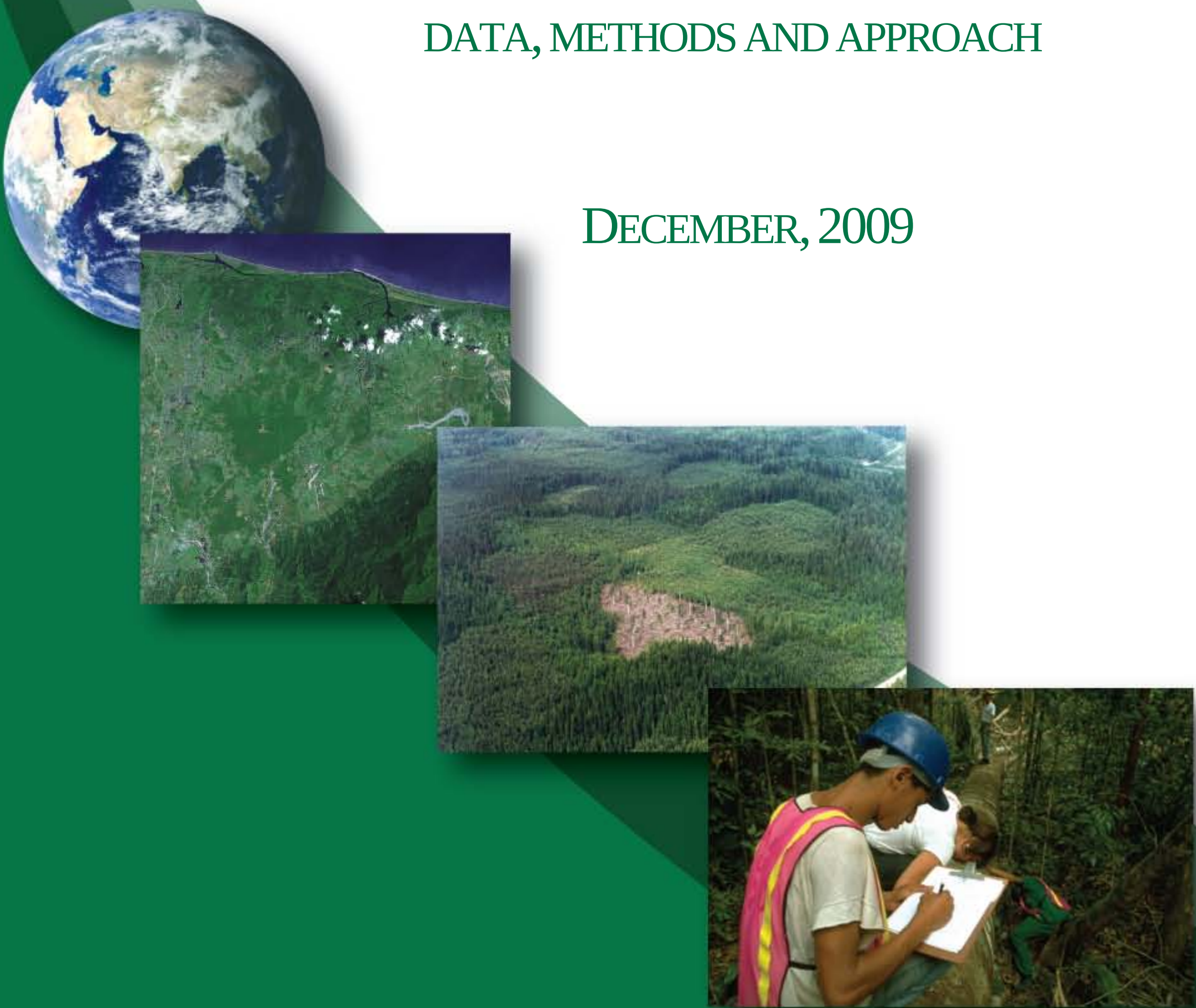
Forest Resources Assessment
Working Paper 155

# THE FRA 2010 REMOTE SENSING SURVEY

## AN OUTLINE OF OBJECTIVES, DATA, METHODS AND APPROACH

DECEMBER, 2009



JRC
EUROPEAN COMMISSION
UCL Université catholique de Louvain
UCL-Geomatics, Belgium
SDSU
FAO FIAT PANIS

## The Global Forest Resources Assessment Programme

Sustainably managed forests have multiple environmental and socio-economic functions which are important at the global, national and local scales, and they play a vital part in sustainable development. Reliable and up-to-date information on the state of forest resources - not only on area and area change, but also on such variables as growing stock, wood and non-wood products, carbon, protected areas, use of forests for recreation and other services, biological diversity and forests' contribution to national economies - is crucial to support decision-making for policies and programmes in forestry and sustainable development at all levels.

FAO, at the request of its member countries, regularly monitors the world's forests and their management and uses through the Global Forest Resources Assessment Programme. The Global Forest Resources Assessment 2010 (FRA 2010) has been requested by the FAO Committee on Forestry in 2007 and will be based on a comprehensive country reporting process, complemented by a global remote sensing survey. The assessment will cover all seven thematic elements of sustainable forest management, including variables related to the policy, legal and institutional framework. FRA 2010 is also aimed at providing information to facilitate the assessment of progress towards the Global Objectives on Forests of the United Nations Forum on Forests and the 2010 Biodiversity Target of the Convention on Biological Diversity. Results are expected to be published in 2010.

The Global Forest Resources Assessment programme is coordinated by the Forestry Department at FAO headquarters in Rome. The contact person is:

Mette Løyche Wilkie
Senior Forestry Officer
FAO Forestry Department
Viale delle Terme di Caracalla
Rome 00153, Italy
E-mail: Mette.LoycheWilkie@fao.org

Readers can also use the following e-mail address: fra@fao.org
More information on the Global Forest Resources Assessment programme can be found at:
www.fao.org/forestry/fra

The coordinators of this work would like to acknowledge the financial contributions made by the European Commission, Governments of Australia and Finland and by FAO.

**Recommended citation:**
FAO, JRC, SDSU and UCL (2009) The 2010 Global Forest Resources Assessment Remote Sensing Survey: an outline of the objectives, data, methods and approach. Forest Resources Assessment Working Paper 155. Published by FAO with FRA RSS partners, Rome, 2009.



.

