Forestry Department

Food and Agriculture Organization of the United Nations

FRA 2000

GLOBAL FOREST COVER MAP

Rome, November 1999

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.

The Forest Resources Assessment Programme is organized under the Forest Resources Division (FOR) at FAO headquarters in Rome. Contact persons are:

Robert Davis   FRA Programme Coordinator   robert.davis@fao.org

Peter Holmgren   FRA Project Director   peter.holmgren@fao.org

or use the e-mail address: fra@fao.org

Table of Contents

Abbreviations

BEF   Biomass Expansion Factor

BV   Biomass of inventoried volume

CATIE   Centro Agronómico Tropical de Investigación y Enseñanza

Cirad   Centre de coopération internationale en recherche agronomique pour le développement

EDC   Eros Data Centre

FAO   Food and Agricultural Organization of the United Nations

FORIS   Forest Resources Information System

FRA   Forest Resources Assessment

GIS   Geographic Information System

SNU   Sub National Unit(s)

UN-ECE   United Nations Economic Commission for Europe

VOB   Volume Over Bark

WD   Wood Density

WCMC   World Conservation Monitoring Centre

1   Introduction

1.1   Abstract

Data about the world's forest cover is an important prerequisite for global environmental change research, from studies on biodiversity and effective conservation to modeling sustainability of forest ecosystems. Expanding on the recently completed U.S. Geological Survey (USGS) global land cover characteristics database, USGS EROS Data Center is producing a global forest cover map for the United Nations Food and Agriculture Organization (FAO). Broad, discrete forest-canopy cover categories are mapped at 1-km resolution for use by FAO's year 2000 Forest Resource Assessment project. Seasonal land cover classes from the USGS database are optimized and adapted to FAO definitions using combinations of remapping, clustering, and linear unmixing techniques. Preliminary forest cover maps have been produced for several continents. Results show that the basic objectives of forest cover mapping and linkage to the USGS database can be met adequately with the methodology.[1]

1.2   Background

The United Nations Food and Agriculture Organization (FAO) conducts periodic forest resource assessment at the global scale (FAO, 1993). The current forest resource assessment for the reference year 2000 (FRA2000) is being conducted to estimate forest area, forest conditions, and the rate of change in a number of important parameters (e.g. area, forest type). In addition to collecting country survey reports and sampling high-resolution satellite scenes, FRA2000 will also, for the first time in its survey history, feature a global forest cover map produced at 1-km spatial resolution. The global forest cover map is being produced at the U.S. Geological Survey (USGS) EROS Data Center (EDC) in cooperation with FAO.

There have been well-conducted studies to map forest cover at the regional or continental extent, such as the TREES study (Malingreau *et al.* 1995) and the Humid Tropical Landsat Pathfinder study (Skole and Tucker, 1993). These studies provide significant opportunities for regional applications, but the studies are limited in scope for a global forest cover map. On the other hand, the recently completed USGS global land cover database (Loveland *et al.*, in press) represents a complete global coverage produced with a consistent methodology and a flexible database philosophy, using Advanced Very High Resolution Radiometer (AVHRR) Normalized Difference Vegetation Index (NDVI) as the primary input data. Two levels of land cover are available from the database: the full classification based on seasonal definitions and the aggregated 17-category International Geosphere and Biosphere Programme (IGBP) classification (Loveland *et al.*, in press). The USGS database is being used for a broad range of earth science applications, from land cover mapping to biological conservation (Reed, 1997). The FAO forest cover mapping effort builds on the full USGS seasonal database, refining forest classes to reflect forest density classification.

The global forest cover map may be used by the FAO FRA2000 project to provide spatial definition to area statistics of survey findings. As a complete enumeration of forest cover in the world, the map is an additional data source and may be used to supplement regions lacking recent, reliable forest inventory (FAO, 1995). As a new addition to the USGS land cover database, the effort should help improve applications of the database when information about forest cover is needed.

---

[1] The work presented here has been carried out by Zhiliang Zhu and Eric Waller, EROS Data Centre, USA (under U.S. Geological Survey contract 1434-CR-97-CN-40274), through a Letter of Agreement with FAO-FRA.

