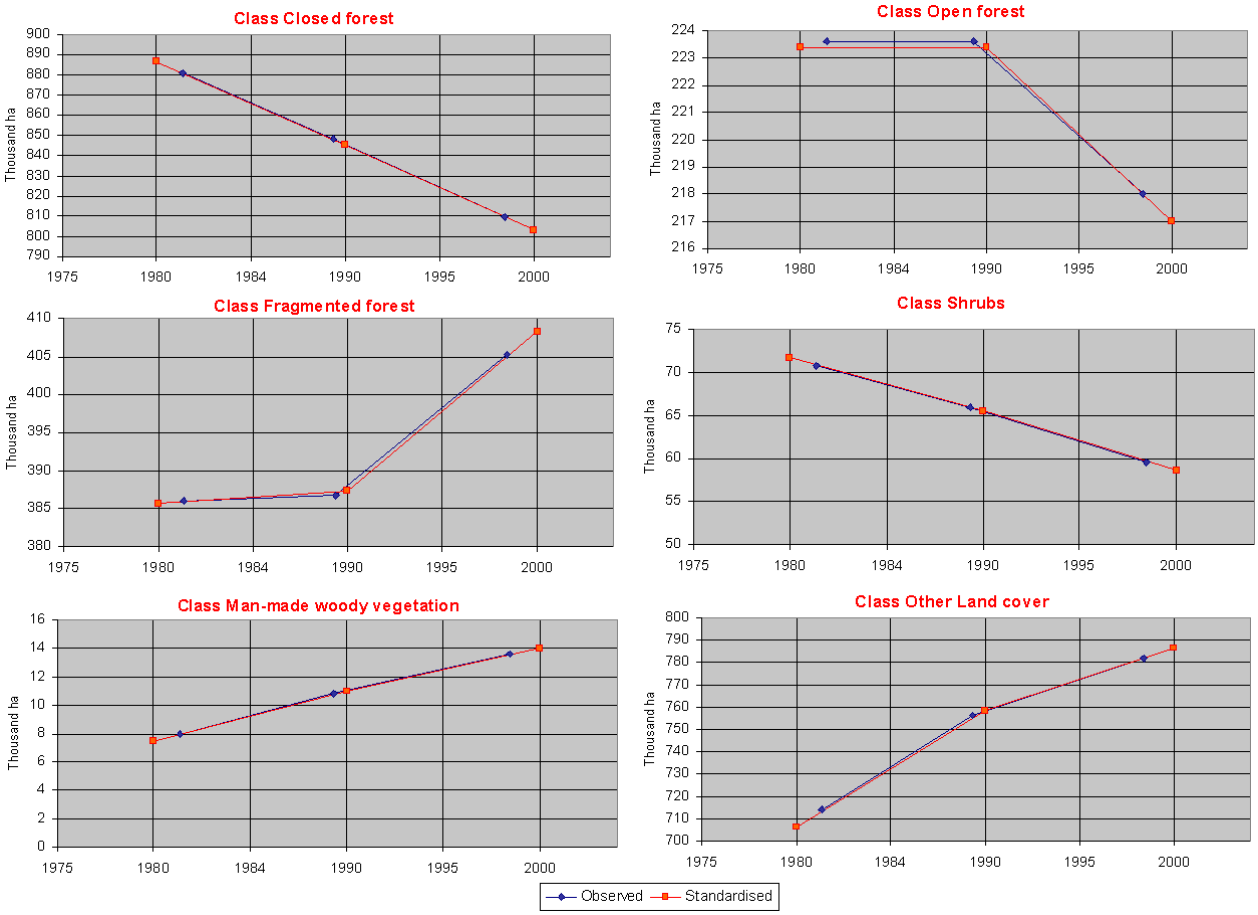
Area transition matrix 1990-2000

(Thousand hectares)

Land cover classes in 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	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 1. The small negative values produced by the mathematical routines, unrealistic, were removed before the aggregation process.

Figure 3. 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.

4.2. 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 (see section 2.5.1 for statistical calculations). 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 confidence intervals of the elements of the matrices were also calculated and are given in Appendix 1.

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

- 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 4.3 where the significance of the differences between the estimates from the two periods is studied.

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

4.2.1.1. 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 (Figure 4 and Table 7): 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 (73 million hectares or 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 6). 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.

