Overview of land cover change in tropical regions

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Abstract The change of tropical forests, reported by the FAO's 2005 Forest Resources Assessment, showed a moderate negative trend: for the period 2000–2005 the net annual change was estimated at –11.8 million ha, while the rate for the previous decade was –11.65. Tropical Asia showed the highest rate and most negative trend, passing from –0.8 to –0.96 percent per year. The remote sensing survey done for previous FRA editions covering the period 1980–2000 revealed distinct change processes in the three tropical regions. Survey results indicated that socio-economic and cultural aspects that characterize and differentiate the geographic regions determine the nature of the change processes and underlying cause–effect mechanisms, while the ecological setting determines the intensity of change and reveals its environmental implications. A comparison of deforestation processes of the two decades indicated an on-going process of radicalization of the dynamics determined by an increasing frequency of high-gradient changes (e.g. total clearing rather than fragmentation and degradation) and by a shift of deforestation fronts towards wetter zones, with a consequent higher per-hectare carbon emission associated with deforested areas.

Key words deforestation; global forest assessments; land cover change processes; tropical forest

GLOBAL FOREST INFORMATION SOURCES

During the last 60 years systematic country by country information on forest area and change have been produced exclusively by the FAO, whose reports, in spite of some criticism (e.g. Stokstadt, 2001), have been the main reference for discussion and analysis at the regional and global level. The FAO's assessment techniques have changed considerably over the time, from the initial "questionnaire" approach that was used until the 1970s, to the review, country-by-country, of original inventory date complemented by experts' judgment (FRA of 1980), to sub-national forest area time series integrated by modelling techniques (FRA of 1990), to the return to national-level statistics complemented by experts' opinions and in-depth studies (FRA of 2000). In addition, a pan-tropical remote sensing survey was implemented during the FRAs of 1990 and 2000 with the aim of producing consistent data on forest cover change, and trends, at the regional and pan-tropical level (FAO, 1996, 2003). The last assessment, the FRA of 2005, whose results have recently been released, based its updated country data on a pre-determined set of tables to be filled in by country correspondents formally appointed by the respective governments; in practice an advanced questionnaire approach based on a set of clear definitions and standard formats. The final country statistics were the result of an iterated dialogue between FRA staff and the national correspondents, especially in cases of incomplete or inconsistent data. This process was led by the countries that remain sole owners of the data finally published, with FRA playing essentially the role of facilitator and coordinator. Unfortunately, in this last assessment the remote sensing survey was discontinued and therefore there are no updates on the analysis of tropical change processes beyond the periods 1980–1990 and 1990–2000.

The TREES project of the European Joint Research Centre (JRC) carried out a survey of forest cover in humid tropical regions (Achard *et al*., 2002) based on an analysis of time series of high-resolution satellite imagery at statistically chosen locations covering the period 1990–1997. The study did not produce country statistics and the comparison at regional scales with FAO data was constrained by the TREES' survey limitation to dense forest formations in humid tropical regions. In spite of these limitations, a combined analysis of FAO and TREES remote sensing surveys revealed a substantial agreement on forest change rates in Africa and Asia, while in the case of Latin America the TREES study gave a much lower rate due, most probably, to the exclusion of seasonally deciduous forests from the analysis (Drigo, in Bonell & Bruijnzeel, 2005).

Other sources of data relevant to the analysis of land cover at the global level are grouped under the Global Observation of Forest and Land Cover Dynamics (GOFC-GOLD) initiative, which is a panel of the Global Terrestrial Observing System (GTOS). The potential of this coordinated effort to assist in the production of globally consistent and reliable information of forest cover and change is great. Specifically, in the context of forest hydrology, spatially-discrete data showing variation of canopy density is far more useful than crude forest–non forest maps and statistics (Held & Rodriguez, in Bonell & Bruijnzeel, 2005). Interesting products in this respect are the global tree cover percent data and the forthcoming change maps based on MODIS satellite data at 500 m resolution (Hansen *et al*., 2003). To date, however, there are no statistics resulting from these programmes that may be considered as an alternative to those produced by the FAO.

In the following sections, FRA 2005 and the pan-tropical remote sensing survey of FRA 1990 and 2000 were used as main sources of information on tropical forests changes.