**Forestry Department**
**Food and Agriculture Organization of the United Nations**

**Forest Resources Assessment Working Paper**

# THE FRA 2010
# REMOTE SENSING SURVEY

## AN OUTLINE OF OBJECTIVES,
## DATA, METHODS AND APPROACH

DECEMBER, 2009

FOREST RESOURCES ASSESSMENT PROGRAMME

WORKING PAPER 155
ROME, ITALY, 2009

## Table of contents



## Acronyms

| | |
|---|---|
| **ETM** | Landsat Enhanced Thematic Mapper |
| **FAO** | Food and Agriculture Organization |
| **FRA** | Global Forest Resource Assessment |
| **GLS** | Global Land Survey |
| **IPCC** | Intergovernmental Panel on Climate Change |
| **JRC** | European Commission Joint Research Centre |
| **LCCS** | FAO Land Cover Classification System |
| **MODIS** | Moderate resolution Imaging Spectroradiometer |
| **NASA** | National Aeronautics and Space Administration |
| **REDD** | Reducing Emissions due to Deforestation and Degradation of forests |
| **RSS** | Remote Sensing Survey |
| **SDSU** | South Dakota State University |
| **UCL** | Catholic University of Louvain |
| **USGS** | United States Geological Survey |
| **UNFCCC** | Unites Nations Framework Convention on Climate Change |
| **VCF** | Vegetation Continuous Fields algorithm |

## Acknowledgements

The FRA 2010 RSS is a partnership between FAO, the Joint Research Centre of the European Commission, US Geological Survey, NASA, South Dakota State University, Friedrich-Schiller University and many national experts.

This paper was based on the work and contributions from many people including: Ralph Ridder (consultant); Adam Gerrand, Erik Lindquist, Mette Wilkie, Rémi D'Annunzio (FAO FRA).

The staff from the European Commission Joint Research Centre (JRC) together with its collaborators from University of Louvain-La-Neuve: Frédéric Achard, René Beuchle, Catherine Bodart, Andreas Brink, Silvia Carboni, François Donnay, Hugh D. Eva, Desirée Johansson, Ouns Kissiyar, Andrea Lupi, Philippe Mayaux, Rastislav Raši, Dario Simonetti, Hans-Jürgen Stibig, Michael Vollmar. Jesús San-Miguel-Ayanz, Pieter Kempeneers, Fernando Sedano, Lucia Seebach, Peter Strobl, Peter Vogt (JRC) Pierre Defourny, Céline Ernst, Astrid Verheggen, Carlos de Wasseige (UCL).

Thomas Loveland (USGS), Matt Hansen, Peter Potapov and Anil Kommareddy (South Dakota State University), John Latham, Renato Cumani, Antonio Di Gregorio, Antonio Martucci, Stefano Giaccio and Ilaria Rosati (FAO NRCE).

Many others have helped in the development of the design of the RSS including FRA National Correspondents and many country experts but space precludes listing them all, please accept our thanks. Funding was supported by initial grants from NASA, the Governments of Finland, Australia, and funding for 2009-11 from the European Commission. For more information please visit our website: http://www.fao.org/forestry/fra2010-remotesensing/en/

## Executive summary

The world's forests provide vital economic, social and environmental benefits. They supply wood and non-wood forest products, support human livelihoods, supply clean water and provide habitat for half the species on the planet. However, approximately 13 million hectares of forest are converted to other land uses annually worldwide. This forest clearing along with other forestry related activities is responsible for about 17 percent of human induced greenhouse gas emissions. International processes related to forests demand accurate information on tree cover and forest resources. Since 1946, the Food and Agriculture Organization of the United Nations (FAO) provides detailed information on the world's forests, their extent, their condition and uses at 5 to 10 year intervals. For the Global Forest Resources Assessment 2010 (FRA 2010), a systematic, comprehensive, global survey of forests based on remote sensing imagery is being undertaken.

The FRA 2010 Remote Sensing Survey (RSS) uses satellite remote sensing of the Earth's surface to improve information on worldwide tree cover and forest land use. The main goal is to obtain systematic information on the distribution and changes in forest cover and forest land use from 1990 to 2000 and 2005 at regional, ecozone and global levels.

The United States Geological Survey's Landsat Global Land Survey dataset (GLS) provided the imagery data for interpretation and classification. The GLS is a spatially consistent, multi-date dataset composed of the single best Landsat image acquisition covering the Earth's land surface. A systematic sampling design based on each longitude and latitude intersection has been implemented (13 689 sites). Each sample tile covers a 10 by 10 kilometre square for which various Landsat optical bands of the GLS acquisitions were compiled, for the three dates (56 219 individual imagery chips). As an experimental addition, for a portion of the sample tiles where persistent cloud cover obscures the forest, TerraSAR-X radar data augment the dataset.

The image processing includes segmentation of the images into polygons based on similar satellite image characteristics and labeling these following a simplified form of the FAO land cover and land use classifications. Polygons, pre-labeled with draft land cover and use attributes, and the remotely sensed imagery are provided to countries and regional experts for validation. Through a series of regional training workshops, and in partnership with the European Commission's Joint Research Centre (JRC) and South Dakota State University (SDSU) in the United States, the RSS brings together leading land cover remote sensing scientists to analyse satellite data and engage with country experts in over 150 countries. A web-based data portal has been built to access the raw data, the pre-labelled land cover polygons and the final, validated land cover and land use attribution. The access to free remote sensing data and software will particularly benefit developing countries with limited forest monitoring data or capacity.

At the time of writing (December 2009) the data compilation has been completed for all 13 689 sample sites. Initial processing has been done on many samples by JRC and FAO and countries are engaged in the Pilot Study and progressively through the initial national validation and training workshops in Africa and South America. Other regions and countries will follow.

The main expected results of the RSS are summary statistics of tree cover and forest area change at global and regional spatial scales. A new updated global tree cover map, based on MODIS images, will also be produced. The RSS will hence improve understanding of total forest area changed, the patterns resulting from this change, and the processes driving forest cover change globally. This is information that governments, land managers, researchers and civil society groups can use to make better-informed decisions regarding the world's forest resources. The main report of the study is planned to be completed by the end of 2011 in the International Year of the Forest.