4.2.1.2. Regional level

The summaries of net changes by region (Figure 5, Figure 6 and Figure 7) 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 12 and Figure 7), 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 10 and Figure 6), 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 8) 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.

Table 6. 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	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	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	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	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 1. 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 4.3.

Figure 4. 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

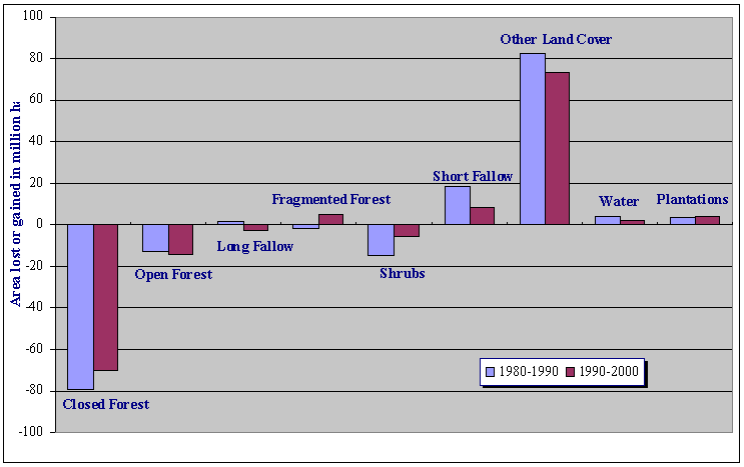


Table 7. Analysis of change for the periods 1980-1990 and 1990-2000 at pan-tropical level (percentages of the total area change)

Period 1: 1980-1990

% of total change

Land cover classes in 1980		Land cover classes in 1990									Total change by class of origin	
		Closed canopy forest	Open canopy forest	Long fallow	Fragmented forest	Shrubs	Short fallow	Other land cover	Water	Plantations	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	ha	**4.7**	**8.7**	**12.2**	**19.9**	**6.0**	**29.9**	**90.9**	**5.3**	**4.5**	**181.9**	
class of destination	%	*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									Total change by class of origin	
		Closed canopy forest	Open canopy forest	Long fallow	Fragmented forest	Shrubs	Short fallow	Other land cover	Water	Plantations	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	ha	**3.7**	**2.6**	**8.3**	**20.3**	**7.1**	**24.5**	**89.3**	**4.6**	**5.1**	**165.5**	
class of destination	%	*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 8. 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 6

Figure 5. 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

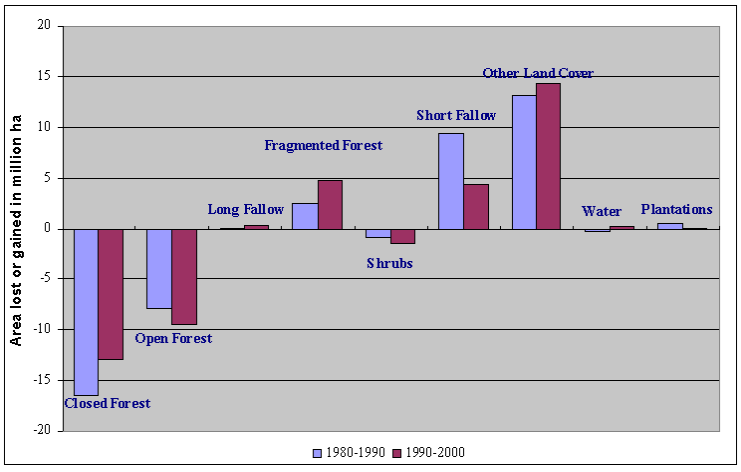


Table 9. Analysis of change for the periods 1980-1990 and 1990-2000 in Africa (percentage of total change)

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 class of destination 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 class of destination 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 7.

Table 10. 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 6.

Figure 6. 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

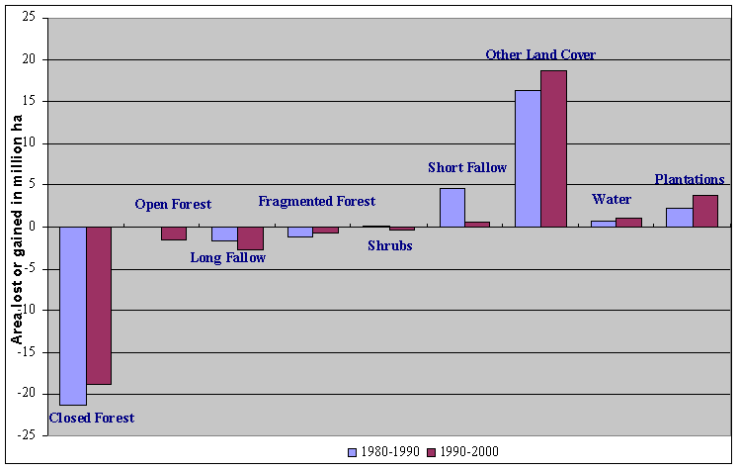


Table 11. Analysis of change for the periods 1980-1990 and 1990-2000 in Asia (percentage of total change)