SUMMARY OF FRA 2005 COUNTRY STATISTICS

The net annual change of tropical forest area, defined as total man-made and natural afforestation minus total deforestation, was estimated at –11.8 million ha for the period 2000–2005, while the rate for the previous decade was –11.65 million ha (Table 1). This represented a non-negligible increase in net annual change rate from –0.59% to –0.63% of the forest areas. This negative trend was observed in all tropical regions, with Asia showing the most negative trend, passing from –0.8 to –0.96% per year. The situation when looking at natural forest only appears even worse. All change rates are higher and Asia deforestation rate rises to 1.11% per year (Table 1, lower section). Still, these values hide the true magnitude of ongoing deforestation, i.e. areas of forest cleared and the land converted to other uses, because they include natural afforestation, i.e. through natural expansion of forests, e.g. on abandoned agricultural land that are not separately reported by the countries (FAO, 2005). A very tentative, and certainly conservative, estimation of the true annual deforestation (determined considering only the countries with negative change and deducting plantation areas) may be in the order of 13.5 million ha at the global level, with some 12.4 million ha in tropical countries alone.

While writing, the media report the terrible disaster of the Philippines, where over a thousand lives from two villages in southern Leyte (the sad count still going on) were taken by a mudflow caused by heavy rains and high deforestation and triggered by a relatively weak earthquake. I checked the table: the current Philippines deforestation rate is 2.1%, the highest in Asia and was 2.8% in the previous decade. A predictable disaster?

Figure 1 provides a global geographic overview of FRA 2005 deforestation statistics from which the dominant role of the tropical countries appears very clearly both in terms of deforestation rates and negative trends.

REGIONAL CHARACTER OF PROCESSES GOVERNING LAND COVER CHANGE

Insight on the processes of change by broad geographic regions and ecological zones was produced by the remote sensing survey carried out by the FRAs of 1990 and 2000 over the entire

Table 1 Tropical forest areas and change rates as assessed by the Forest Resources Assessment 2005 of FAO.

Tropical sub-regions	Area			Annual change rate			
	1990 1000 ha	2000 1000 ha	2005 1000 ha	1990–2000 1000 ha year^{-1}	2000–2005 1000 ha year^{-1}	1990–2000 %	2000–2005 %
	Total forest (natural and plantations)						
Tropical Africa	682 698	638 179	617 679	–4 452	–4 100	–0.65	–0.64
Tropical America	941 393	896 866	873 515	–4 453	–4 670	–0.47	–0.52
Tropical Asia	323 156	297 380	283 126	–2 578	–2 851	–0.80	–0.96
Tropical Oceania	36 891	35 164	34 268	–173	–179	–0.47	–0.51
Tropical World	1 984 138	1 867 589	1 808 588	–11 655	–11 800	–0.59	–0.63
	Natural forest *						
Tropical Africa	673 569	628 847	608 154	–4 472	–4 139	–0.66	–0.66
Tropical America	934 177	888 730	865 033	–4 545	–4 739	–0.49	–0.53
Tropical Asia	310 391	282 179	266 492	–2 821	–3 137	–0.91	–1.11
Tropical Oceania	36 696	34 928	34 021	–177	–181	–0.48	–0.52
Tropical World	1,954 833	1 834 684	1 773 700	–12 015	–12 197	–0.61	–0.66

* Natural forest values were not reported by FRA 2005 but were calculated by the author by deducting from the total forest the areas of plantations. Since for several countries plantation statistics were missing or incomplete, the calculated values should be considered as indicative only. This means that natural forest areas are probably smaller and that their changes are probably higher. Source: Elaboration of FAO, 2005.

