Forestry Department

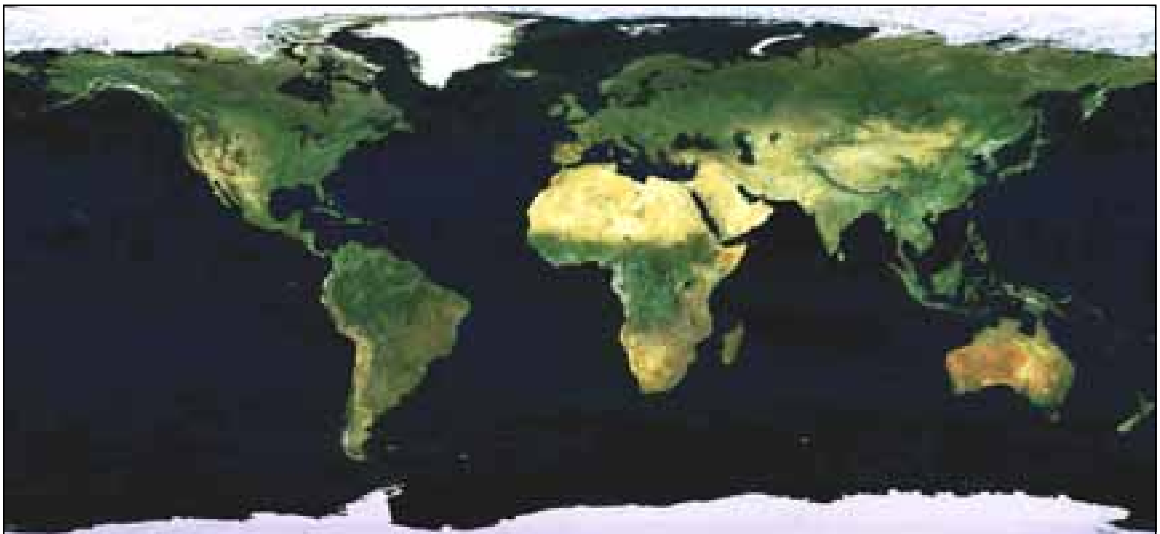
Food and Agriculture Organization of the United Nations

GLOBAL FOREST RESOURCES ASSESSMENT 2010

OPTIONS AND RECOMMENDATIONS FOR A GLOBAL REMOTE SENSING SURVEY OF FORESTS

RALPH M. RIDDER

MARCH, 2007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FOREST RESOURCES ASSESSMENT PROGRAMME **WORKING PAPER 141**

ROME, 2007

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:

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Ralph M. RIDDER Rome and Washington DC, March 2007

Executive summary

FAO has been coordinating global forest resources assessments every five to ten years since 1946 (FAO, 2006), with the objective to provide a periodic global and uniform picture of existing forests, derived trends and statistics. Especially FAO's periodically reported deforestation rates enjoy a high degree of public attention and are widely cited in literature. The estimates of FAO's Global Forest Resources Assessment (FRA) programme are largely based on national statistics and inventory reports, which contain detailed information on the forests of individual countries reported by each government. "*However, differences among data sets from the various countries can be great owing to the methods applied, the terms and definitions employed and the currency of the information in the individual inventories. Despite adjustments made to accommodate these differences, uncertainties can still arise when statistics from different countries are compared*" (FAO, 2002).

Resulting key issues are the lack of regionally harmonized information on (i) forest areas changes and on (ii) land use dynamics.

To complement the national reporting, to provide an independent picture of forest cover trends and to specifically address regional forest area changes and land use dynamics in the 1980s and 1990s, FAO conducted two pan-tropical remote sensing surveys as part of FRA 1990 and FRA 2000. To build on and further strengthen the concept of previous remote sensing surveys and increase in-country mapping and assessment capacity FAO is planning to carry out its first global Remote Sensing Survey of Forests (RSS) within the framework of the upcoming FRA 2010.

The expected outputs of the FRA 2010 RSS are:

- Monitor forests for the time period **1975 to 1990 to 2000 to 2005** at regional, biome and global levels, delivering (i) **area change statistics,** (ii) **information on land use dynamics** (change matrices), and (iii) **forest maps**.
- **Establish** a publicly accessible **information framework in support of monitoring of forests, land use and the environment**, including to facilitate further global or regional monitoring of the terrestrial environment at large, as well as to assist national monitoring efforts.

"*Technology improvements and better access to remote sensing data make it possible to expand the scope of the planned 2010 RSS compared to previous FRA 1990 and FRA*

2000 remote sensing surveys" (FAO, 2004). New components of the FRA 2010 RSS are:

- All land area of the world will be represented by the Survey, not only the pan-tropical zone.
- A larger number of smaller Landsat satellite image samples will be included to increase the precision of the forest area and change estimates and land use change dynamics, as e.g. recommended by Mayaux *et al.* (2005) and Stehman *et al.* (2005).
- A proposed medium resolution full coverage remote sensing component will add the dimension of forest location or spatial forest distribution to the statistics on the overall forest area and change rates that are more accurately assessed by sampling methods.
- A decentralized implementation approach is planned which will ensure (i) an increased involvement of countries and the use of national and local expertise, and (ii) increased mapping and assessment capacities where needed.

The main reasons and justification for promoting the FRA 2010 RSS are:

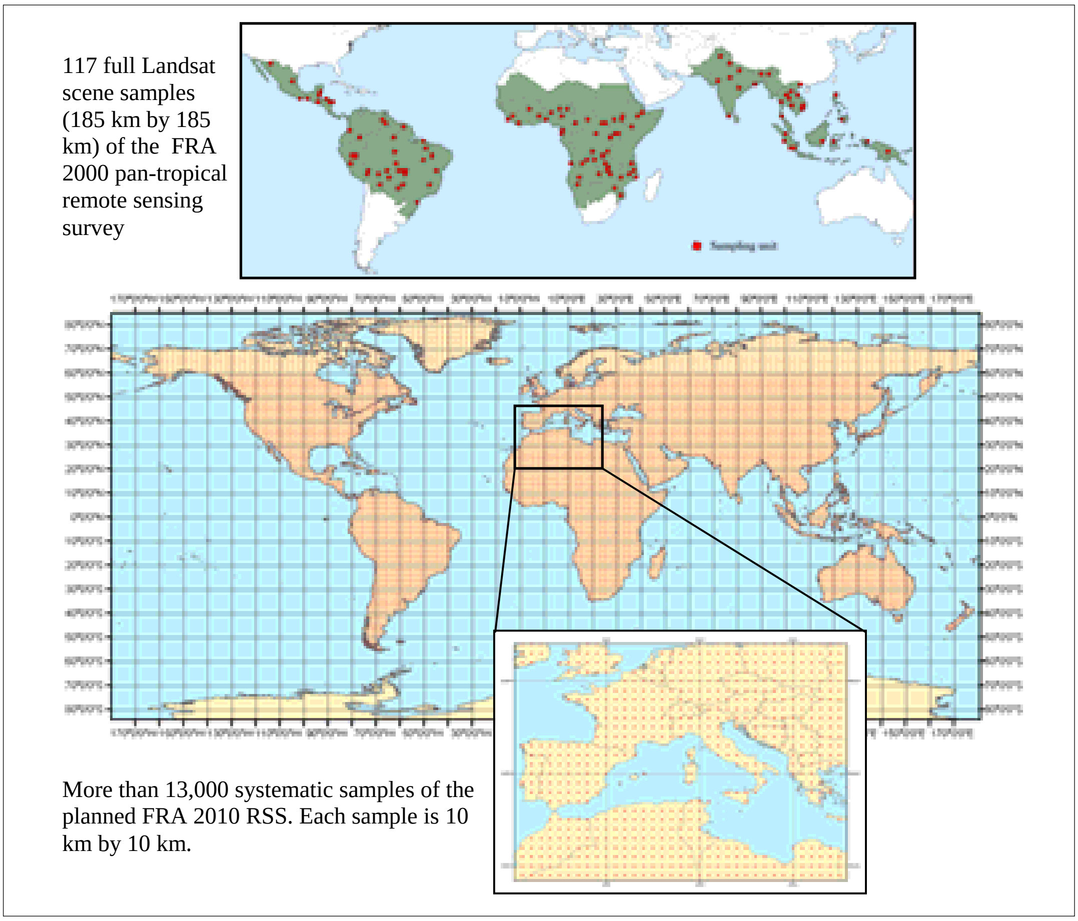
- The RSS will be **complementary to the national reporting** by providing a regionally harmonized picture of the extent of forests and other wooded land at regional, biome and global levels and on forest change dynamics that will allow a better understanding of the causes of deforestation.
- The RSS will contribute to **increase national capacity** in mapping, monitoring, reporting and assessment techniques. In certain countries this may form the basis for the preparation of a national monitoring system and testing of additional variables.
- On specific request by national governments the RSS can help to **strengthen** the FRA **national reporting**, e.g. in large countries where recent forest inventory information is outdated.