2   Objectives

The global forest mapping is an extension to the USGS land cover mapping project. The forest mapping effort is aimed to: 1) develop a general, actual forest cover map linking to the USGS land cover database, 2) map broad forest cover categories that can be consistently extracted from AVHRR 1 km composite data, and 3) use the map to support the FAO year 2000 global forest survey.

Six land cover categories are initially targeted: closed forest, open forest, fragmented forest, woody savanna, other land cover, and water. These categories loosely follow canopy density definitions that have been suggested by FAO Forestry as required for global assessment using remotely sensed data (1995). The first three categories are considered to be forested land cover.

3   Methods

Vegetation classification and descriptions in the USGS land cover database are built on characteristics of vegetation seasonality determined in terms of AVHRR NDVI. In the database, unique NDVI signatures and associated attributes such as terrain and ecoregions characterise large-area land cover patterns. The magnitude of integrated NDVI over the length of the temporal period helped separate successively decreasing vegetation biomass, from healthy, dense forestlands to open woodland, shrub and grass, and sparse land cover. On the other hand, seasonal variations were investigated to partially support identification of vegetation physiognomy (e.g. separating deciduous from evergreen forests). The use of both integrated NDVI and seasonal NDVI variations has been found useful in applications such as monitoring large-area vegetation inter-annual variations (Reed et al. 1994) and mapping tropical deforestation and fragmentation (Skole and Tucker, 1993).

Because the USGS seasonal land cover database was not intended to optimize for forest cover, no direct relationship exits to enable a simple conversion of the seasonal land cover classes to the six FAO classes. Rather, a two-step methodology has been designed that allows certain interactive flexibility in deriving and correcting for the FAO classes.

- Adapting the USGS seasonal land cover classes to the FAO classification. The full USGS seasonal land cover classes are used as the baseline data, on the continent-by-continent basis. The refinement methods to fit USGS classes to FAO definitions are similar to the methods used in producing these USGS classes, namely that refinements depend on local conditions of land cover and rely on a careful study of all available evidence. The country-level forest database maintained by FAO is also used as a general reference for country level forest classification. Loveland *et al*. (in press) describes the overall approach in detail.   Class merges and splits are aided by ancillary data sets such as ecoregions and digital elevation models. Spectral reclustering as well as user defined polygon splits are also used. This approach has been found to be effective for many seasonal land cover classes, including most nonforest classes such as sparsely vegetated areas. However, some highly mixed land cover patterns require further analysis to differentiate both mixture conditions and the degree of forest canopy openness.

- Estimating percent forest cover using two techniques. The concept of spectral mixture analysis quantifies pixels as fractions of basic surface components (Smith *et al*., 1990, Wessman *et al*. 1996), or "endmembers", such as green vegetation, soil, and shade. It is generally understood that, in relatively small study areas and with sufficient spectral information, unique and representative endmembers can be identified to produce reasonable results. Unfortunately, endmember fractions do not directly correspond to forest fractions, closed forests can consist of mixtures of green vegetation, and shade (Roberts, *et al*., 1991). This, together with limited spectral bands and large mapping area, led to the development of a combined linear mixture modeling and NDVI scaling approach.

  In the combined approach, the traditional unmixing method is modified slightly to apply only to bright pixels (pixels with high reflectance) in AVHRR bands 2 (infrared) and 1 (visible) spectral space. These bright pixels tend to be mixtures of forest (particularly deciduous forest), cropland, and bare soil having high reflectance in these bands. These cover types are treated as endmembers and the bright pixels are unmixed on each monthly AVHRR composite. Fraction classes range from closed forest to open forest, fragmented forest, and nonforest land cover. Dark pixels (low reflectance) in AVHRR bands 1 and 2, on the other

hand, are generally found to be indicative of more undisturbed forests, particularly conifer forests. However these dense forests can be confused with low illumination or flooding. A scaled NDVI is a better indicator of forest density than mixture analysis for these dark pixels. Closed forests, open forest, and woody savanna are found to be closely related to decreasing NDVI, approximately between 0.8 and 0.3.