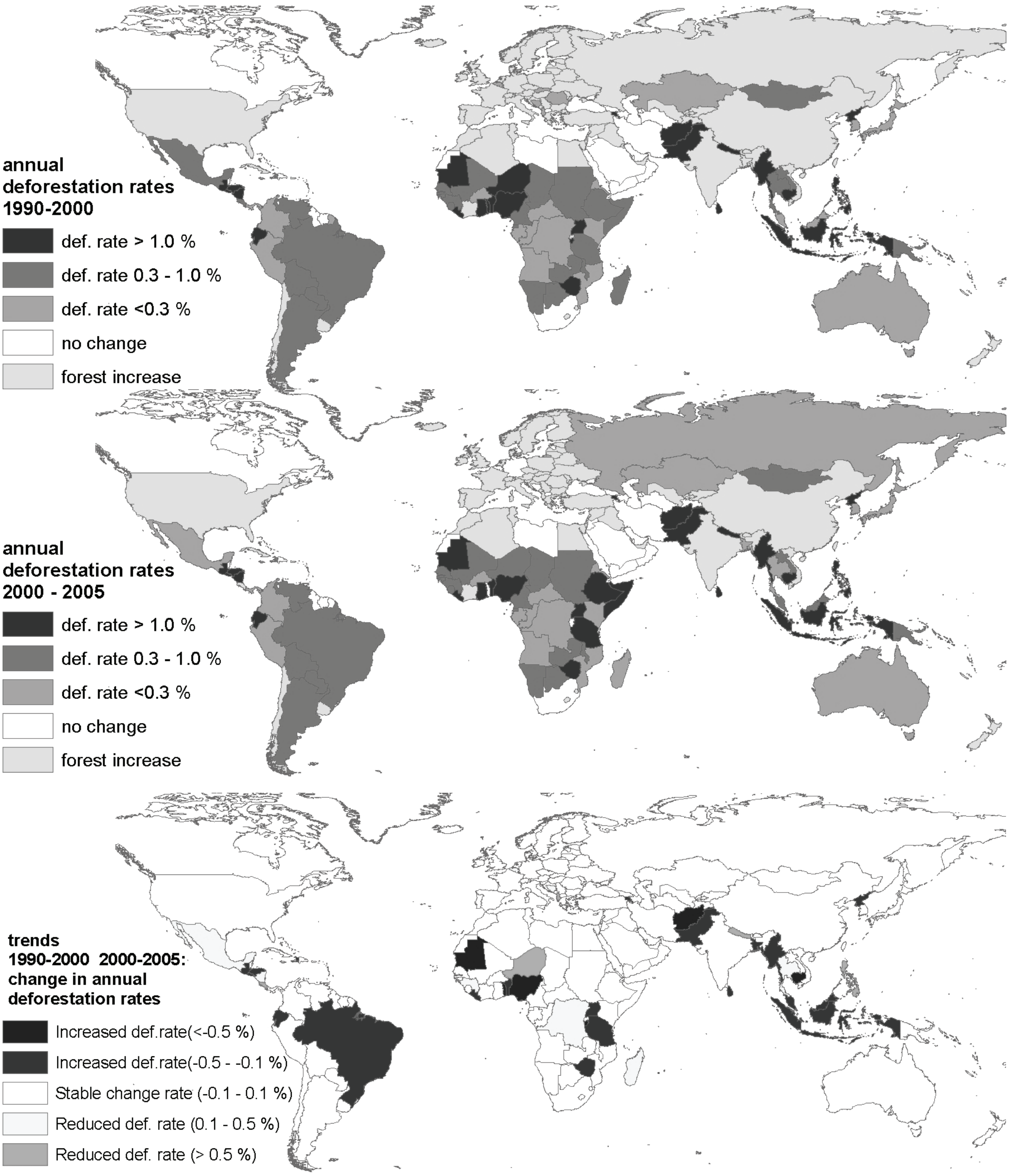

Fig. 1 Global maps of annual deforestation rates for the periods 1990–2000 and 2000–2005 and trends.

tropical belt. The country data discussed above and the remote sensing survey are independent and complementary and the latter is here presented in order to analyse the typology rather than the quantity of change. The survey was based on a 10% sample, consisting of 117 randomly selected sampling units, each unit covering approximately 3.2 million ha (FAO, 1996, 2003). At each sample location, satellite images of the best quality and appropriate season, separated by an approximate 10-year interval, tentatively 1980, 1990 and 2000, were analysed following the interdependent interpretation method (FAO, 1991, 1996; Drigo, 1996) to assess class-to-class transitions within the two periods and the main trends.