The following approach is recommended for the FRA 2010 RSS:

- High resolution (i.e. 20 to 30 m pixel) sampling based on optical imagery (Landsat and equivalent imagery) complemented by SAR imagery where needed and available, to produce (i) forest area and area change statistics and (ii) change matrices on other land uses.

- Complement the sampling based statistical analysis with annual global full coverage mapping of tree cover and tree cover change using MODIS 250 m vegetation continuous fields (VCF).

Options and details of the recommended approach and implementation process are described in this report.



Comparison of sampling units between the FRA 2000 pan-tropical remote sensing survey and the planned FRA 2010 RSS.

Abbreviations

ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AVHRR	Advanced Very High Resolution Radiometer
CBD	Convention on Biological Diversity
COFO	Committee on Forestry of FAO member governments
EC	European Commission
FAO	Food and Agriculture Organization of the United Nations
FGDC	Federal Geographic Data Committee
FRA 1990	Global Forest Resources Assessment 1990
FRA 2000	Global Forest Resources Assessment 2000
FRA 2005	Global Forest Resources Assessment 2005
GIS	Geographic Information System
IPCC	Intergovernmental Panel on Climate Change
IRS	Indian Remote Sensing Satellite
JRC	Joint Research Centre of the European Commission
Landsat ETM+	Landsat Enhanced Thematic Mapper Plus
Landsat MSS	Landsat Multispectral Scanner
Landsat TM	Landsat Thematic Mapper
LCCS	Land Cover Classification System (of FAO/UNEP)
LCTC	Land Cover Topic Center (of FAO)
LCLUC	Land Cover Land Use Change
MDG	United Nations' Millennium Development Goals
MDGLS	NASA-USGS Mid-Decadal Global Land Survey
MERIS	Medium Resolution Imaging Spectrometer
NASA	US National Aeronautics and Space Administration
NFA	National Forest Assessment
NFI	National Forest Inventory
NPOESS	National Polar-orbiting Operational Environmental Satellite System
RS	Remote Sensing
RSS	Remote Sensing Survey (of FRA 2010)
SAR	Synthetic Aperture Radar
SDRN	Natural Resources Management Service
SDSU	South Dakota State University
SLC	Scan Line Corrector
SPOT	System Probatoire pour l'Observation de la Terre
TREES 3	EC program on Tropical Ecosystem Environment observation by Satellite
UMD	University of Maryland
UNFCCC	United Nations Framework Convention on Climate Change
USGS	US Geological Survey
VCF	Vegetation Continuous Fields algorithm
VIIRS	Visible Infrared Imager / Radiometer Suite on NPOESS
WGS 84	World Geodetic System 1984

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1. Background

FAO has been coordinating global forest resources assessments every five to ten years since 1946 (FAO, 2006), with the objective to provide a periodic global and uniform picture of existing forests, derived trends and statistics. Especially FAO's periodically reported deforestation rates enjoy a high degree of public attention and are widely cited in literature. The estimates of FAO's Global Forest Resources Assessment (FRA) programme are largely based on national statistics and inventory reports, which contain detailed information on the forests of individual countries reported by each government. "*However, differences among data sets from the various countries can be great owing to the methods applied, the terms and definitions employed and the currency of the information in the individual inventories. Despite adjustments made to accommodate these differences, uncertainties can still arise when statistics from different countries are compared*" (FAO, 2002).

An example of such inconsistencies from national reporting is visualized in Figure 1. It shows that in 2000 different countries either lacked up-to-date information on their national forest resources or reported on forests using different forest definitions or a combination of both (Hansen, 2004). Nevertheless the reported state and trends are relevant at the national level even if they might not be comparable or harmonized internationally.

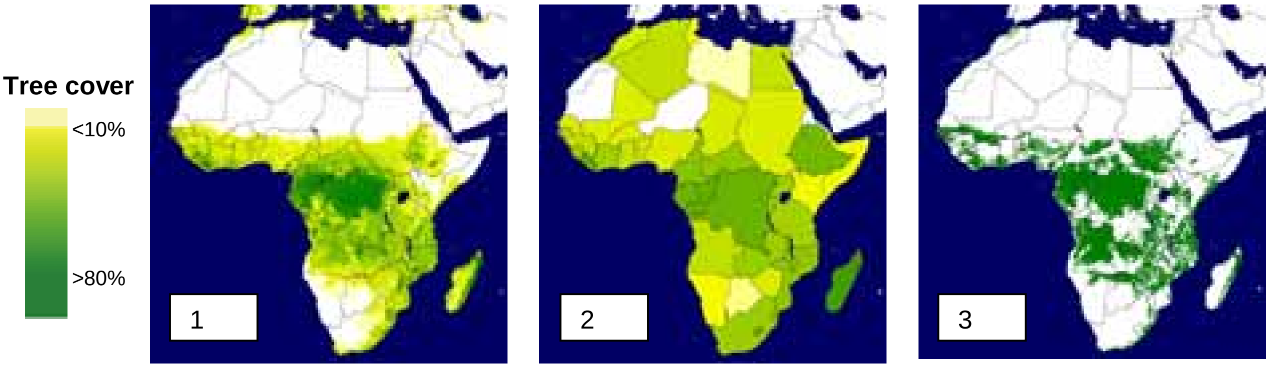

Figure 1: Comparison of remote sensing and national reporting for Africa.

1: 1997 percent tree cover classification for Africa (Hansen, 2005).

2: 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 (Hansen, 2005).

3: Resulting forest map where per country forested area match FRA 2000 totals. Green = forest, white = non-forest (Hansen, 2005). Pictures 1 through 3 confirm that national reporting and remote sensing analysis diverge for Africa (Mayaux et al., 2005).