## 1 Background and Justification

The world's forests provide vital economic, social and environmental benefits. They supply wood and non-wood forest products, support human livelihoods, supply clean water and provide habitat for half the species on the planet. Forests and forest management are coming under increasing scrutiny as agents of climate change mitigation, most notably through the Reducing Emissions from Deforestation and Degradation (REDD) initiatives [since Bali, 2007]. During a 2008 G-8 Summit, world leaders "*encouraged actions for REDD including the development of an international forest monitoring network building on existing initiatives*" [1]. As part of the 2010 Global Forest Resources Assessment (FRA), the Food and Agriculture Organization of the United Nations (FAO), its member countries and partners are undertaking a systematic remote sensing survey which will form the basis for a consistent long-term global forest monitoring system. Such a system will help meet the G-8 recommendations and assist developing countries to prepare and benefit from a possible REDD mechanism.

### *1.1 History of the Global Forest Resources Assessment*

FAO provides detailed information on the world's forests, their condition and their uses, at 5 to 10 year intervals, based on data that countries provide to FAO in response to a questionnaire. FAO compiles and analyses the information and presents the current status of the world's forest resources and their changes over time. Historically, FRA reporting has evolved to reflect the major issues of concern at the time. Early reports focused on timber stocks in response to post-war (WWII) needs for building materials while more recent emphasis has shifted to deforestation and conservation issues. The breadth and quality has also improved as individual countries gain reporting capacity and information availability increases. The most recent assessment in 2005 was the most comprehensive in scope ever and aimed at assessing progress towards sustainable forest management[2].

### *1.2 The need for accurate and timely information on forest area*

Forest cover dynamics change on local to regional scales but contribute to local, regional, and global impacts on climate, biodiversity and ecosystem services. According to the FRA2005[2], approximately 13 million hectares of forest cover are converted to other land uses annually worldwide. With respect to climate change alone, the Intergovernmental Panel on Climate Change (IPCC) states that forest clearing along with other forestry related activities is responsible for about 17 percent of human-produced greenhouse gas emissions annually[3]. The Clean Development Mechanism under the United Nations Framework Convention on Climate Change (UNFCCC) and REDD are two of the initiatives being developed to help reduce the negative effects of forest loss on climate but issues of accounting for and monitoring forest resources remain difficult to resolve.

International and national processes related to forests require accurate information on tree cover and forest resources and the FRA processes aim to provide data relevant to these. Historically, however, the quantity and quality of data available for reporting varies widely on a country-by-country basis. Forest definitions change from place to place based on national definitions cultural values and the purpose of the assessment and the methodology used. Many countries also lack consistent, historical records and technical or financial capacity to adequately report on changes in forest area over time. Through the FRA process, FAO is working to strengthen national technical capacity thereby improving forestry-related information gathering and reporting. The FRA 2010 Remote Sensing Survey (hereafter simply RSS) will continue this process using satellite remote sensing of the Earth's surface to improve information on tree cover and forest land use changes worldwide.

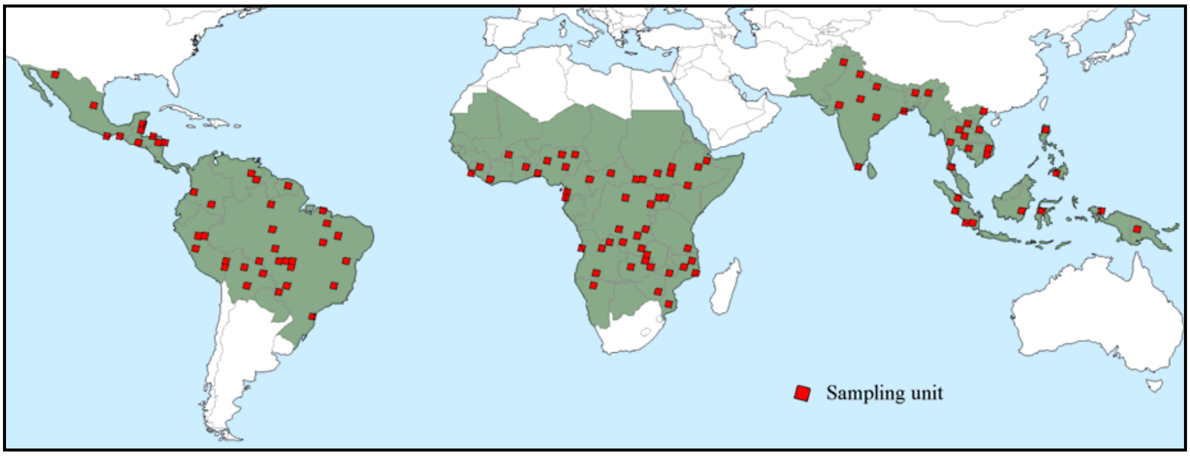



**Figure 1. Distribution of Landsat scenes used in the 1990 and 2000 FRA remote sensing surveys. The analyses focused on the tropics and represented a 10 percent sample of the area of the tropics. Compare this distribution to the current FRA 2010 RSS shown in Figure 3.**

*1.3 Why remote sensing?*

Satellite remote sensing offers the advantage of broad area coverage, systematic observations, and the ability to use standardized, repeatable analyses to characterize the Earth's surface. It is one of the only comprehensive sources of information available for many of the large, forested areas on Earth. Though remote sensing does not replace the need for field-collected data, it offers distinct benefits when conducting large-area surveys for broad vegetation-type categories.

FRA 1990[4] and FRA 2000[5] both included a remote sensing component to complement national reporting, focusing on tropical areas. The remote sensing studies provided an independent assessment of tropical tree cover changes and land use dynamics in the 1980s and 1990s. These surveys were based on a stratified random sampling and on temporal analysis of Landsat satellite images (Figure 1). For each of the 117 selected sample units, three Landsat satellite images from different dates provided the information for producing statistics on forest and other land cover changes from the period 1980 to 1990 and from 1990 to 2000 for the tropics as a whole and for Africa, Asia and Latin America separately.

The FRA 2010 RSS will build on and further strengthen the previous remote sensing surveys through a globally comprehensive approach and increase in-country mapping and inventory capacity. In partnership with the European Commission's Joint Research Centre (JRC) and South Dakota State University (SDSU) in the United States, the RSS brings together the comprehensive Landsat Global Land Survey satellite imagery database[6] and leading land cover remote sensing scientists to analyse satellite data and engage with country experts in over 150 countries. The goals of the RSS are to obtain systematic information on the distribution and changes in forest cover and forest land use from 1990 to 2000 to 2005 at regional, ecozone and global levels. The RSS also provides a consistent framework upon which future global assessments and more detailed regional assessments can be based.