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 ha	**2.1**	**2.3**	**7.0**	**1.9**	**1.7**	**10.5**	**18.2**	**0.9**	**3.3**	**47.9**	
class of destination %	*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 ha	**1.1**	**0.6**	**4.9**	**1.4**	**0.7**	**8.1**	**22.4**	**1.3**	**4.5**	**45.1**	
class of destination %	*2.4*	*1.4*	*10.8*	*3.1*	*1.6*	*18.1*	*49.7*	*2.8*	*9.9*		*100*

Notes: See notes Table 7.

Table 12. 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 6.

Figure 7. 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

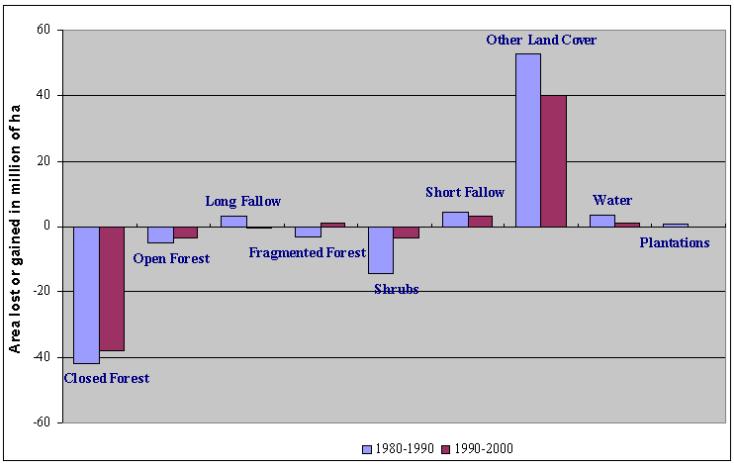


Table 13. Analysis of change for the periods 1980-1990 and 1990-2000 in Latin America (percentage of total change)

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	ha	**0.9**	**2.0**	**3.8**	**6.3**	**3.6**	**6.9**	**56.1**	**4.1**	**0.7**	**84.3**	
class of destination	%	*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	ha	**1.4**	**0.6**	**2.1**	**5.9**	**5.8**	**6.6**	**50.9**	**2.9**	**0.4**	**76.5**	
class of destination	%	*1.8*	*0.7*	*2.7*	*7.7*	*7.5*	*8.5*	*66.5*	*3.7*	*0.4*		*100*

Notes: See notes Table 7.

Area transition matrices at subregional level are also given as an indication in Appendix 3 with the corresponding standard errors. It is indeed important to analyse their contribution in the results at both regional and pan-tropical levels.

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

4.2.2.1. 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 and section 2.5.2 for the formulae).

Table 14 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 14. Estimates of forest area by region and at the pan-tropical level in 2000

	Forest definition f1				Forest definition f2				Forest definition f3			
	Absolute forest area *(million ha)*		Relative forest area *(percent)*		Absolute forest area *(million ha)*		Relative forest area *(percent)*		Relative forest area *(million ha)*		Relative forest area *(percent)*	
	Mean	*SE*	*Mean*	*SE*	*Mean*	*SE*	*Mean*	*SE*	*Mean*	*SE*	*Mean*	*SE*
Africa	263	39	21	3	484	38	40	3	519	37	42	3
Latin America	678	47	55	4	767	49	62	4	780	49	63	4
Asia	194	18	32	3	224	18	37	3	272	23	45	4
Pan-tropical	1135	63	37	2	1475	65	48	2	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 different definitions of forest f1, f2 and f3 (cf. part 1, section 2.2.2). SE=Standard error of the mean.