The issues arising from use of national statistics for global and multi-national forest assessments are well known (Wayson *et al.*, 2000, Stokstad, 2001, FAO, 2002) and are based on the fact that "*each nation optimises their own national forest inventory within their own funding constraints to address their own national issues; and the importance of international comparability is too rarely considered. Few tropical nations regularly conduct national forest inventories, and many are incomplete and out of date. There is no universally accepted definition of forest cover, which has a major affect on national estimates for sparse forests in arid or cold regions. Funding disparities among nations cause differences in methods and data quality. Definitions and methods in each nation can change over time. Some national governments use expert opinion to adjust for these shortcomings but expert opinion is difficult to validate and vulnerable to unknown biases*" (Czaplewski, 2003).

Resulting key issues are the lack of regionally harmonized information on (i) forest area changes and on (ii) land use dynamics to characterize the causality visualized in Figure 2. There is no quick solution to this issue. To help address the situation, improve national inventory statistics, reduce international reporting inconsistencies and subsequently increase precision of FRA statistics, FAO is promoting a range of activities:

- **Support to National Forest Assessments (NFA)**: FAO provides technical and financial support to carry out NFAs. Within the last 5 years 10 countries received NFA assistance. 30 more countries applied for it.
- **Standardized forest-related definitions**: E.g. (i) FRA tables on forest extent, forest characteristics, etc.; (ii) FAO's Land Cover Classification System (LCCS) that is slowly but steadily turning into a widely used and internationally recognized land cover standard.
- **Capacity building for national reporting** on forests and forestry as part of the global forest resources assessment process.

Increasing quality of national reports confirm that the undertaken measures are slowly paying off.

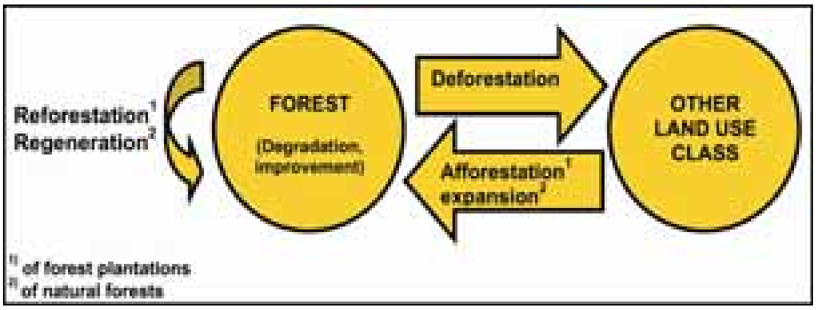

Figure 2: Forest change processes (FAO, 2000).

To complement the FRA national reporting, to provide an independent picture of forest cover trends and to specifically address regional forest area changes and land use dynamics in the 1980s and 1990s, FAO conducted two pan-tropical remote sensing surveys as part of FRA 1990 and FRA 2000 respectively. These surveys were based on a 10 percent stratified random sampling and on multi-temporal analysis of Landsat satellite images. For each of the 117 selected sample units, three Landsat satellite images from different dates provided the raw material 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 (developing country areas) and for Africa, Asia and Latin America separately (FAO, 2004). Figure 3 shows the results on land use dynamics for the period 1990-2000.

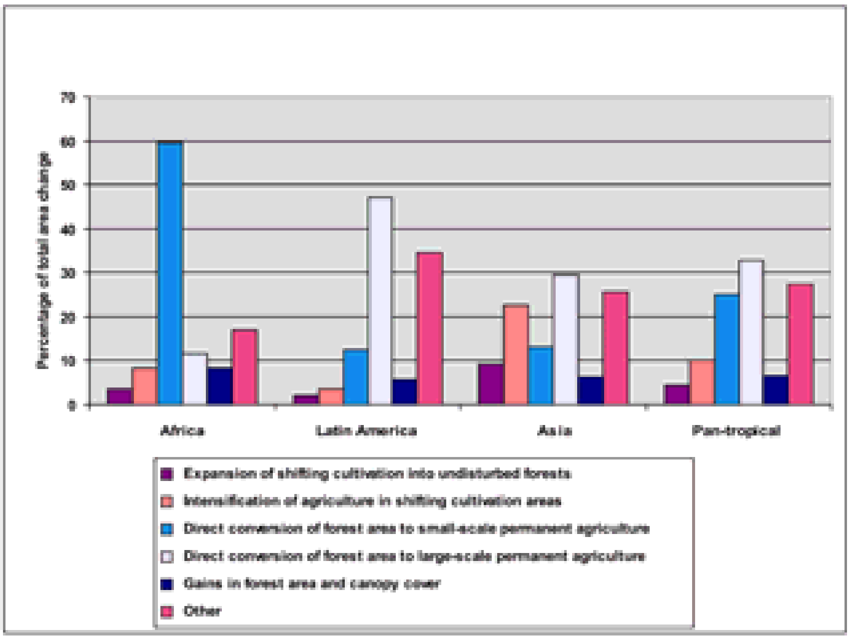

Figure 3: Forest change dynamics 1990-2000 (FAO, 2000).

2. Concept for a global remote sensing survey of forests

To build on and further strengthen the concept of previous remote sensing surveys and increase in-country mapping and inventory capacity FAO is planning to carry out a global Remote Sensing Survey (RSS) within the framework of the upcoming FRA 2010.

2.1 Scope and purpose

The scope and overall purpose of the proposed RSS is to:

- Provide information on the spatial distribution of forests at global and regional levels.
- Generate concise land use change information, including data on deforestation, fragmentation and forest degradation.
- Provide consistent information over time and space.
- Establish a common framework and methodology for forest monitoring purposes.
- Be fully complementary to FRA national reporting and establish close links with existing and planned national monitoring systems.
- Increase in-country capacity where needed.

The RSS will be **complementary** to the national reporting by providing a regionally harmonized picture on specific variables (forest extent and forest cover) and forest change dynamics that will allow a better understanding of the causes of forest degradation, fragmentation and deforestation.

The RSS will contribute to **increase national capacity** in mapping, monitoring, reporting and inventory techniques. In certain countries this may form the basis for the preparation of a national monitoring system and testing of additional variables.

On specific request by national governments the RSS can **help to strengthen the FRA national reporting**, e.g. in large countries where recent forest inventory information is outdated.

2.2 Expected outputs

The expected key outputs of the proposed FRA 2010 remote sensing survey are:

- Monitoring forests for the time period **1975 to 1990 to 2000 to 2005** at regional, biome and global levels, delivering (i) **area change statistics**, (ii) **information on land use dynamics** (change matrices), and (iii) **forest maps**.
- **Establishing** a publicly accessible **information framework in support of monitoring of forests, land use and the environment**, including to facilitate

further global or regional monitoring of the terrestrial environment at large, as well as to assist national monitoring efforts.

Furthermore the results will provide baseline data for research, modelling and further monitoring efforts.

"*Technology improvements and better access to remote sensing data make it possible to expand the scope of the planned 2010 RSS compared to previous FRA 1990 and FRA 2000 remote sensing surveys*" (FAO, 2004).

The FRA 2010 RSS will offer a range of advantages over past surveys and it can be repeated in future FRAs:

- All land area of the world will be represented by the RSS, not only the pan-tropical zone.
- A larger number of smaller Landsat satellite image samples will be included to increase the precision of the forest area and change estimates and land use change dynamics, as also recommended by Mayaux *et al.* (2005) and Stehman *et al.* (2005).
- A proposed medium resolution full coverage remote sensing monitoring component will add the dimension of forest location or spatial forest distribution to the statistics on the overall forest area and change rates that are more accurately assessed by sampling methods.
- A decentralized implementation approach is planned which will ensure (i) an increased involvement of countries and the use of national and local expertise, e.g. creating links with national monitoring efforts, and (ii) that in-country technical mapping and assessment capacities are increased where needed.