*1.4 Land cover and land use*

The RSS will produce results on both tree cover and forest land use. Land cover refers to the biophysical attributes of the Earth's surface and can be directly detected from a remote sensing instrument, like the Landsat satellite. Land use involves a human dimension or purpose characterizing a location. It can sometimes be inferred from remotely sensed data, however, is typically only verified with local, expert knowledge or data collected from field inspections. Accurate information on land use is critical to understand the drivers of forest cover change and help develop effective policies and strategies to reverse forest loss. By incorporating both land cover and use, the remotely sensed imagery and classification process of the RSS will more adequately describe both physical tree cover and the variably defined ‘forest area’. An example of how remotely sensed tree cover and country-defined forest area compare is in Figure 2.

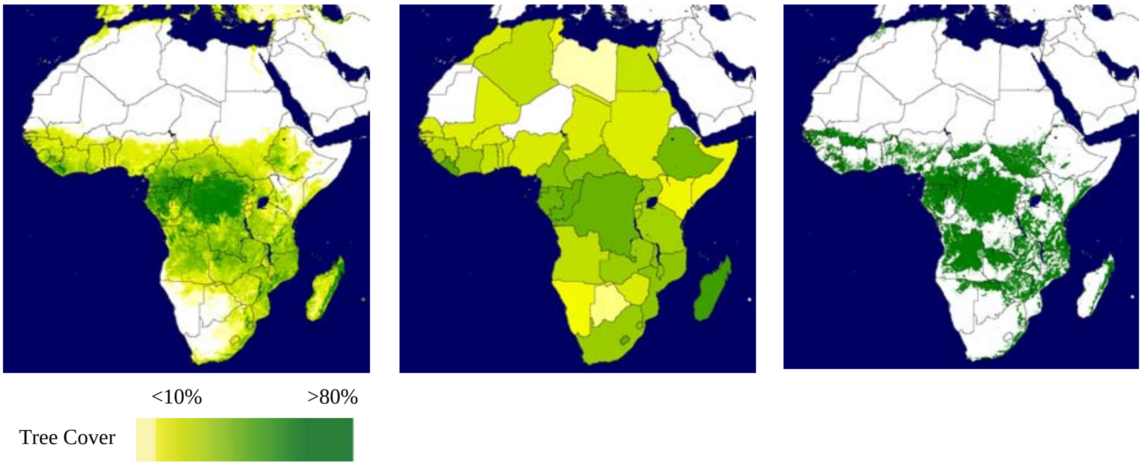



**Figure 2. Comparison of remote sensing and national reporting for Africa showing (left) percent tree cover classification for Africa from 2001 MODIS Vegetation Continuous Fields[7] (VCF) product and (center) percent tree cover threshold which yields a forest area estimate for each country which matches that reported to FRA 2000. This map was created by starting at the densest tree cover per country and sliding the threshold down from there until the forest areas matched that reported for FRA 2000. (Right) Forest map where per country forested area match FRA 2000 totals. Green = forest, white = non-forest. From Dr. Matthew Hansen at South Dakota State University.**

## 2 Methods

### *2.1 Sample grid and satellite imagery*

The RSS global sampling grid consists of 13 689 sites and covers the globe between 75 degrees North and South in latitude (Figure 3). A systematic sampling design based on each longitude and latitude intersection has been implemented, with a reduced intensity above 60 degrees North/South latitude due to the curvature of the Earth (every second intersection sampled in between 60 and 75 degrees North/South). Each sample tile covers a 10 by 10 kilometre square at every one-degree latitude and longitude junction (approximately 100km apart). This grid of sample plots is the same basic layout but at a lower intensity (wider spacing) than the national forest assessments supported by FAO[8]. Tiles were included on a land mask derived from the VMAP0 (Vector Map Level 0, United States National Imagery and Mapping Agency) data layer. Antarctica was excluded from the land mask. Sample locations within deserts, permanent ice, or otherwise non-tree covered are also excluded from analysis leaving a total number of 9 329 sites. The JRC, as part of their already mature TREES, FOREST, and MONDE research programs, will process 5 967 tiles and the FAO will process 3 362 tiles.

### *2.2 Remote sensing inputs*

The United States Geological Survey’s Landsat Global Land Survey dataset (GLS) provided the imagery data for interpretation and classification. The GLS is a spatially consistent, multi-date dataset composed of the single best Landsat image acquisition covering most of the Earth’s land surface and centered on the years 1975, 1990, 2000, and 2005[6].

**Figure 3. Distribution of the 13 689 FRA 2010 RSS global survey sites. Inset shows detail of sample sites across parts of Europe and N. Africa.**

The initial focus of the RSS is the GLS1990, GLS2000 and GLS2005 datasets. Where possible, 1975 Landsat data will also be analysed. For each survey tile, Landsat optical bands 1-5 and 7 (also 8 in the case of ETM+) of the GLS acquisitions were compiled. These were clipped to a 20km by 20km box centered on each one-degree latitude and longitude intersection to create imagery 'chips'. This produced 56 219 individual imagery chips for the three time periods. The central 10km by 10km box of each sampling tile will be used for area calculations and statistical analysis.
Complementary satellite imagery (Landsat TM, ASTER, or IRS-LISS) provided by space agencies (INPE-Brazil, GISTDA-Thailand, Geoscience-Australia, and ISRO-India) or acquired through satellite image providers has been used to fill a number of gaps (clouds, missing data) existing in the initial Landsat GLS database.