4.2.2.2. 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 15). 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 15. Annual deforestation and net forest area changes during the period 1990-2000 by region and at pan-tropical level

a) Forest definition f1

	Annual deforestation *(million ha/year)*	Annual net forest area change *(million ha/year)*		Deforestation rate *(percent/year)*	
	Mean	*Mean*	SE	*Mean*	*SE*
Africa	1.4	-1.3	0.4	0.47	0.11
Asia	2.0	-1.9	0.5	0.88	0.03
Latin America	3.9	-3.8	1.0	0.53	0.03
Pan-tropical	7.4	-7.0	1.2	0.58	0.10

b) Forest definition f2

	Annual deforestation *(million ha/year)*	Annual net forest area change *(million ha/year)*		Deforestation rate *(percent/year)*	
	Mean	*Mean*	SE	*Mean*	*SE*
Africa	2.4	-2.2	0.4	0.43	0.07
Asia	2.2	-2.0	0.5	0.84	0.14
Latin America	4.4	-4.1	1.0	0.51	0.04
Pan-tropical	8.9	-8.3	1.2	0.54	0.08

c) Forest definition f3

	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

4.2.3. 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 characteristics of the ecological zones considered in the survey are described in Appendix 6. 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 (Appendix 7). 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 led to relatively high differences with the results at ecological zone level for the period 1980-1990 as reported in FRA 1990 (FAO 1996, pp 61-66).

The calculations of the estimates for ecological zones are explained in the section 2.5.1.4. Detailed results such as transition matrices and corresponding standard errors and confidence intervals, summary of net change by land cover classes by ecological zones are presented in Appendix 8.

The distribution of forests by ecological zones, as given in Figure 8 showed that the surveyed forests are mainly in the tropical rain forest ecological zone. Deforestation estimates by ecological zone (Table 16) show that the forest loss is also concentrated in the rain forest ecological zone.

Figure 8. Distribution of the forest by ecological zone in 2000 (f3 definition)

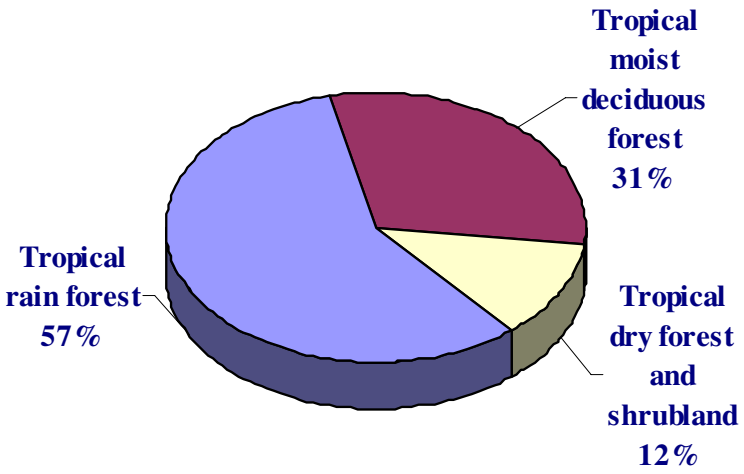


Table 16. Annual deforestation and net forest area change during the period 1990-2000 by ecological zone

	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 shrublands	0.8	-0.7	0.3	0.38	0.13

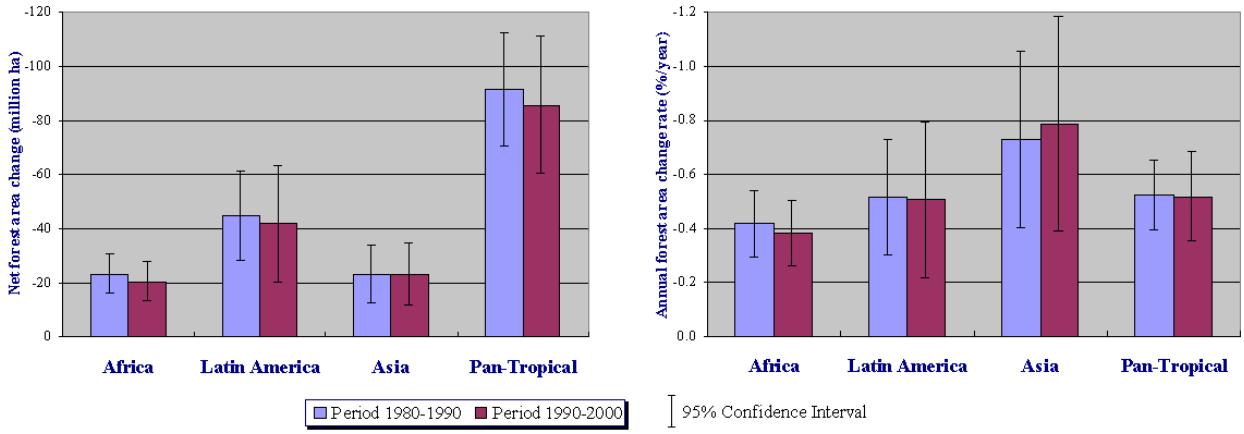
4.3. Trend analysis: comparison of the forest changes 1980-1990 and 1990-2000