The only apparent 'disadvantage' of the improved RSS may be increased cost.

A key requirement to enable governments to take best advantage of the planned RSS is the availability of RSS results well before the national reports are submitted to FAO. This timing constraint should be carefully watched during the RSS implementation.

Further reasons to promote the 2010 remote sensing survey include:

- Accurate and timely information on forest and forest area change is essential for policy relevant at various levels. It provides usually lacking input and reference information to good forest governance processes and to national forest programmes (BMZ, 2004).

- The new RSS approach promises to provide the best possible globally consistent data on forest cover by ecological zone which can provide valuable input information to biomass and carbon stock assessments. This is expected to be useful to new FRA user communities, e.g. CBD, MDG (specifically indicator 25 ‘proportion of land area covered by forest’ under goal 7 ‘ensure environmental sustainability’), global forest fire applications, as well as the climate change and carbon community.
- Institutions involved in sector wide policy and structural adjustments can use frequently updated forest monitoring information to check if changed policies do or do not have the intended impact on forests.
- The Survey is expected to advance science in global natural resources monitoring.

3. Introductory considerations

3.1 Statistical sampling versus full coverage monitoring

Statistical sampling of stand populations is a commonly accepted practice in forest inventories. More diverging opinions exist in the remote sensing community on the use of sampling versus full cover Land Cover Land Use Change (LCLUC) assessments. Gallego (2004) and Stehman *et al.* (2003 and 2005) provide literature overviews on this subject. In short the international discussion can be summarized as follows.

Generally "*sampling reduces data collection costs relative to complete coverage because less time is required for interpreting imagery and classifying land use and / or land cover. Having to interpret only sample blocks permits more intensive effort over a smaller area, consequently reducing measurement error in the data. The smaller area covered by a sample relative to complete coverage also requires less data storage and allows use of a smaller pixel size. In summary statistical sampling cannot replace full cover mapping if spatially explicit representation of results is required. However, when the objective is to estimate LCLUC gross change, a sampling approach is likely to be more cost-effective, more practical and less subject to measurement error than complete coverage*" (Stehman *et al*., 2003).

Several deforestation studies based on samples of high-resolution imagery have been performed at regional scales (FAO, 1996; FAO, 2001; Achard *et al*. 2002), but have lacked a precise method for targeting likely areas of change. Some researchers maintain that sampling high resolution imagery cannot efficiently estimate deforestation rates (Hunsaker *et al*., 1994, Sanchez-Azofeifa *et al.* 1997; Tucker and Townshend, 2002). The rarity of land cover types and changes, and the presence of outliers in the population, are prime culprits contributing to poor precision of sampling-based estimates of land cover composition and land cover change (Stehman *et al*., 2003). This has reinforced the use of regional wall-to-wall mapping strategies (Skole and Tucker 1993; Townshend *et al.* 1995). However, Czaplewski (2003) has shown that sample-based estimates are efficient if the target region is sufficiently large, e. g. at a global scale, and if change is sufficiently represented in the samples. Stehman *et al.* (2006) noted that the high variance of sampling-based estimators found by Tucker and Townshend (2002) could at least in part be attributed to a single extremely high deforestation value for one element in the population evaluated. Although Tucker and Townshends's (2002) results raise an important concern related to the impact of "outliers" on precision, Stehman *et al.* (2006) found that a sampling strategy using smaller sampling units and employing a regression estimator can produce more precise estimates of change than a design based on larger sampling units (e.g. full Landsat scenes) with this comparison assuming the same fixed total cost for both approaches.

3.2 Different types of monitoring require different approaches

Another aspect to be carefully considered when choosing the most appropriate approach is the monitoring purpose. Usually specific user needs define the monitoring approach. There is no 'one fits all' approach. Different monitoring approaches include:

Monitoring of forestry operations: Typically this requires a once a year monitoring of production forest areas to evaluate whether planned and implemented operations match up. This type of monitoring can help to integrate unscheduled events like salvage logging after insect calamities and storm damage into the long-term management plans.

FLEG-proposed monitoring: Forest areas prone to illegal logging may require frequent, i.e. monthly or more frequent, monitoring of production, conservation and other forest areas to compare approved logging operations with actually carried out operations, e.g. to detect logging in national parks. It may also require monitoring of financial flows to detect money laundering, as well as monitoring of court cases to detect flaws in the national legal system (World Bank, 2006).

Monitoring of forest fires: Since it is difficult to predict where wild fires appear, fire monitoring requires full cover monitoring in rather short time intervals, preferably several times per day with heat sensitive sensors. Large area fire monitoring is currently carried out using automated interpretation of MODIS satellite imagery alerting specific clients, e.g. with short SMS messages. Other sensors with multiple daily coverage are under development.

Monitoring of national forest resources: National forest inventories (NFI) are carried out for strategic planning purposes, e.g. to balance national timber increment with the overall annual harvesting. Typically this is carried out with ground stand sampling in a frequency ranging between 10 and 20 years. As a preparatory step towards establishing a detailed NFI process FAO offers national level support for national forest assessments (NFA).

FRA monitoring: FRA tries to summarize key variables from NFIs at the regional and global level to gain overarching knowledge on deforestation, fragmentation, degradation and others forest-related aspects. Till 2000 this was carried out every 10 years, since then the monitoring interval was shortened to 5 years. This trend of ever more frequent global monitoring may eventually lead to annual or biennial and permanent on-line reporting of global forest resources.

3.3 Satellite imagery suitable for monitoring

The requirements for satellite imagery to be used for the FRA 2010 RSS can be summarized as follows. Imagery should be:

- Available at no or low cost to FAO and member governments and ideally also to a wider user community without copyright restrictions.
- Optimised for differentiating vegetation, especially forest classes.
- Suitable for monitoring, i.e. have a short repeat cycle.
- Available for entire or at least major parts of the intended monitoring period of 1975 to 1990 to 2000 to 2005 and with global coverage.
- Satellite sensors should have a long future lifespan to enable imagery use in future global assessments and to justify possible interpretation development cost.

Image type	Free / low cost	No copy right	Optimised for vegetation	Length of repeat cycle	Available time range	Future sensor continuation
Optical, 5 to 50 m pixel resolution						
ASTER	+	-	+	- (16 days)	2000 onwards	unclear
CBERS CCD + IR-MSS	?	?	+	- (26 days)	2000 onwards	expected
DMC	-	-	+	+ (near daily)	2005 onwards	unclear
IRS LISS	-	-	+	- (5-24 days)	1997 onwards	expected
Landsat MSS	+	+	+	- (16 days)	1972-1984	N/A
Landsat TM & ETM+	+	+	+	- (16 days)	1984 onwards, since 05/2003 SLC off	LDCM
RapidEye	-	-	+	+ (daily)	2007	unclear
SPOT HRV	-	-	+	- (26 days)	?	expected
Optical, 150 to 1000 m pixel resolution						
CBERS WFI	?	?	+	+ (3-5 days)	2000 onwards	expected
IRS WIFS	-	-	+	- (24 days)	1997 onwards	expected
MERIS	?	?	+	+ (daily)	2000 onwards	expected
MODIS	+	+	+	+ (daily)	2000 onwards	VIIRS
SPOT VEGETATION	+	-	+	+ (daily)	1998 onwards	Vegetation 2
SAR						
ERS	-	-	-			
JERS	+	-	+			
RADARSAT	-	-	-			
ENVISAT	-	-	-			
TerraSAR-X	-	-	+/-		To be launched in 2007	unclear
ALOS PALSAR	-	-	+		2006 onwards	unclear

Table 1: Suitability of a selection of available satellite sensors for forest monitoring.