*2.3 Use of radar data*

For a portion of the sample tiles where persistent cloud cover obscures the forest, TerraSAR-X radar data will augment the dataset[9]. This is an experimental addition to the core optical imagery being used in the RSS (Figure 4). For more information, see http://www.frasar2010.uni-jena.de/

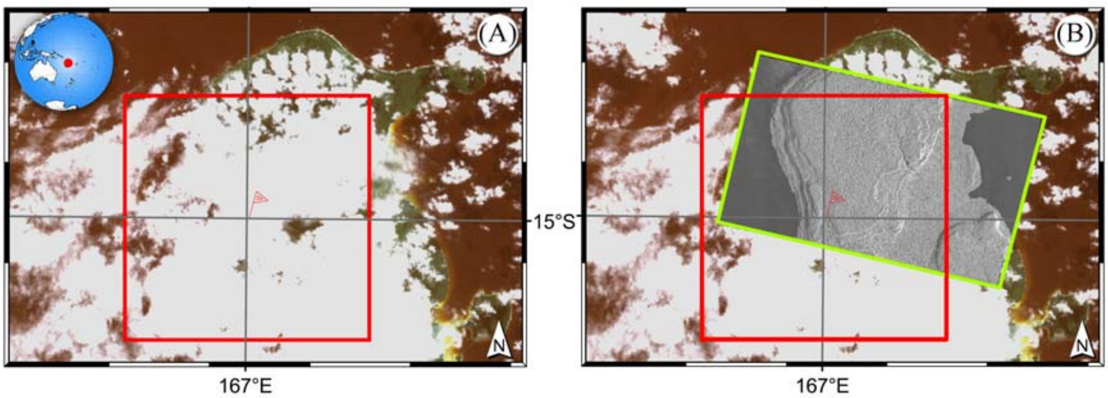



**Figure 4. An example from the FRA-SAR (Friedrich-Schiller University) project highlighting the utility of SAR (radar) data where cloud cover obscures optical remote sensing. A RSS sample site (red box) with cloud cover (A). The TerraSAR-X image ©DLR (green box in B) shows the ability to penetrate cloud cover and provide data capable of producing meaningful estimates of tree cover.**

*2.4 Processing optical data, Segmentation and Classification, Labeling and Legend*

The Landsat satellite imagery of the different sites needs to be first radiometrically corrected and harmonized. The imagery has been processed to high level enhanced and normalized products. Normalization and enhancement reduce atmospheric interference and improve the interpretability of the imagery. Additional imagery inputs for each chip include a cloud mask, water mask, and data/no data mask.

The RSS uses a multi-date, multi-resolution image segmentation approach[10] for classifying each survey tile (Figure 5). Normalized Landsat bands 3, 4, and 5 from the GLS1990, 2000, and 2005 datasets are used for producing segmented images on the sample sites. Image segmentation is performed using mainly the commercially available software e-Cognition[11] (and JRC in-house software for Europe). The results are polygon layers containing information from the different time periods of imagery. The polygon layers are classified separately for each time period using Landsat optical bands (1-5 and 7), resulting in three land cover maps for the 1990s, 2000s, and 2005s. Changes in land cover over time are captured in the polygons and reflected in changes in land cover labels assigned during the classification process (Figure 6). Several tuning parameters can be adjusted to optimize segmentation results and in the case of the RSS, are adjusted on an image by image basis such that the resulting minimum mapping unit is approximately 5 hectares.

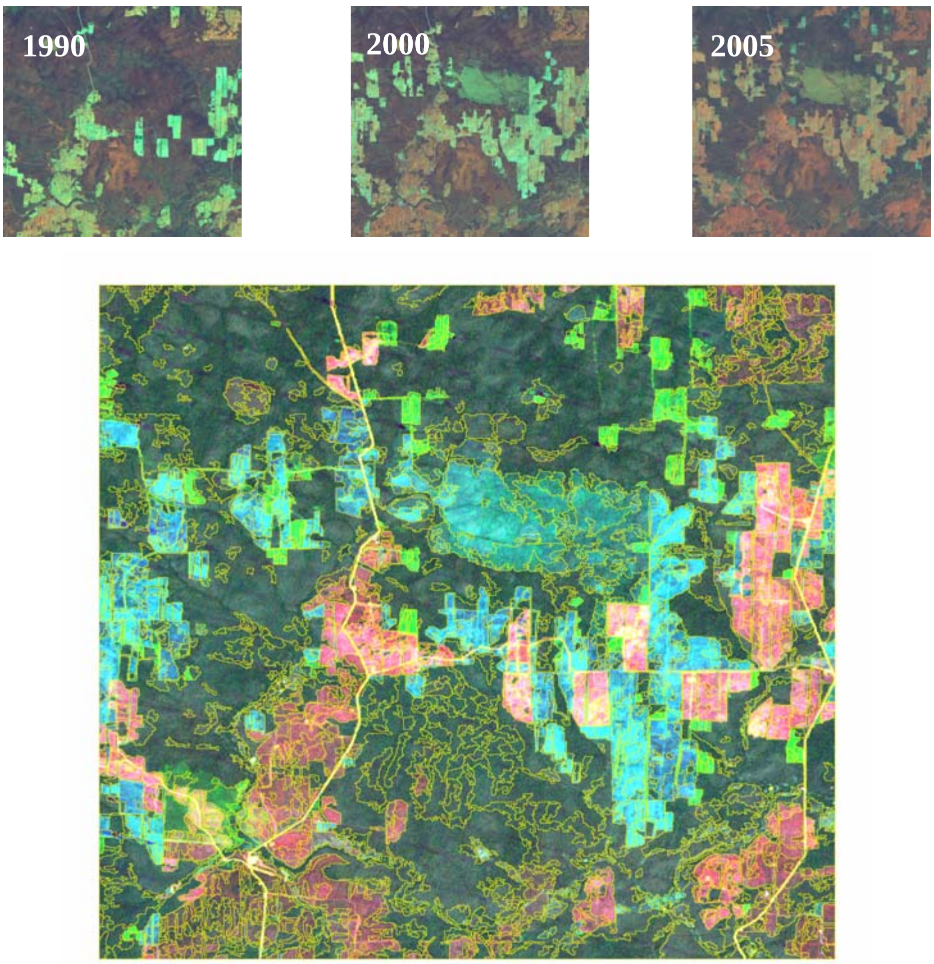



**Figure 5. Time 1, 2, and 3 imagery (above) combined into a multi-date image (below) and segmentation polygons overlaid (in yellow). Clearings present in time 1 (1990) appear red, new clearings in time 2 (2000) appear blue, and new clearings in time 3 (2005) appear light green. The single polygon layer from segmentation includes all of this information and will contain classification labels for each time period.**

Producing the final land cover polygons is a two-step process. The first step is a draft pre-labeling exercise followed by label correction and validation by in-country experts. Polygons are classified and pre-labeled in one of two ways: (i) automatically using spectral training signatures and (ii) by visual interpretation. Automated classification and labeling by the JRC will be applied to survey tiles in the humid tropics, Russian boreal forests, and Europe[12]. For all other regions, FAO specialists will use a combination of automated methods and visual interpretation to classify and label polygons.