The regional processes of change may be best visualized through the flux diagrams (Fig. 2). In these diagrams the changes (x-axis, divided into positive and negative changes) are associated to an indicative biomass density gradient (y-axis, with the land cover classes used in the study ordered by their estimated biomass per hectare) that allows visualization and better understanding of the change processes, and even assessment of their environmental impact through the release or sequestration of woody biomass related carbon. The left side of the graph shows the positive class transitions (the arrow pointing upward indicates an increment in biomass), while the right-hand side of the graph shows the negative class transitions (the arrow pointing downward indicates a loss of biomass).

Each transition is defined by the % of total change observed in the region (x-axis) and by the biomass value determined as the difference between the biomass values of the class of destination and the class of origin (y-axis) (FAO, 1996). Each flux diagram represents a kind of signature of the dynamic processes taking place. From the diagrams in Fig. 2, which show the changes for the period 1990–2000, we can rapidly visualize the considerable differences in the processes of changes among the three regions, which can be summarized as follows:

Africa

In Africa, the processes of change show phases of progressive degradation, rather than outright deforestation, caused mainly by high rural and urban population pressure (Fig. 2, top). The typology of change appeared as characterized by a variety of relatively small changes, both in terms of area and biomass, caused mainly by rural population demands for land (subsistence farming, pastures) and wood (mainly woodfuels and, to a lower extent, timber and construction material). The dominant transitions are:

– **closed forest → short fallow**, which is the effect of small-scale subsistence farming whereby the fertility of the soil is regenerated during fallow periods of a few years;
– the sequence **closed forest → open forest → fragmented forest → other land cover** clearly represents the various stages of forest depletion, and is an effect of rural and urban population needs for land and energy. Most probably, commercial logging triggered many of these processes, at least in the more productive forest zones.

Key factors behind the pressure on forests in Africa are (FAO, 2001a): rapid population growth, particularly that of the urban population; poverty, slow economic development, inadequate economy; wars and conflicts; insecurity of land tenure; desertification/climate change (Drigo, in Bonell & Bruijnzeel, 2005). Among the direct causes of deforestation the following can be identified (FAO, 2001a): poor farming practices; conversion to cash crop estates; shrimp farming in mangrove areas; increased clearing and tree cutting for fuelwood and charcoal; poor logging practices and overexploitation; commercial logging as a direct cause of degradation and indirect cause of full deforestation; mining; desertification in Sahelian countries.

Woodfuels (wood-based fuels such as fuelwood and charcoal) play an important but largely undisclosed role in the cause–effect mechanisms associated with deforestation and forest degradation in tropical regions and particularly in Africa (Drigo, 2001, Drigo, in Bonell & Bruijnzeel, 2005). An element of special concern that should be studied with priority is the fast rising demand for charcoal linked to the rapid increase in urbanization.

Latin America

A totally different typology of change dominates in Latin America. Here the single transition **closed forest → other land cover**, which represents deforestation with the highest possible biomass loss resulting mainly from the direct conversion of the original forest to cattle ranching and permanent agriculture, was by far the most important change (Fig. 2, middle). The estimated biomass loss associated with these transitions certainly is the highest anywhere in the tropics.

The second most frequent transition, **shrubs → other land cover**, represents the large areas of Brazilian *caatinga* (steppe typical of the northeast regions of Brazil) and *cerrado* formations (tree and shrub savanna of south-west and central Brazil) that were being converted to cattle ranching.

Most of these changes were the effect of policies and incentives to cattle ranching and other centrally planned operations on a comparatively large scale (large land ownership, energy schemes, resettlement and forest exploitation/conversion programmes), usually availing of consistent financial investment and heavy mechanization (Serrao, in Bonell & Bruijnzeel, 2005).