Based on Table 1, Landsat and MODIS imagery appears to be best suited for the FRA 2010 RSS, while a range of other image types could supplement the sample interpretation in problem areas.

Landsat

Three global NASA/USGS Landsat data sets are available free of charge, a fourth dataset is foreseen to be made available soon (Refer to Figure 4):

- circa 1975 (acquisition period 1973 through 1988),
- circa 1990 (acquisition period 1986 through 1992),
- circa 2000 (acquisition period 2000 through 2003),
- circa 2005 (acquisition period 2004 through 2007)

These 3 global Landsat data sets are freely available at USGS EROS (see http://edc.usgs.gov/products/satellite/landsat_ortho.html) and at the Land Cover Topic Center (LCTC) at FAO. The Landsat MSS images provides the opportunity to expand the planned FRA 2010 RSS monitoring period by 15 years into the past using the 1975 global data set.

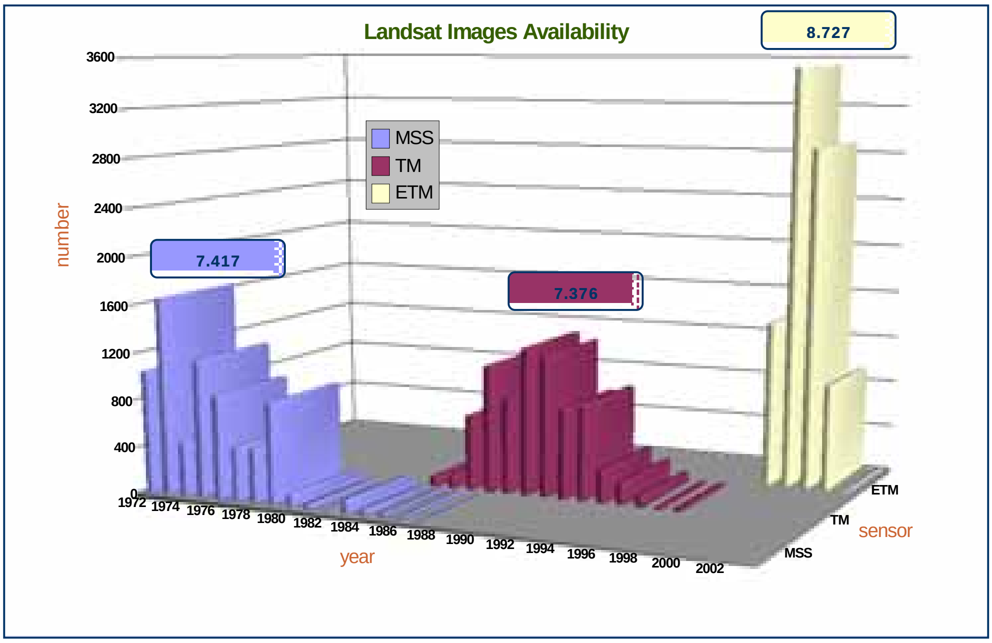

Figure 4: Type, number of satellite images per acquisition year archived in SDRN's LCTC. All these images are distributed on request free of charge to UN agencies (Latham, 2006).

All 3 existing global data sets were ortho-rectified by EarthSat Corporation (now MDA Federal) in Rockville, thus mosaic and edge-match well. Further details are given in Annex 3.

NASA and USGS recently announced their decision to carry out the mid-decadal global land survey (MDGLS) based on a fourth global Landsat dataset, ca. 2005, primarily consisting of Landsat TM and ETM+ imagery. Islands and reefs will be covered by ALI and ASTER imagery filling the data gap caused by the malfunctioning ETM+. Since May 2003 ETM+ delivers stripy images due to operating in scan line corrector (SLC) off mode.

Limitations: The global Landsat data sets are more or less impacted by atmospheric conditions like haze and clouds, as well as by seasonality. The three global Landsat data sets show that decadal monitoring is difficult in the tropics where the sensor often delivers less than one usable image (with less than 20% cloud cover) per scene per year. There are also a number of issues related to the inferior quality of the MSS imagery (1973 through 1988).

Ideally, satellite forest monitoring should be based on comparison of imagery from just before and/or just after vegetation peak seasons to avoid that mapped change is mixed with seasonal changes.

MODIS

MODIS appears to be the best vegetation monitoring instrument for more regular monitoring: (i) The near daily global repeat cycle helps to minimize cloud cover problems and allows for repeated mapping of forest cover conditions at national, regional and global levels; (ii) all imagery is available free of charge on the Internet; (iii) ensured long life expectancy with VIIRS to be launched in 2008.

The two key downsides of MODIS is that imagery is available only since 2000 and that the medium pixel resolution does not allow for exact area and area change calculations. But it can be used in an integrated approach with higher resolution data such as Landsat.

Landsat and MODIS technical specifications are summarized in Annexes 1 and 2.

4. Key components

Based on the above considerations and on recommendations from an intense stakeholder consultation process that started in 2003 a 2-pronged approach is recommended for the FRA 2010 global RSS, supported by the :

- High resolution (i.e. 20 to 30 m pixel) sampling based on optical imagery (Landsat and equivalent imagery) complemented by SAR imagery where needed and available, to produce (i) area and area change statistics and (ii) change matrices on
  - Forest cover using the FAO Land Cover Classification System (LCCS),
  - Forest area, forest characteristics and other land uses.
- Complement the sampling based statistical analysis with annual global full coverage mapping of tree cover and tree cover change using MODIS 250 m vegetation continuous fields (VCF).

Key reasons for including full coverage medium resolution monitoring in the RSS:

- Full cover monitoring adds the dimension of geographic location of forests to the area and area change statistics of sampling. Spatially explicit information is useful for a range of applications, such forest landscape assessments, overlays with other maps e.g. of protected areas and thus it widens the RSS user community.
- Full cover monitoring can help increase precision of sampling estimates by enabling stratified sampling (identifying deforestation hot and cold spots) e.g. at national level to make sure that rare events like changes of smaller forest types and cover classes, e.g. mangroves, are well represented. Conversely sampling can increase the precision of full cover monitoring by providing representative and transparent reference data for calibration.

Statistical sampling and full-coverage monitoring approaches appear to be well complementary.

This chapter describes the approach as far as it is currently defined. Open questions that require a consultation process to provide answers are dealt with in chapter 5 ‘Implementation process’.

4.1 High resolution sampling

4.1.1 Sampling design

Sampling frame

Previous FAO remote sensing surveys and other Land Cover and Land Use assessments used the Landsat World Reference System 2 as sampling frame with Landsat full or quarter scenes as sampling units. Small numbers of large sampling units led to rather high standard errors (Stehman, 2003). More and smaller sampling units are expected to result in more precise statistics (Mayaux, 2005, Stehman, 2005). Furthermore a sampling frame that is independent of satellite sensors and sensor orbit geometry is recommendable (Stehman, 2005).