The original broad land cover classes will be transformed into similarly broad land use classes (forest, other wooded land, other land use, water) but where there is a change to/from forest, we will undertake a more detailed land use and cover classification of the "other land" category. The main purpose of labeling polygons by land use is to assess forest area change and the major drivers of these changes.

The FAO-developed Land Cover Classification System (LCCS)[13] has been adapted for labeling polygons by land cover and includes six land cover classes (plus no data). Survey tiles processed by the JRC use a slightly different initial legend and will be re-coded to fit the FRA cover classes. Nine land-use codes have been developed for use in the RSS based on FRA definitions (Table 1).

**Table 1: Land cover (left column) and land-use (right column) classes to be used in the RSS. Grey-shaded classes represent a more detailed level of classification to be labelled where possible.**

| **Land Cover Class** |
|---|
| Tree Cover |
| Shrub Cover |
| Herbaceous |
| Bare/Non-vegetated |
| Wetlands |
| Water |
| No data |

| **Land Use Class** |
|---|
| Forest |
| Other wooded land |
| Other land with tree cover |
| Grass and herbaceous cover |
| Agricultural crops |
| Built up habitation |
| Bare land |
| Wetlands |
| Water |
| No data |

Polygons, pre-labeled with land cover and use attributes, and the remotely sensed imagery will be provided to countries and regional experts for validation. Polygon labels will be checked for accuracy against each time period of imagery. Ancillary, country-specific data sets (such as forest inventory and vegetation type maps where available) and qualitative information obtained from the Degree Confluence Project (www.confluence.org), Panoramio™ and Google Earth™ will also be used for validation. Forest area changes both positive (afforestation or natural expansion) and negative (deforestation) between time periods will be summarized by global ecological zones and at regional levels.

## 3 Results and Discussion

At the time of writing (December 2009), the RSS is a work in progress. The expected results of the RSS include summary statistics of tree cover and forest area change at global and regional spatial scales. Where forest areas have changed to other land uses or vice-versa, the land use change over time will be further analyzed to provide insight into the main mechanisms driving the changes.

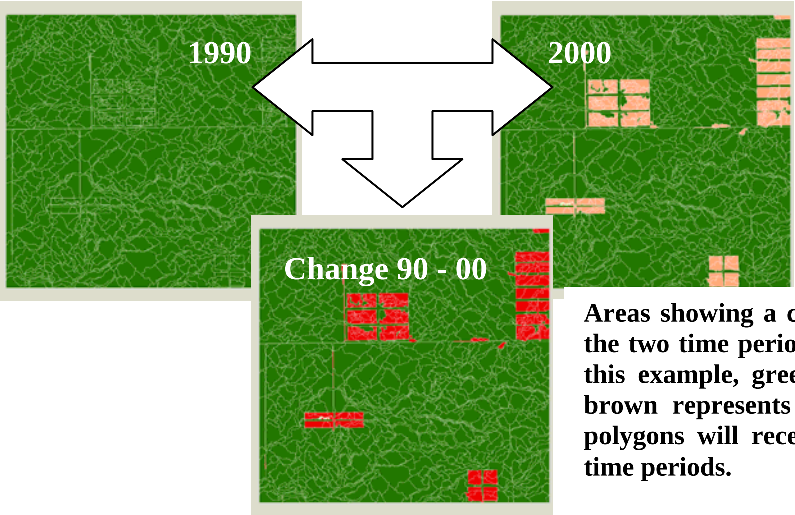



**Figure 6. A sample site showing the draft pre-labeled polygons resulting from multi-date segmentation classified by land cover for 1990 (left) and 2000 (right).**

**Areas showing a change in land cover between the two time periods are shown in red (left). In this example, green represents tree cover and brown represents herbaceous cover. Changed polygons will receive land use labels for both time periods.**

A new, updated global tree cover map, similar to figure 7, will also be produced as part of the RSS. This product will be spatially comprehensive ("wall-to-wall"), and have a pixel size of 250 meters by 250 meters, which is far more detailed than the 1km resolution for the FRA2000 forest map. Produced at South Dakota State University, it will use the MODIS sensor and the Vegetation Continuous Fields (VCF) algorithm[7]. The VCF product depicts pixels as percent tree cover from zero to 100. The validated land cover polygons from the RSS sample tiles will be used to validate the VCF results and improve the VCF algorithm for future global tree cover maps.

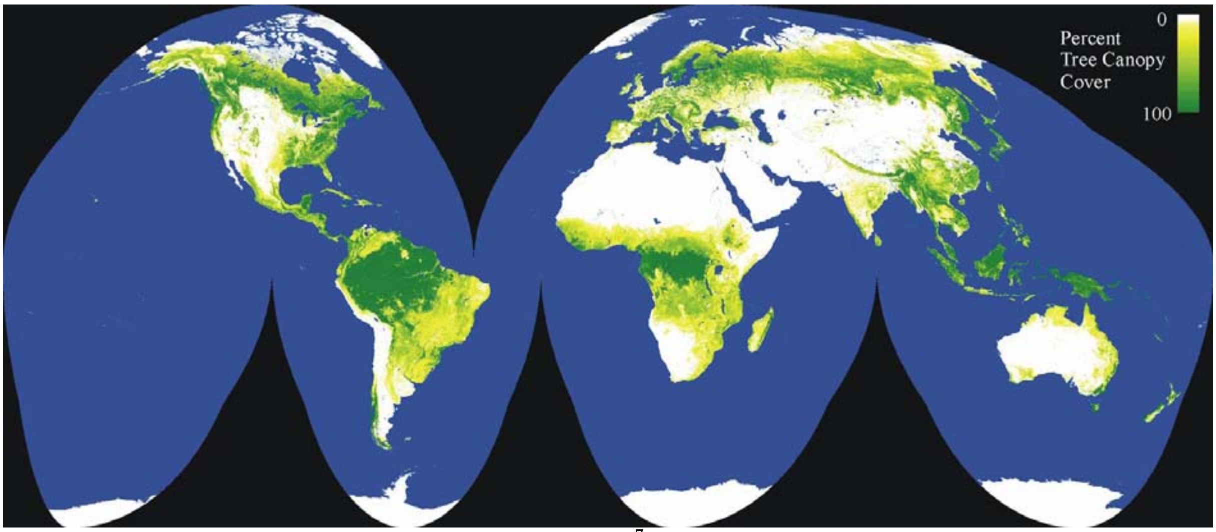



**Figure 7. The global MODIS VCF product circa 2000[7] showing percent tree canopy cover at 500 x 500 meter pixel size. Validated RSS sample sites may help improve the results of global map products.**