4.3.1. 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 (see section 2.5.3).

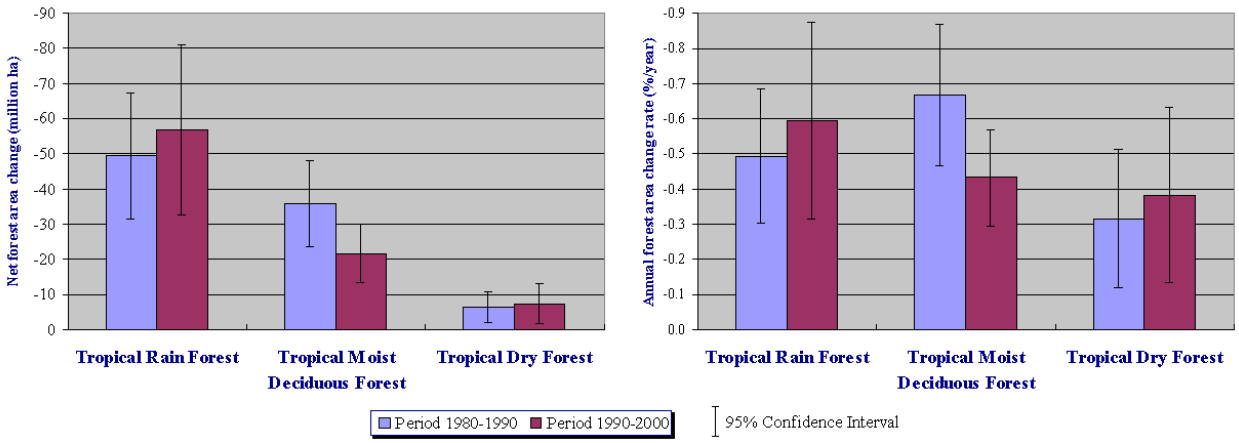
Figure 9 compares the absolute and relative changes of forest area between the two periods, with a 95 percent confidence interval indicated. Results showed that there was no significant difference in the estimates of deforestation at the 5 percent level of significance for the two study periods (1980-1990 and 1990-2000) at either regional or pan-tropical level.

Figure 9. 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 10). For the other ecological zones, differences in the net forest area change and annual deforestation rate was not significant.

Figure 10. 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).



4.3.2. Difference in the transition estimates

The following tables (Table 17 and Table 18) gives by geographical and ecological 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 17. 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 above table. 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.

Table 18. Comparison of the transition probability estimates 1980-1990 with 1990-2000 by ecological zone

	Transitions with significant difference between the periods		Increase/ Decrease
Tropical rain forest	Closed canopy forest	► Open canopy forest	Decrease
	Closed canopy forest	► Short fallow	Decrease
	Closed canopy forest	► Other Land cover	Increase
	Long fallow	► Other Land cover	Increase
	Other land cover	► Plantations	Increase
Tropical moist deciduous forest	Closed canopy forest	► Open canopy forest	Decrease
	Closed canopy forest	► Long fallow	Decrease
	Open canopy forest	► Other Land cover	Decrease
	Short fallow	► Other Land cover	Decrease
	Other land cover	► Shrubs	Increase
Tropical dry forest and shrubland	None above 1 million hectares		

By ecological zone, the comparison between both periods (Table 18) shows that the decrease of the degradation of closed canopy forest into open canopy forest was also significant in all the ecological zones. Less pressure is observable on the forest classes in the Tropical moist deciduous forest ecological zone. At the opposite, direct conversion of the forests into other land cover increased significantly in the Tropical rain forest ecological zone. The changed area covered by the tropical dry forest and shrubland ecological zone was small and most of the transitions where significant difference could be detected are below 1 million ha.