Different grid systems are available for spatial sampling purposes, including rectilinear grids based on degrees of geographical latitude and longitude (lat./long.), and Cartesian grids on map projections. These grids run into problems when very large areas or indeed all of the Earth are considered. The issues arise essentially from the classic map projection problem: It is not possible to maintain shape and area on the projection plane and gross distortions of either one or the other are inevitable when considering the entire globe. Maintaining of shape and equal area are mutually exclusive goals if based on the latitude, longitude grid (Richards *et al.*, 2000). Consequently "*sampling schemes that seek to define either systematic or random distribution of observation units on the Earth's surface can neither be truly systematic nor random if applied to a global rectilinear or lat./long. grid system*" (Richards *et al.*, 2000).

The use of a lat./long. grid system for the FRA 2010 RSS raises a key issue: The samples will not be equidistant nor truly systematic. Around the equator, where most changes are expected, the sampling density will be lowest, increasing towards northern and southern latitudes (see Figure 4). Hence, the grid does not provide equal probability for detecting change, e.g. when comparing the tropics with temperate areas. However, considering that RSS results will mostly be used at regional or biome level then the lack of equal probability will have limited impact.

FAO and the University of Maryland calculated that a 1 degree by 1 degree latitude-longitude sampling frame results in 13,482 intersection points on land, including islands, based on the following parameters (Branthomme, 2003; Davis, *et al.*, 2003):

- Starting with 60 degrees North, every other potential point was excluded to prevent over-representation of northern samples.

- Excluding all points on land below 56 degrees South as all those areas lack vegetation.
- The northern boundary is set to 84 degrees North as no land occurs above this latitude.

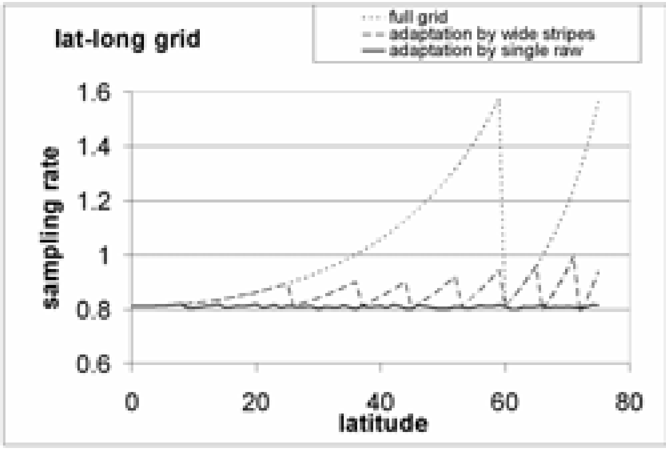

Figure 4: The sampling rate as a function of latitude. This graph shows that the sampling rate or sampling density of a 1 degree by 1 degree lat./long. grid increases with increasing latitude (Belward *et al*., 2006).

As a next step the number of samples that fall in non-forest areas, e.g. in deserts or urban area, can be identified and subtracted from the above overall amount to identify the number of samples that have to be analyzed. A rough estimation can be based on the global VCF land cover classification at 1km spatial resolution (Hansen *et al.*, 2000) that states that about 30-40% of the land surface is either bare ground or have less than 10 % tree cover. Consequently this would reduce the number of samples to about 9,000.

Advantages of a 1 degree by 1 degree lat./long. grid system are:

- The latitude-longitude grid is easy to understand and to communicate to national governments.
- Sample locations can be easily identified on every map.
- The FAO supported National Forests Assessments (NFA) use this latitude-longitude grid; so information from field plots located within the sample units will be available to support the interpretation for many countries.
- The European commission's Joint Research Centre (JRC)'s TREES III programme for the humid tropics will use the same 1 degree by 1 degree lat./long. grid.

- The ‘degree confluence project’ is posting photos of each latitude and longitude integer degree intersection on the Internet (see http://www.confluence.org). These photos can provide a substantial support to the FRA 2010 RSS sample interpreters.

An alternative is the use of a hexagon grid. However, the seemingly trivial task of creating a distribution of points on a sphere, such that they are all the same distance apart and which form centre points of a network of Thiessen polygons has not yet been solved. Nevertheless approximations are available. Geographers and modellers have used planar hexagonal systems for many years (Selkirk, 1982). Hexagonal grids have the following advantages over Cartesian grids (Richards *et al.*, 2000):

- The grid elements do not have gaps or overlaps.
- The cells have approximately equal areas and the same shape.
- The topology of the cells is symmetrical and invariant.
- The centre of each cell is the same distance from its neighbours. This ensures equal probability.
- The cells can be recursively partitioned.

Consequently a hexagon grid, with 10 km by 10 km squared sample units at the centre point of each hexagon cell, appears to be an interesting alternative to the proposed latitude-longitude grid.

A third option could be the use of existing national inventory grids rather than creating a new global grid from scratch. The advantages are:

- National grids are already in place in many countries, tailored to each country’s needs. Hence they work well for each country.
- If the grid-related national inventory information is available to the RSS this could save time and cost for Landsat sample interpretation and validation.
- Use of national grids may better ensure country buy-in than other grids.

Possible disadvantage of a sampling strategy based on the use of national grids are:

- It may be time consuming to document all needed details of national inventory frameworks and receive access to the needed inventory information.

- Meshing national grids at the global level adds complexity.
- Different grid densities might lead to less precise estimates per unit cost than could be achieved by a uniform global grid sampling strategy.
- Not all countries have a national forest inventory or land cover/land use assessment.

From a pragmatic point of view it might be easier, faster, less expensive and more precise to choose a global sampling grid rather than getting involved in time consuming research on national grids.

Sample unit shape

A square shape harmonizes better with raster format of remote sensing imagery to be used in comparison to a circle. A square shape also accommodates the requirement of equidistant samples; unlike rectangular sample shapes.

Sample unit size

According to the experience of Loveland *et al*. (2002) and Stehman *et al*. (2003) with the US land cover trend project, a nationwide Land Cover/Land Use change assessment based on stratified random sampling per eco-zone, a sampling unit size of 10 km by 10 km is sufficient for change assessments. This size even results in more precise change estimations than 20 km by 20 km sampling units (Stehman *et al.*, 2003).

Whether the same sample unit size is equally appropriate to characterize landscape change pattern and forest fragmentation is unclear. Such an objective may motivate selection of larger sampling units to reduce the effect on landscape pattern metrics of introducing artificial edges at the sampling unit boundaries. An answer requires (i) clarification on how fragmentation should be considered in the RSS and (ii) conducting certain sampling tests.

In general terms, smaller sampling units require a greater total quantity of imagery which translates into higher cost, and data management becomes more complex if more but smaller sampling units are used. Conversely, a sample of smaller units will often result in more precise estimates than an equivalent area sampled via larger units (Cochran, 1977, Harrison & Dunn, 1993). Smaller plots also across different Landsat scenes results in fewer samples falling requiring the creation of a mosaic. Therefore typical national forest inventories use very small sample plots - too small for a remote sensing based monitoring exercise.

Sampling protocol

A systematic global sampling protocol without stratification considers all countries in the same way. It certainly reflects a democratic element and is politically appealing. That alone may be justification enough to use such a protocol.