*3.1 Statistical sampling versus wall-to-wall mapping*

There are many options in choosing a sampling design for forest monitoring and these were evaluated for the FRA2010 RSS[14,15]. The RSS uses a globally comprehensive, systematic sampling approach covering one percent of the land surface of the Earth. Systematic sampling of medium spatial resolution imagery was chosen as a solution that achieves manageable data volumes, comprehensive coverage of sample plot locations, and returns statistically valid results at regional and global spatial scales. Though global coverage, remotely sensed land cover products do exist, they exhibit a relatively coarse spatial resolution (250+ meters) and many forest cover

changes take place at spatial scales smaller than can adequately be measured with 'large' pixels, especially in the tropics.
Landsat data was chosen as the preferred data source for the FRA RSS because it has a suitable pixel size (30m) to detect small patches of forest change and because it has the best historical archive of global data[16]. The commendable decision in 2008 by the USGS to open the entire Landsat archive for free use overcomes one of the major historical limitations to use of these data. However, the large data volumes and difficulties of automating the processing to produce successful results across a wide variety of ecosystems, currently limit the ability to develop a global, wall-to-wall map of the worlds forests at Landsat-scale. These constraints are being addressed and promising results are emerging on regional and continental scales in North America[17], South America[18], Australia[19], Central Africa[20], and Europe[21].

*3.2 Country involvement and capacity building*
FAO and its partners will work closely with remote sensing and forest inventory specialists in national governments and with a wide range of non-governmental organizations to complete the RSS. The analysis and validation of land cover and use will benefit greatly from individual country contributions including national data and local knowledge to help ensure accurate results. FAO and JRC will provide computer software free of charge to all participating countries for viewing the imagery and labelling land cover and land use changes. A series of training workshops will be held around the world in regional centres to improve the technical capacity of local staff to interpret remotely sensed imagery. The access to free remote sensing data and software will particularly benefit developing countries with limited forest monitoring data or capacity.

FAO has also built a web-based data portal to facilitate access to the subset and pre-processed Landsat imagery used in the survey, pre-labelled land cover polygons and the final, validated land cover and land use product of the RSS. Password protected download and upload capabilities are provided to all participating countries enabling them to access and store the results of validation work as it is completed. Upload of ancillary data such as photographs or other information is also facilitated.

FAO and JRC are currently seeking nominations for country specialists to assist with the land cover and land use validation exercises of the RSS. Ideally suited candidates will have some experience in remote sensing and/or geographic information systems as well as knowledge of forest and national land cover or land use attributes. FAO will provide funding to developing countries for their nominated specialist to attend the regional training workshops for their region. Those countries with a large number of sample tiles may be eligible for funding support to complete the validation exercises. The RSS is scheduled for completion by the end of 2011, International year of Forests.

## 4 Conclusion

The FRA 2010 Remote Sensing survey is a systematic, comprehensive, global study of tree cover and forest land-use changes from 1990 to 2000 to 2005. It presents a consistent methodology for monitoring forest change at a global level that can be expanded for more detailed studies. It is expected that the survey will improve understanding of total forest area changed, the patterns resulting from this change, and the processes driving forest cover change globally. This is information that governments, land managers, researchers and civil society groups can use to make better-informed decisions regarding the world's forest resources.

Outreach and training activities by FAO, JRC and partners will help build technical capacity to monitor forest resources in many countries. FAO and JRC will provide access to remote sensing imagery both through the internet and hard media. The imagery and the processing software included as part of the RSS and presented in regional training workshops can be used for other studies and monitoring purposes. Additionally, a global network of remote sensing specialists will be built representing a powerful human resource for improved technical capacity and proficiency in many countries.

The FRA 2010 country reporting process and the RSS combined will provide a basis for reporting on progress towards sections of: (i) the Convention on Biological Diversity's target of reversing biodiversity loss by 2010, (ii) the Millennium Development Goals, (iii) the Global Objectives of the UN Forum on Forests, (iv) the International Tropical Timber Organization's Objective 2000. If countries choose and have the resources to do so, the methods have the potential to form a platform for developing more detailed reporting capabilities at a national level such as those required on land use and land use change for the UN Framework Convention on Climate Change and the Kyoto Protocol and the REDD mechanism currently being negotiated.