To provide the least atmospherically affected result, final percent forest cover is determined over the course of the year based n the maximum monthly forest cover value achieved, regardless of the methods chosen (mixture analysis or scaled NDVI). Figure 1 illustrates the two techniques used in estimating percent forest cover. The selection of endmembers and determination of what pixels are bright or dark are based on studies of the imagery and vary between regions. This modeling process is used to guide decisions on the difficult or mixed seasonal classes from the first step. The modeling process determines the level of forest fragmentation if forest density is from the modified mixture analysis; whiles separation of various types of forest and woodland from other land cover is based on results from the linear NDVI scaling. Because of varying ecological conditions within and between continents, flexible regional rules are developed according to reference data in determining forest density threshold values for the FAO forest classes.
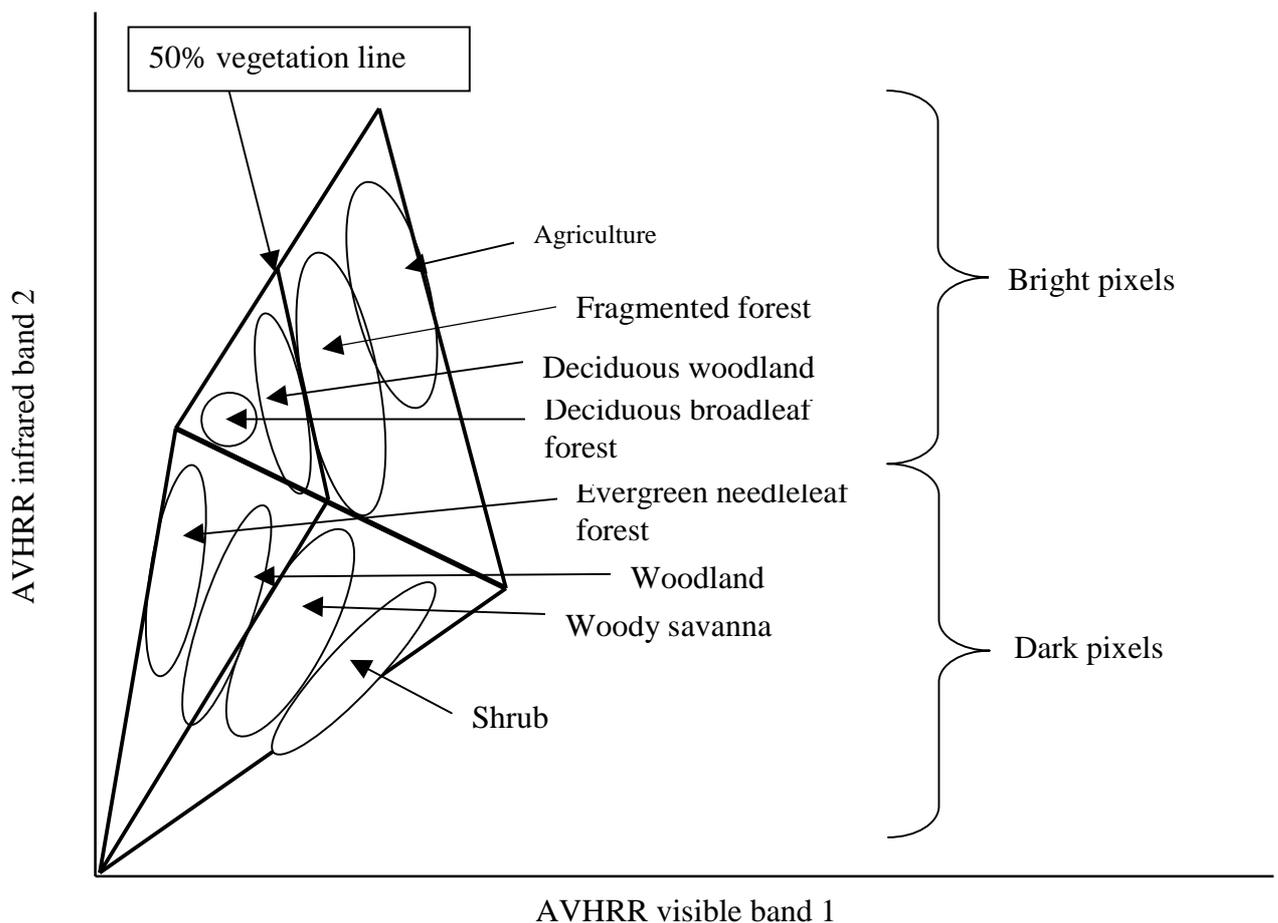