However, it might be worthwhile considering alternative options suggested in literature: Mayaux *et al*. (2005) recommend orienting the sampling protocol towards Land cover change by use of stratified sampling, a commonly used option to better represent rare change events in the samples and so improve precision of area estimates.

Design-based stratification can reduce the amount of samples to be interpreted while maintaining a comparable standard error as can be achieved with systematic sampling. Hence, stratification can save interpretation time and resources.

Effective stratification for precisely estimating Land Cover/Land Use change can consist of strata defined by expected high change, low to moderate change, and no change. Information on forest distribution and fragmentation from coarse resolution satellite imagery as well as expert knowledge on deforestation hot or cold spots can help to design the stratification procedure (Mayaux *et al*., 2005). Lambin *et al.* (2001) caution to oversimplify causes of tropical deforestation and use population density and poverty for stratification, while others do suggest exactly this (Mather and Needle, 2000).

A promising option to avoid stratum assignment error is the use of post-classification estimators to increase precision of change estimations. This allows strata construction after the sample has been selected and incorporated in a post-classification analysis (Stehman, 2005).

Successful stratification depends on the ability to accurately assign area units to strata. Difficulties arise because true change for a unit is unknown until it is sampled, so *a priori* assignment of units to strata is subject to stratum assignment error (Stehman, 2005). Another difficulty is that stratification designed for forest change might not be effective for forest extent. Furthermore, stratification that is effective for one monitoring period might not be as effective for other periods. This is a particular concern where the monitoring period is long, as is the case for this assessment.

If it were decided to go with a stratified sampling protocol it would be recommendable to (i) further consult with leading statisticians on best available options and possibly (ii) test some options using existing imagery and interpretations, e.g. for Brazil, central Africa or USA, before applying the approach globally.

Sampling intensity

In general terms the 1 % sample - based on a 10 km by 10 km sampling units and a 1 degree by 1 degree lat./long. grid - of the defined study area consisting of about 13,500 sample units appears to be very adequate (Stehman *et al*., 2003) assuming that a good proportion of the sample units fall into forest and are likely to hit change areas.

Recommendation on sampling design

Based on the above cited arguments and recommendations from consulted stakeholders it is recommended to use the 1 degree by 1 degree ‘systematic’ lat./long grid with 10 km by 10 km sampling units plus a 5 km buffer. To compensate the increase of sampling density with increasing latitude it is recommended to decrease the sampling rate from 60 degrees Northern latitude onwards to 1 by 2 degree lat./long. Refer to Figure 5.

This choice is in line with JRC’s decision to use the same grid for the TREES III program.

4.1.2 Classification system and legends

It is recommended that the 2010 RSS includes a dual sample interpretation: mapping of forest cover and forest use, mainly for 2 reasons: (ii) to increase compatibility between FRA national report and the RSS at the regional level; and (ii) to demonstrate and visualize the difference between forest cover and use – a ‘historical’ point of contention between foresters and the remote sensing community (see Matthews, 2001).

Maintaining the forest cover interpretation (as analysed in previous surveys) will enable the use of MODIS tree cover results for the Landsat sampling and vice versa.

Another interesting result of the proposed dual interpretation will be forest cover / use matrices explaining the relation between these categories (see Table 2).

		Land use	
Tree cover	Forest (> 10%, etc.)	Forest	Other land with tree cover
	Non forest < 10% cover	Temporarily unstocked forest	Other land

Table 2: Example of a simplified forest cover-forest use matrix.

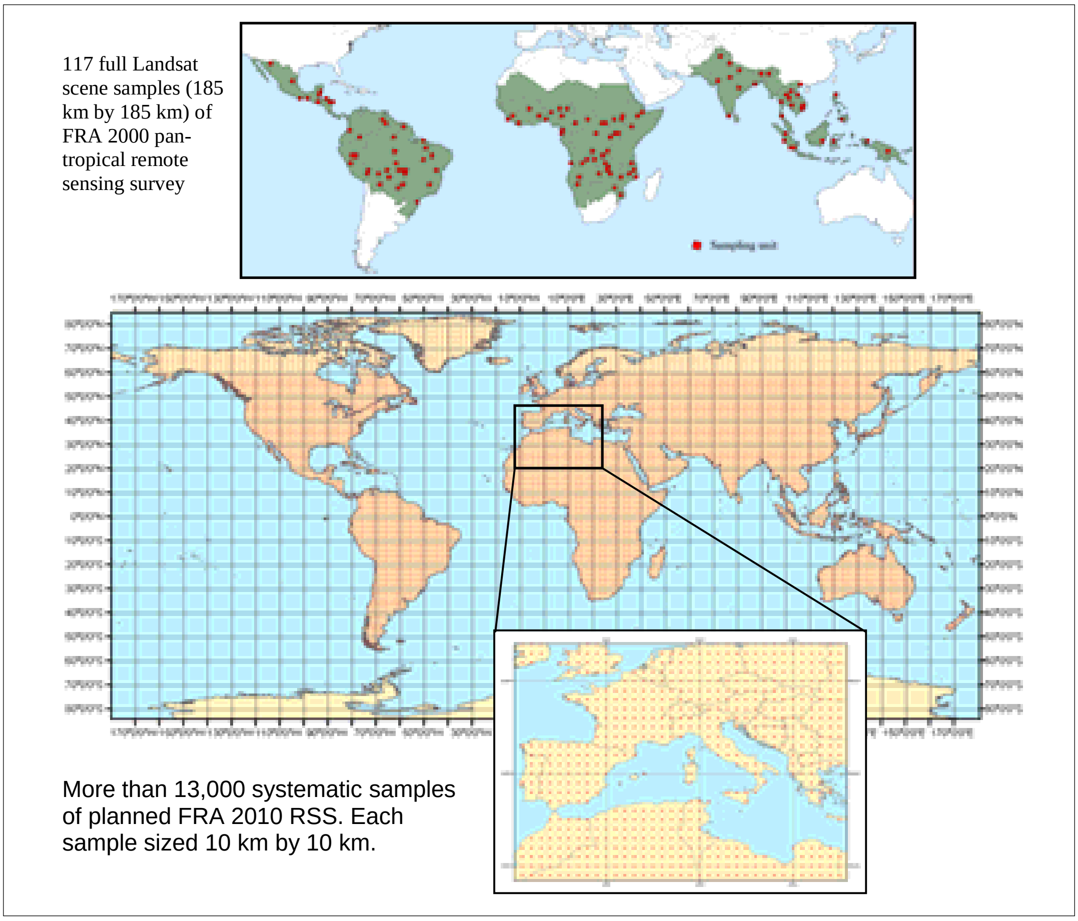

Figure 5: Comparison of sampling units between FRA 2000 pan-tropical remote sensing survey and the planned global 2010 RSS (Branthomme, 2005).

Land cover classification system and derived legends

In 2000 FAO published its first edition of the Land Cover Classification System (LCCS). Since then LCCS has evolved into an international land cover standard that is widely used. "*LCCS is a comprehensive, standardized classification system that can accommodate any land cover identified anywhere in the world. The classification uses a set of independent diagnostic criteria that allow correlation with existing classifications and legends. Land cover classes are defined by a combination of a set of independent diagnostic criteria – the so-called classifiers – that are hierarchically arranged to assure a high degree of geographical accuracy. […] The advantages of the classifier, or parametric, approach are manifold. The system created is a highly flexible a priori land cover classification in which each land cover class is clearly and systematically defined, thus providing internal consistency. The system is truly hierarchical and applicable at a variety of scales. Re-arrangement of classes based on re-grouping of the classifiers used facilitates extensive use of the outputs by a wide variety of end-users*" (Di Gregorio *et al*., 2000).