The transition **closed forest → short fallow** as well as a number of other, less frequent changes in land cover, represent the effect of high rural population pressure and small-scale farming, such as in the Amazon and Yucatan, and is often associated with resettlement programmes. This type of changes appeared less frequent than in the previous decade due to several factors such as, for

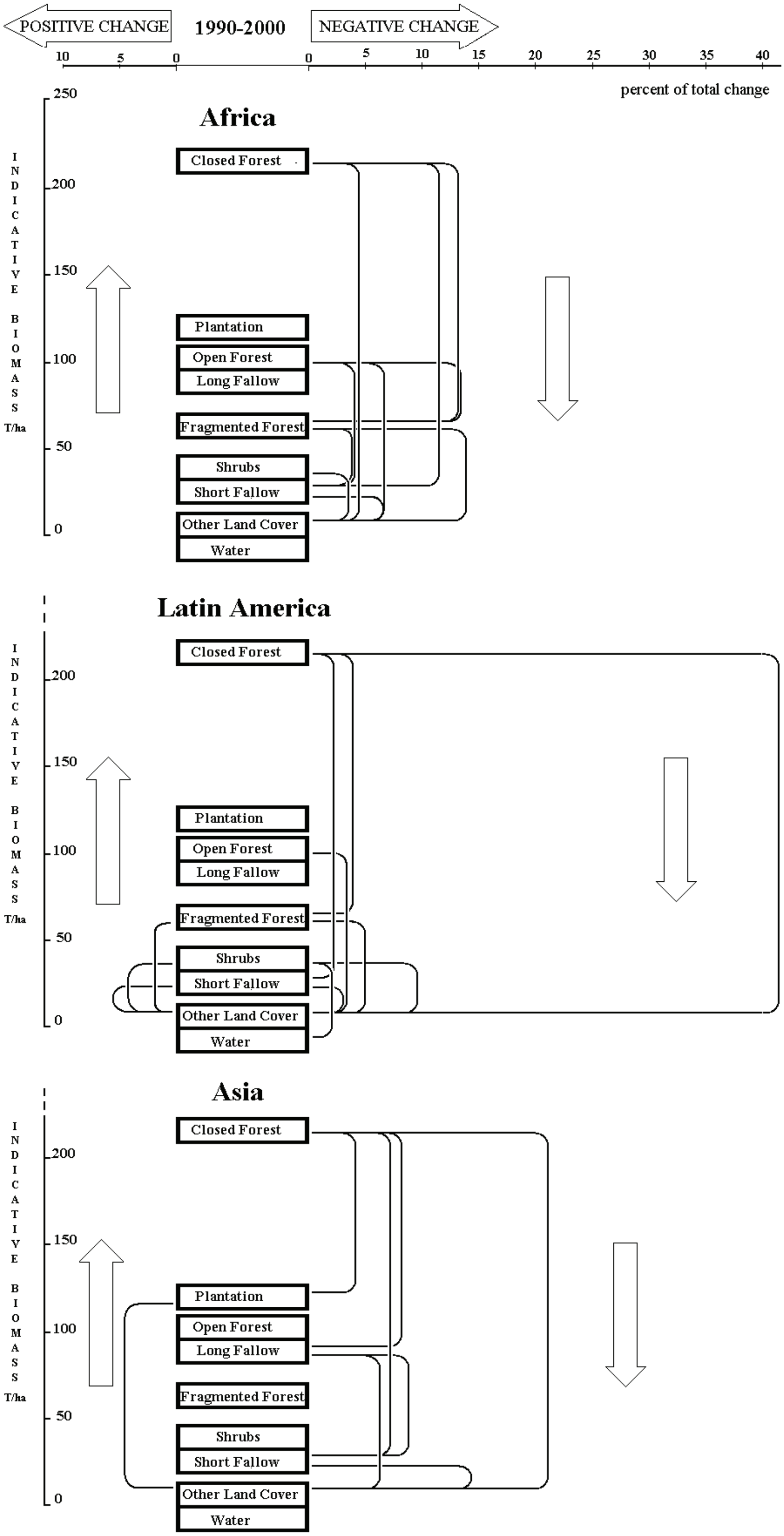

Fig. 2 Woody biomass flux diagrams for tropical Africa, Latin America and Asia for the period 1990–2000 (elaboration of FAO, 2003; transitions below 2% are not shown).

instance, changes in Brazilian policies regarding resettlement programmes (Serrao, in Bonell & Bruijnzeel, 2005). Nowadays it seems that the overwhelming majority of cleared forest is converted for cattle ranching rather than agriculture (Fujisaka *et al*., 1996).