Figure 1.— Estimating percent forest cover using the traditional mixture analysis for "bright" pixels and linear scaling of NDVI for "dark" pixels. The ellipses indicate pixel clouds of likely land cover types in the spectral space of the AVHRR bands 1 and 2.

4   Results and discussion

Early results have been obtained for continents of South America, Africa, and North America. For South America, for example, combined results from the two-step methodology produced a continental FAO forest cover map. Figure 2 shows an area in Bolivia, South America. The left image in the figure is estimated percent forest, the right image is derived FAO forest cover map (only three classes).
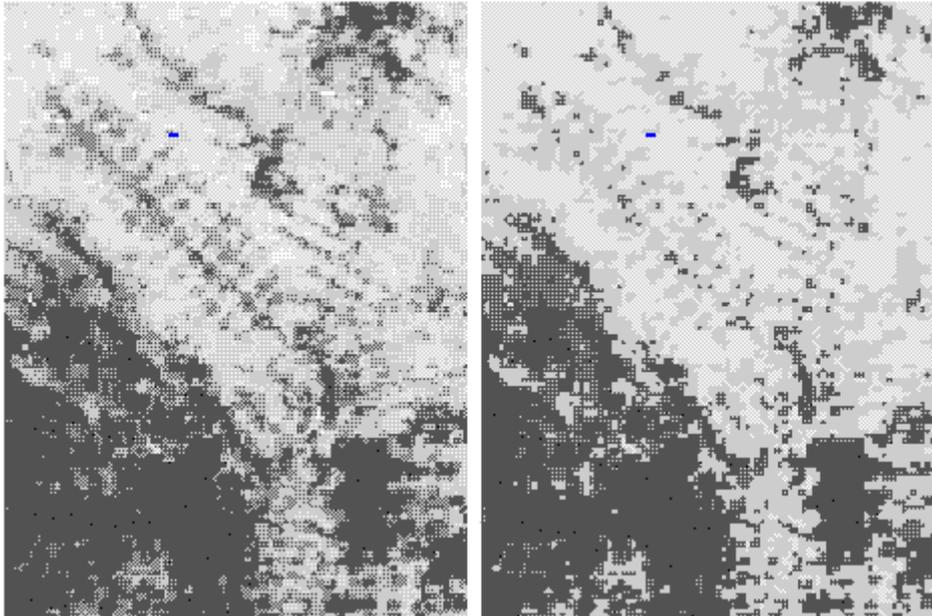

Figure 2.— Estimated percent forest cover (left) and corresponding FAO forest classification (right) centered on 62.75° W and 16.75° S in South America. For the forest cover map on the right, only three classes shown from white to dark grey scale: closed forest, open forest, and fragmented forest.

In addition to the derived forest cover map, results also include look-up tables linking the USGS seasonal land cover classes to the six-category map legend. Comparisons with the FAO forest resource information system are also made at the country level to guide the mapping work. However, it is not the objective of this effort to calculate forest area statistics based on the digital map, recognizing that, with limited spatial and spectral resolution, the data are best suited for showing where forests are, rather than quantity of forests.

Most of the seasonal land cover classes from the USGS database were translated well into the FAO categories. For South America, for example, only 34 out of 167 seasonal classes needed further processing under the second step. Detailed attributes on most of the seasonal classes, not only land cover descriptions but also characteristics of vegetation physiognomy and canopy openness, are an advantage in aiding the translation and reclassification. In most cases, FAO forest density classes benefited from corresponding seasonal land cover classes because of integrated NDVI used for labeling process. For example, the estimated percent forest cover in South America, in average, correlates well with integrated NDVI (Figure 3).