4.4. 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.

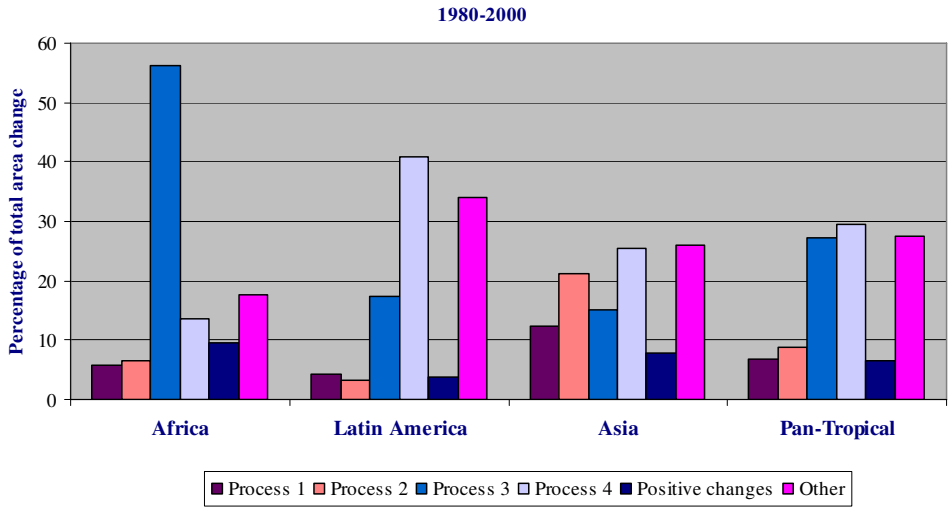
- **Intensification of agriculture in shifting cultivation areas.** This process occurred in forests already impacted by shifting agriculture practices in 1980. It also occurred where shifting cultivation had become more intense (where fallow period decreased) or where a complete transition from shifting 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 11. 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 11).

- ***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.

4.5. Comparison with FRA 2000 country statistics

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 the following respects.

- **Resolution.** The country statistics provided estimates at the national level, while the remote sensing survey was designed to provide information at the pan-tropical and regional levels.

- **Definitions**. The forest definitions used were close but did not correspond exactly between the two approaches. Country statistics were adjusted to a FRA 2000 global forest definition based on both use and cover, while the remote sensing survey used a uniform land cover definition based on photo-interpretation criteria.

- **Geographic coverage.** The areas surveyed were different. While the assessment based on country information was conducted worldwide, the remote sensing survey covered only 63 percent of the land area in the tropics,

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- **Geographic coverage.** The areas surveyed were different. While the assessment based on country information was conducted worldwide, the remote sensing survey covered only 63 percent of the land area in the tropics, representing about 87 percent of the world's tropical forests. Within the land area of the survey, Landsat scenes with less than 10 percent forest were placed into a stratum that was not sampled. Landsat frames with land area of less than 1 million hectares were also not included, whereas information from countries theoretically covered the entire land area.

- **Measurement techniques**. Country statistics were based on a wide range of reference data derived from a number of methods (expert opinion, maps based on satellite

imagery, field surveys and sampling), while the remote sensing survey relied on interpreted satellite imagery and objective statistical sampling.

- **Currency of information.** The remote sensing survey was based on imagery acquired near the reference years 1980, 1990 and 2000 (with some variations), while the average date of the country information from developing countries was 1994, although some of the country data were older or more recent.

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 19). 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 12.

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 19. 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.