Asia

Tropical Asia presented the highest rates of deforestation and forest degradation among the three regions, as confirmed also by FRA 2005 statistics (Table 1). These rapid changes were the effect of both high rural population pressure and centrally planned conversion programmes, as can be deduced from Fig. 2 (bottom). Deforestation was represented by the conversion of forests to **other land cover** and to **short fallow shifting cultivation**. The former is largely the effect of centrally planned conversion programmes, mostly in the form of large resettlement schemes involving forest exploitation/conversion (particularly in Indonesia and Malaysia) and intensification of permanent agriculture on traditional shifting cultivation areas (South and Southeast continental Asia). The second major conversion reflects the effect of high rural population pressure, and is represented by the expansion of subsistence farming into forest areas along logging roads and from existing croplands. The process of forest **degradation** is represented mainly by the expansion of traditional shifting cultivation (long fallow shifting cultivation), that encroached on previously dense or undisturbed forest. An equal amount of the **long fallow** forest class was converted to **short fallow** and, a little less, to **other land cover**, reflecting a sequence of progressive forest depletion as a direct effect of the growing population and related needs for farm land. Shifting cultivation is by definition a cyclic form of land use. Traditionally, new areas under shifting cultivation were balanced by areas where cultivation was abandoned to revert to (secondary) forest conditions. Since a long time, this balance has been lost, thereby converting the cycle into a sequence of progressive degradation. The difference between the forest area going into long fallow and the area of long fallow reverting to forest shows how unbalanced, and hence unsustainable, this originally sound practice has become (cf. Malmer *et al*., in Bonell & Bruijnzeel, 2005).

The area covered by plantations in Asia, both forestry and agricultural plantations, increased significantly, partly at the expense of closed forest and partly in previous denuded lands (other land cover).

The comparison with the changes of the previous decade gave the impression of a certain radicalization that favored land use changes associated with high-gradient transitions (i.e., clear-felling). Another difference is that in the previous period the quasi-totality of the new plantation area was established on previous dense forest areas. This represents an important element counterbalancing, to a small extent at least, the negative general trend.

SUMMARY OF REGIONAL PERSPECTIVE

Comparing the three regional situations, the dominance of the changes in Latin America becomes even more pronounced, as these combine the largest area of change (Table 1) with the highest biomass loss. In fact, the biomass gradient of Latin America's most frequent class transition (**closed forest → other land cover**), represents the maximum biomass loss observed anywhere (cf. Fig. 2).

The effects of **centrally planned operations** are evident in Latin America and in Asia but to a much lesser degree in Africa. Typical land uses related to these processes are: cattle ranching in the Brazilian Amazon, large resettlement and plantation programmes in Southeast Asia and, to a lesser degree, in West Africa. Comparing the 1980s and 1990s there are strong indications that, except for Africa, these relatively high-investment and high-gradient transitions are taking the lead in recent years, thereby contributing to the radicalization of land use change (Drigo, in Bonell & Bruijnzeel, 2005).

The other important component of the process, **rural population pressure**, is characterized by combinations of low-gradient transitions associated with subsistence and small-scale farming, such as long and short fallow shifting cultivation, processes of forest fragmentation and degradation, etc. This component remains dominant in Africa but it seems to be losing terrain in Asia and Latin America.

ECO-REGIONAL DISTRIBUTION OF FOREST CHANGE

Another interesting perspective is offered by the analysis of land cover change by broad ecological zones (FAO, 1996, 2003). Main results indicated that in all regions the forest resources of the moist tropical zone (rainfall 1000–2000 mm) suffered the highest pressure, both in the form of full deforestation and forest degradation, with a rate of change which appeared to be (at least) twice of that observed for the wet (rainfall >2000 mm) and dry (rainfall 200–1000 mm) zones (FAO, 1996). More specifically, a comparison of the different ecological zoning adopted by FRA 1990 and FRA 2000 allowed the deduction that the most active fronts of deforestation during 1980–1990 was within the wetter Moist sub zone characterized by a short dry season, and that these hot fronts are getting more intense and that they are fast moving towards the wetter cores of the remaining forest areas (Drigo, in Bonell & Bruijnzeel, 2005). This impression is confirmed by the acceleration of the deforestation rate in the Rain Forest zone, where the corresponding annual rate of change went up from –0.50 to –0.61%, which is one of the statistically most significant trends observed (FAO, 2003). This acceleration is accompanied by the indication of a possible deceleration of the deforestation rate in the Moist Deciduous Forest. Arguably, this shift of the deforestation front towards the wetter zones is the most significant trend observed in this study.