On the other hand, there are mixed seasonal classes in the USGS database that portray co-occurrence of natural land cover patterns. Atmospheric conditions such as clouds also affect temporal patterns and

cause certain seasonal classes to be mixed among different land cover types. For these mixed classes, estimating percent forest cover is a useful tool to help derive canopy-openness classes.

For the techniques of estimating percent forest cover to be effective, careful studies of regional and local land cover are very important, as is required for conventional classification methods. Due to the
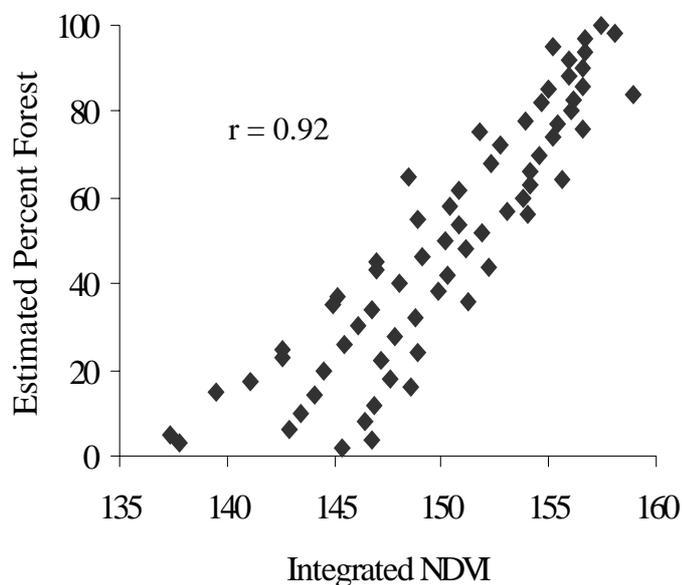

Figure 3.—Scatter plot of estimated percent forest
cover vs. integrated NDVI for South America.
NDVI is averaged for each percentage value,
thus removing all variations.

constraints of large mapping area and limited spectral bands, no unique endmembers can be found that will represent all typical forest cover types and densities. Therefore, regional or local stratification is necessary. In this study, existing ecoregions have been used as the primary stratification tools. However, in cases where only a small number of seasonal classes need the second step of the methodology, it is also possible that stratification is based on these seasonal classes.

Professionals from countries are also being used to validate and calibrate the maps. FAO is releasing the regional versions of the maps, as they become available, to forestry professionals participating in the FRA2000 workshops. The foresters are trained in the workshops in the protocols for map validation. Once validated the maps will then be returned with comments to FAO and EDC. EDC will use this information to revise a final map product.

Accuracy assessment has been conducted for the USGS land cover database at the IGBP 17-class level based on a set of Landsat scenes (Loveland *et al*., in press), with results pending. It may be reasoned that the FAO forest cover, as an associated layer of the database, would have accuracy comparable to that of the IGBP forest classes. Additional misclassification errors from this work may come from some land cover patterns such as flooded grassland causing confusions in the models used to estimate percent forest cover. A concerted effort will be made to conduct an independent accuracy assessment for the FAO mapping project, most likely using the available IGBP Landsat data set and adopting a similar validation strategy (Loveland *et al*., in press).

5   Conclusion

Land cover mapping is a complex task, requiring careful research of interactions between the satellite sensor, atmospheric conditions, elements of earth ecosystems and use of expert knowledge and ancillary materials needed for validation and calibration. This study finds that the USGS global land cover database is an innovative and convenient mapping framework, from which a new, and different, global forest cover map is derived. The techniques used for deriving the FAO forest cover has worked effectively when regional stratification is properly adopted, providing a useful tool and product for the FRA2000 global assessment. Factors affecting quality of the derived global forest cover map include misclassification errors from the USGS product, errors of translation to the FAO legend, data quality problems, and accuracy of the linear unmixing approach.

References

Food and Agriculture Organization (FAO) of the United Nations, 1995. *Forest resources assessment 1990, global synthesis*. FAO Forestry Paper 124, Rome. 46 p.