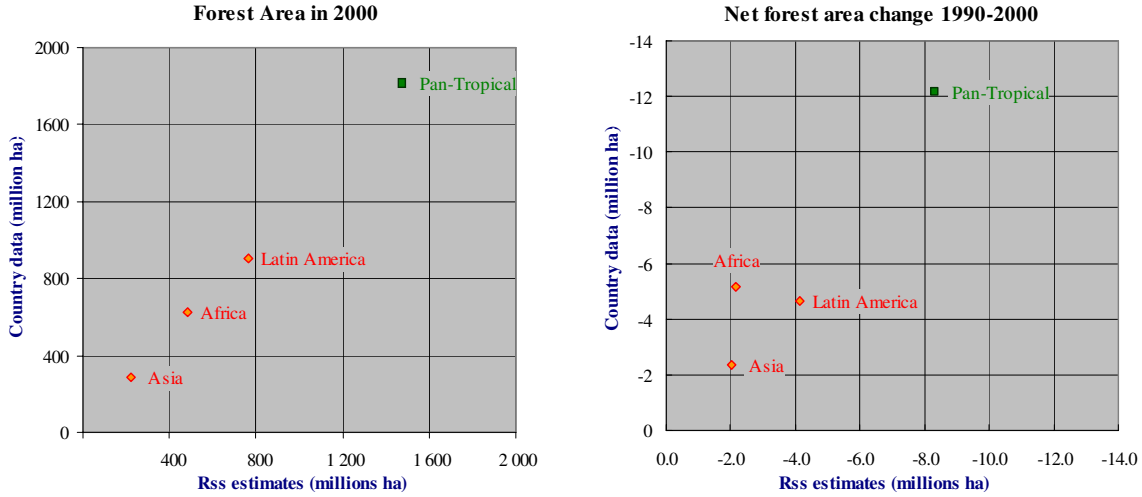
*Notes: Only the results from the countries included in the remote sensing survey were compiled to obtain the country data given in the table. The remote sensing estimates refer to the F2 definition of forest.The hypothesis tested in the table is that the country data value is the true value of the sampled 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.*

Table 20. 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	RSS f2	Significant	RSS f3	Significant	Country data	RSS f2	Significant	RSS f3	Significant	Country data	RSS f2	Significant	RSS f3	Significant
SR 13	97	37	CD H **	39	CD H **	-1.3	-0.2	CD S ***	-0.2	CD S ***	1.16	0.42	CD H **	0.42	CD H **
SR 14	85	61	CD H *	74	n.s.	-1.4	-0.7	CD S *	-0.7	CD S **	1.37	1.06	n.s.	0.85	CD H *
SR 15	228	222	n.s.	229	n.s.	-0.8	-0.5	CD S *	-0.5	CD S *	0.35	0.22	CD H *	0.21	CD H*
SR 16	213	164	CD H **	177	CD H *	-1.7	-0.8	CD S ***	-0.7	CD S ***	0.76	0.44	CD H **	0.40	CD H **
Total surveyed Africa	**622**	**484**	**CD H ****	**519**	**CD H ****	**-5.2**	**-2.2**	**CD S *****	**-2.1**	**CD S *****	**0.77**	**0.43**	**CD H *****	**-0.38**	**CD H *****
SR 44	77	55	CD H **	65	n.s	-0.1	-0.1	n.s.	-0.1	n.s.	0.13	0.14	n.s.	0.21	n.s.
SR 45	81	71	n.s.	90	n.s.	-0.6	-0.4	n.s.	-0.4	n.s.	0.78	0.59	n.s.	0.46	CD H *
SR 46	131	98	CD H **	117	n.s.	-1.6	-1.5	n.s.	-1.8	n.s.	1.11	1.35	n.s.	1.30	n.s.
Total surveyed Asia	**289**	**224**	**CD H ****	**272**	n.s.	**-2.4**	**-2.0**	n.s.	**-2.3**	n.s.	**0.78**	**0.84**	n.s.	**0.79**	n.s.
SR 31	73	69	n.s.	73	n.s.	-1.0	-0.3	CD S ***	-0.2	CD S ***	1.17	0.41	CD H ***	0.31	CD H ***
SR 34	290	315	n.s.	317	n.s.	-1.1	-0.4	CD S ***	-0.4	CD S ***	0.38	0.12	CD H ***	0.11	CD H ***
SR 35	544	383	CD H ***	390	CD H **	-2.3	-3.4	n.s.	-3.6	n.s.	0.41	0.83	n.s.	0.84	n.s.
Total surveyed Latin America	**907**	**767**	**CD H ****	**780**	**CD H ****	**-4.6**	**-4.1**	n.s.	**-4.2**	n.s.	0.47	**0.51**	n.s.	**0.51**	n.s.
Total surveyed Pan-tropical	**1,818**	**1 475**	**CD H *****	**1 571**	**CD H ****	**-12.2**	**-8.3**	**CD S ****	**-8.6**	**CD S ****	**-0.62**	**-0.54**	**n.s.**	**-0.52**	**n.s.**

CD H = country data higher *CD S = country data smaller*

Figure 12. Forest area in 2000 (left) and net forest area change (right) - comparison between country data and remote sensing survey estimates (million hectares)



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