GENERAL TRENDS OF PROCESSES OF CHANGE

A comparison of deforestation processes of the two decades of the FRA survey indicated that the conversion to subsistence farming associated with re-settlement programs and traditional practices, which represented a large share of the total change in the pre-1990 period, was reduced considerably during the 1990–2000 decade. This reduction, combined with the increased frequency of the transition from **closed forest** to other **land cove**r, which appeared significant at least in the Tropical Rain Forest Zone, gives strong indications of an on-going process of radicalization of the dynamics whereby the expansion of large-scale cattle ranching and permanent agriculture becomes more and more the dominant land use change associated with deforestation (Drigo, in Bonell & Bruijnzeel, 2005). This transition towards high-gradient changes, associated with the "wet" shift of the deforestation front and the consequent higher biomass densities of the forest formations being cleared and degraded, implies a significant trend towards a higher per-hectare carbon emission associated with deforested areas. These elements further strengthen the impression of a radicalization of the processes of tropical deforestation. In fact, from the carbon budget viewpoint, the increased biomass density of the forests currently under pressure will probably offset the beneficial effect of the slight reduction in the net forest area change announced by FRA 2005 at global level (FAO, 2005).

The analysis of change processes is far more informative than country time series of forest areas. It is highly recommended that FAO in its future assessments, or other programmes, continue global/regional/ecological level analyses taking advantage of the experience already accreted on monitoring methodologies and of the progress in satellite data availability.

REFERENCES

Achard, F., Eva, H., Stibig, H. J. Mayaoux, P., Gallego, J., Richards, T. & Malingreau, J.-P. (2002) Determination of deforestation rates of the world's Humid Tropical Forests. *Science* **297**, 999.

Bonell M. & Bruijnzeel, L. A. (eds) (2005) *Forests, Water and People in the Humid Tropics. Past, Present and Future Hydrological Research for Integrated Land and Water Management*. Cambridge University Press, Cambridge, UK.

Drigo, R. (1996) Survey of pan-tropical forest resources based on multi-date high resolution satellite data. In: *Proc. EUROSTAT Esquilino Seminar* (November 1995), 111–141.

Drigo, R. (2001) Wood energy information in Africa. Working Document FOPW/01/4, FAO Project GCP/RAF/354/EC.

FAO (1981) Tropical Forest Resources Assessment project (in the framework of GEMS). Asia; Latin America; Africa. Rome.

FAO (1991) Monitoring Methodology. Forest Resources Assessment 1990 Project Paper by R. Drigo.

FAO (1993) Forest Resources Assessment 1990. Tropical Countries. *FAO Forestry Paper 112.*

FAO (1996) Survey of tropical forest cover and study of change processes. *FAO Forestry Paper 130.*

FAO (2001) Global Forest Resources Assessment 2000. Main report. *FAO Forestry Paper 140.*

FAO (2003) Pan-tropical survey of forest cover changes 1980–2000. *FRA Working Paper 49.*

FAO (2005) Global Forest Resources Assessment 2005. *FAO Forestry Paper 147.* http://www.fao.org/docrep/008/a0400e/a0400e00.HTM.

Fujisaka, S., Bell, W., Thomas, N., Hurtado, L. & Crawford, E. (1996) Slash-and-burn agriculture, conversion to pasture and deforestation in two Brazilian Amazon colonies. *Agric. Ecosystems & Environ.* **59**, 115–130.

GOFC-GOLD (2006) Global Observation of Forest and Land Cover Dynamics http://www.fao.org/gtos/gofc-gold/index.html.

Hansen, M., DeFries, R., Townshend, J. R., Carroll, M., Dimiceli, C. & Sohlberg, R. (2003) 500m MODIS Vegetation Continuous Fields. The Global Land Cover Facility. College Park, Maryland, USA.

Stokstad, E. (2001 UN Report suggests slowed forest losses (A review of:) *Science* **291**, 2294.