Loveland, T.R., Reed, B.C., Brown, J.F., Ohlen, D.O., Zhu, Z., Yang, L, and Merchant, J.W., (in press). *Development of a global land cover characteristics database and IGBP DISCover from 1-km AVHRR data*. Photogrammetric Engineering and Remote Sensing.

Reed, B. 1997. *Applications of the U.S. Geological Survey's global land cover product*. Acta Astronautica, 41:671-680.

Reed, B.C., Brown, J.F., VanderZee, D., Loveland, T.L., Merchant, J.W., and Ohlen, D.O. 1994. *Measuring phenological variability from satellite imagery*. Journal of Vegetation Science, 5:703-714.

Malingreau, J.P., Achard, F., D'Souza, G., and others. 1995. *AVHRR for global tropical forest monitoring: the lessons of the TREES project*, Remote Sensing Reviews 12:29-40.

Roberts, D.A., Smith, M.O., and Adams, J.B. 1991. *Green vegetation, non-photosynthetic vegetation, and soils in AVIRIS data.* Remote Sensing of Environment, 44:255-269.

Skole, D. and Tucker, C. 1993. *Tropical deforestation and habitat fragmentation in the Amazon: satellite data from 1978 to 1988*. Science, 260:1905-1910.

Smith, M.O., Ustin, S., Adams, J.B., and Gillespie, A.R. 1990. *Vegetation in deserts: I. A regional measure of abundance from multispectral images*. Remote Sensing of Environment, 31:1-26.

Wessman, C.A., Bateson, C.A., and Benning, T.L. 1996. *Detecting fire and grazing patterns in tallgrass prairie using spectral mixture analysis. Ecological Applications, 7(2):493-511.*

FRA Working Papers

0. *How to write a FRA Working Paper (10 pp. – E)*

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

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

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

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

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

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

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

8. *Remote Sensing and Forest Monitoring in FRA 2000 and beyond. (22 pp. - E)*

9. *Volume/Biomass special Study: Georeferenced Forest Volume Data for Tropical Africa (97 pp. – E)*

10. *Memorias del Taller sobre el Programa de Evaluación de los Recursos Forestales en once Países Latinoamericanos (S)*

11. *Non-wood forest Products study for Mexico, Cuba and South America (draft for comments) (82 pp. – E)*

12. *Annotated bibliography on Forest cover change – Nepal (59 pp. – E)*

13. *Annotated bibliography on Forest cover change – Guatemala (66 pp. – E)*

14. *Forest Resources of Bhutan - Country Report (18 pp. – E)*

15. *Forest Resources of Bangladesh – Country Report (89 pp. – E)*

16. *Forest Resources of Nepal – Country Report (under preparation)*

17. *Forest Resources of Sri Lanka – Country Report (under preparation)*

18. *Forest plantation resource in developing countries (75 pp. – E)*

19. *Global forest cover map (14 pp. – E)*

20. *A concept and strategy for ecological zoning for the global FRA 2000 (23 pp. – E)*

21. *Planning and information needs assessment for forest fires component (32 pp. – E)*

22. *Evaluación de los productos forestales no madereros en América Central (102 pp. – S)*

23. *Forest resources documentation, archiving and research for the Global FRA 2000 (77 pp.–E)*

24. *Maintenance of Country Texts on the FAO Forestry Department Website (25 pp. – E))*

25. *Field documentation of forest cover changes for the Global FRA 2000 (under preparation)*

26. *FRA 2000 Global Ecological Zones Mapping Workshop Report Cambridge, 28-30 July 1999 (53 pp. –E)*

27. *Tropical Deforestation Literature:Geographical and Historical Patterns in the Availability of Information and the Analysis of Causes (17 pp. – E)*

28. *World Forest Survey – Concept Paper (under preparation)*

29. *Forest cover mapping and monitoring with NOAA-AVHRR and other coarse spatial resolution sensors (42 pp. E)*

30. *Web Page Editorial Guidelines (22 pp. – E)*

Please send a message to fra@fao.org for electronic copies or download from
http://www.fao.org/FORESTRY/FO/FRA/index.jsp (under Publications)