## Literature Cited


1. The Group of Eight Summit, 2008. Hokkaido, Tokyo G8 Summit Leaders Declaration Hokkaido Toyako, 8 July 2008. http://www.g8summit.go.jp/eng/doc/doc080714_en.html
2. FAO, 2006. Global Forest Resources Assessment 2005, FAO Forestry Paper 147. ftp://ftp.fao.org/docrep/fao/008/a0400e/
3. Intergovernmental Panel on Climate Change, 2007. Climate change 2007-The Physical Science Basis: Contribution of Working Group I to the Fourth Assessment Report of the IPCC (Cambridge University Press, Cambridge, UK).
4. FAO, 1995. Forest resources assessment 1990 – global synthesis. FAO Forestry Paper 124. Rome, Italy.
5. FAO, 2001. FRA 2000 Main Report. FAO Forestry Paper 140. Rome, Italy. http://www.fao.org/forestry/fra2000report/en/
6. Gutman, G., Byrnes, R., Masek, J., Covington, S., Justice, C., Franks, S. and Kurtz, R., 2008. Towards monitoring land-cover and land-use changes at a global scale: The Global Land Survey 2005. *Photogrammetric Engineering and Remote Sensing*, 74, pp. 6–10.
7. Hansen, M.C., Dimiceli, C., Sohlberg, R.A., 2003. Global percent tree cover at a spatial resolution of 500 meters: First results of the MODIS vegetation continuous fields algorithm, *Earth Interactions*, 7, paper no. 10, 15 pp.
8. FAO, 2008. National Forest Monitoring and Assessment- Manual for integrated field data collection. National Forest Monitoring and Assessment Working Paper NFMA 37/E. Rome
9. Knuth, R., Eckardt, R. , Richter, N., Thiel, C. Schmullius, C., 2009. FRA-SAR 2010 - An experimental analysis of high resolution synthetic aperture radar within the framework of the FAO's FRA 2010. *Proceedings of the 33rd International Symposium on Remote Sensing of the Environment*, Stresa, Italy, April 17, 2009.
10. Desclée, B, Bogaert, P., Defourny, P., 2006. Forest change detection by statistical object-based method. *Remote Sensing of Environment*, 102, pp. 1-11.
11. Baatz, M. and Schape, A., 2000. Multiresolution segmentation: an optimization approach for high quality multi-scale image segmentation. In: Strobl, J., Blaschke, T., Griesebner, G. (Eds.), Angewandte Geographische Informations-Verarbeitung XII. Wichmann Verlag, Karlsruhe, p.p. 12– 23, 2000.
12. Bodart, C., Beuchle, R., Simonetti, D., Eva, H., Raši, R., Carboni, S., Brink, A., Stibig, H. Achard, F., Mayaux, P. 2009. Global monitoring of tropical forest cover changes by means of a sample approach and object-based classification of multi-scene Landsat imagery: pre-processing and first results. *Proceedings of the 33rd International Symposium on Remote Sensing of the Environment*, Stresa, Italy, April 17, 2009.
13. FAO, 2005. Land Cover Classification System (LCCS), Version 2: Classification Concepts and User Manual. Ed. Di Gregorio, A. http://www.fao.org/docrep/008/y7220e/y7220e00.htm
14. FAO 2007a. Global Forest Resources Assessment 2010, Options and recommendations for a global remote sensing survey of forests. Forest Resources Assessment programme Working Paper 141. ftp://ftp.fao.org/docrep/fao/010/ai074e/ai074e00.pdf.

15. Mayaux, P., Holmgren, P., Achard, F., Eva, H., Stibig H.J., and Branthomme, A. 2005. Tropical forest cover change in the 1990s and options for future monitoring. *Phil. Trans. R. Soc. B 2005 360, 373-384*
16. Williams, D.L., Goward, S. and Arvidson, T., 2006. Landsat: yesterday, today, and tomorrow. *Photogrammetric Engineering and Remote Sensing*, 72, pp. 1171–1178.
17. Masek, J.G., Vermote, E.F., Saleous, N.E., Wolfe, R., Hall, F.G., Huemmrich, K.F., Gao, F., Kutler, J., Lim, T., 2006. A Landsat surface reflectance dataset for North America, 1990-2000. *IEEE Geoscience and Remote Sensing Letters*, 3, pp. 68-72.
18. INPE, 2008. Monitoramento da Floresta Amazônica Brasileira por Satêlite. *Projeto PRODES* http://www.obt.inpe.br/prodes.
19. Caccetta, P.A., Furby, S.L., O'Connell, J., Wallace, J.F. and Wu, X. 2007. Continental Monitoring: 34 Years of Land Cover Change Using Landsat Imagery, *32nd International Symposium on Remote Sensing of Environment*, June 25-29, 2007, San José, Costa Rica.
20. Hansen, M., Roy, D.P., Lindquist, E., Justice, C., Altstatt, A., 2008a. A method for integrating MODIS and Landsat data for systematic monitoring of forest cover and change in Central Africa. *Remote Sensing of Environment*, 112, pp. 2495–2513.
21. Pekkarinen, A., Reithmaier, L. Strobl, P., 2009. Pan-European forest/non-forest mapping with Landsat ETM+ and Corine Land Cover 2000 data. *ISPRS Journal of Photogrammetry and Remote Sensing* 64, 171-183.

## Further Reading

Achard, F., Eva, H.D, Stibig, H.J., Mayeaux, P., Gallego, J., Richards, T., Malingreau, J.P., 2002. Determination of deforestation rates of the world's humid tropical forests. *Science*, 297, pp. 999-1002.

Bonan, G.B., 2008. Forests and climate change: forcings, feedbacks, and the climate benefit of forests. *Science*, 320, pp. 1444-1449.

Duveiller, G., Defourny, P., Desclée, B., Mayeaux, P., 2008. Deforestation in Central Africa: estimates at regional, national and landscape levels by advanced processing of systematically-distributed Landsat extracts. *Remote Sensing of Environment*, 112, pp. 1969-1981.

FAO, 2001. Global Ecological Zoning for the Global Forest Resources Assessment, 2000. Forest Resources Assessment - Working Paper 56. Rome, Italy. http://www.fao.org/docrep/006/ad652e/ad652e00.htm.

FAO, 2007b. Specification of National Reporting Tables for FRA 2010. Forest Resources Assessment Programme Working Paper 135. http://www.fao.org/forestry/media/14119/1/0/

Grainger, A. 2008. Difficulties in tracking the long-term global trend in tropical forest area. *Proceedings of the National Academy of Sciences*: 105: 818-823. 0703015105.

Hansen, M.C., Stehman, S.V., Potapov, P.V., Loveland, T.R., Townshend, J.R.G., DeFries, R.S., Pittman, K.W., Arunarwati, B., Stolle, F., Steininger, M.K., Carroll, M., Dimiceli, C., 2008b.Humid tropical forest clearing from 2000 to 2005 quantified by using multitemporal and multiresolution remotely sensed data. *Proceedings of the National Academy of Science:* 105, pp. 9439-9444.

Lambin, E., and Geist, H., (eds), 2005. *Land Use and Land Cover Change: Local Processes, Global Impacts* (Springer, New York).

Potapov, P., Hansen, M.C., Stehman, S.V., Loveland, T.R., Pittman, K., 2008. Combining MODIS and Landsat imagery to estimate and map boreal forest cover loss. *Remote Sensing of Environment*, 112, pp. 3708-3719.

Stehman, S.V., 2003. Statistical sampling to characterize land cover change. *Remote Sensing of Environment*, 86, pp. 517-529.

Tucker, C.J., Grant, D.M., Dykstra, J.D., 2004. NASA's global orthorectified Landsat data set. *Photogrammetric Engineering and Remote Sensing*, 70, pp. 313–322.

UNFF, 2007. Non-legally Binding Instrument on all Types of Forests. UN General Assembly A/C.2/62/L.5.

Wilson, Edward O. (ed.), 1988. Biodiversity. National Academy Press, Washington, DC, 521pp.