LCCS' many advantages and its wide application suggest its use for the interpretation of Landsat samples within the 2010 RSS.

LCCS allows each country participating in the FRA 2010 RSS to define or bring in and translate its own specific land cover legend. These national legends can then be aggregated to simplified regional and global LCCS land cover legends that are compatible e.g. with MODIS results (see Figure 6). This was tested by FAO and South Dakota State University (SDSU) for an area in Africa.

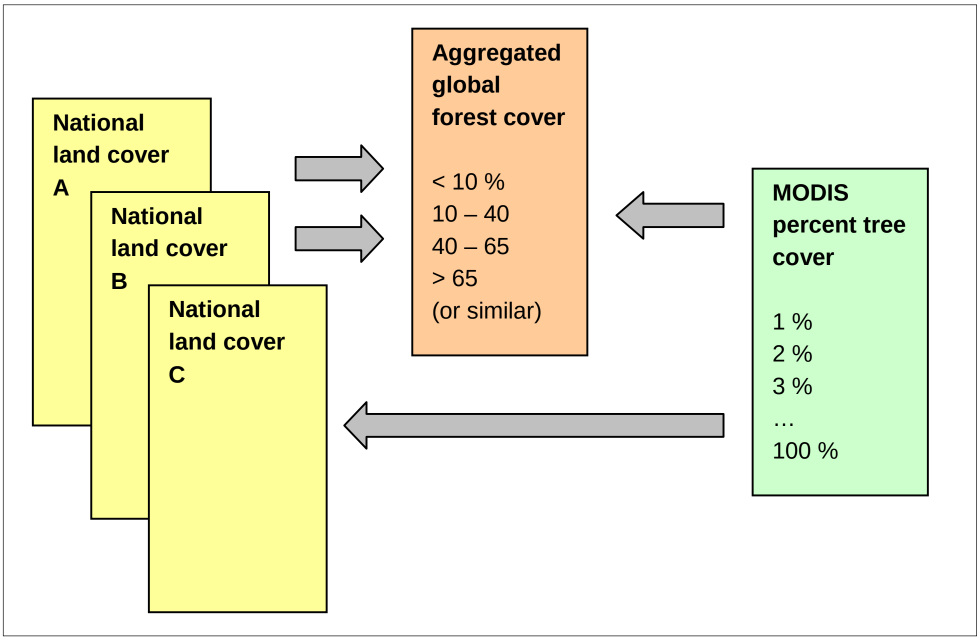

Figure 6: The link between national and global legends. National LCCS based land cover legends can be aggregated to a global forest cover legend. And the MODIS based percent tree cover legend can be translated into each national legend as well as into the aggregated global legend.

Forest use legend

The RSS forest use legend should ideally be fully consistent with and linked to the FRA 2010 national reporting (see Table 3). Forest use can only be differentiated on imagery with relevant *in situ* sample site knowledge. Hence, it needs to be ensured that the national Landsat sample interpretation crews do have access to the required *in situ* knowledge. This is a task to be taken care of by each country participating in the FRA 2010 RSS. Without the planned decentralized 2010 RSS implementation approach such required *in situ* knowledge could not be accessed.

Class	Definition
Forest	Land spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds *in situ*. It does not include land that is predominantly under agricultural or urban land use.
Other wooded land	Land not classified as "Forest", spanning more than 0.5 hectares; with trees higher than 5 meters and a canopy cover of 5-10 percent, or trees able to reach these thresholds *in situ*; or with a combined cover of shrubs, bushes and trees above 10 percent. It does not include land that is predominantly under agricultural or urban land use.
Other land	All land that is not classified as "Forest" or "Other Wooded Land".
Other land with tree cover	Land classified as "Other land", spanning more than 0.5 hectares with a canopy cover of more than 10 percent of trees able to reach a height of 5 meters at maturity.
Inland water bodies	Inland water bodies generally include major rivers, lakes and water reservoirs.

Table 3: FRA categories that should be addressed with the Landsat sample interpretation.

Tests in a few key regions might help to verify if this forest use legend is applicable to Landsat samples.

An advantage of this proposed legend is that it will look the same in all countries. Hence, there is no need for class translation and aggregation to the global level.

4.1.3 Decentralized sample interpretation and validation

Sample image pre-processing

The ortho-rectified Landsat images from the 3 existing ortho-rectified NASA / USGS global datasets, 1975, 1990 and 2000 will be provided free of charge. These 3 datasets are not copy right protected, can be freely exchanged and imagery can be centrally pre-processed. Furthermore each image is accompanied by Federal Geographic Data Committee (FGDC) meta data. When available (expected by end 2008) the NASA / USGS mid-decadal global Landsat dataset (MDGLS), year 2005, will be added. Pre-processing will follow these steps:

- Clipping of 54,000 Landsat samples (4 times 13,500 multi-temporal samples) for 1975, 1990, 2000 and 2005. Each sample image clipping will have a size of 20 km by 20 km (= 10 km by 10 km plus a five 5 buffer around the sample to facilitate the interpretation).
- Adding a vector layer to each sample image showing the sample unit boundary, to be used as boundary for the on-screen digitizing of sample interpretations.
- Normalize the clipped image samples to support interpretation by eliminating haze and similar atmospheric influences and make forest look alike in all samples.

Sample image pre-processing seems highly advisable for the following reasons:

- It allows focussing of national experts on the image interpretation/validation without having to worry about precise clipping of sample units or drawing the sample unit boundaries. This reduces the national / regional interpretation team work load and consequently will speed up the process.
- Central processing ensures consistent clipping of sample units using the same rules (see Table 4) thus ensuring a consistent quality standard.
- Image normalization will reduce interpretation bias.

Proposed rules to clip sample unit imagery
▪ Sampling area located between 84° Northern and 56° Southern latitude, using WGS 1984.
▪ Off shore lat/long degree points will not be part of the sample base.
▪ Sample units with more than 50% coverage by in-land water bodies will not be part of the sample base.
▪ Use of least cloud and atmosphere impacted image if sampling unit center point falls on WRS overlap area. If both image parts are cloud free or equally cloudy then use the scene with the acquisition data closer to the vegetation peak season ('greenest season').
▪ Do not move the sample unit to locate it in an area with less cloud cover.
▪ If sample unit imagery has cloud cover > 15% or has a sub-optimal acquisition date (seasonality issues) then involved stakeholders should look for replacement imagery.

Table 4: Rules for clipping of sample unit imagery. These rules will need further refinement.

Sample unit interpretation and validation

The FRA RSS 1990 and 2000 were based on visual interdependent interpretation of land cover on Landsat image hard copies by national experts (FAO, 2002, FAO, 1996). This concept has proven to be successful.

Due to ever-cheaper and faster hard- and software it can be recommended that the FRA 2010 RSS interpretation technique is 'upgraded' to visual on-screen digitizing of forest use and land cover, as recommended by FAO (2004): "*The interpretation work will be significantly improved moving from fully manual mapping on hard copy to digital on-screen mapping, in terms of data handling and distribution, drawing accuracy, visual enhancement and digital outputs. The need of a digital approach has been highlighted in reports and comments to FRA 2000 survey, because this will ensure better data transfer and storage, facilitate analysis on the dataset, in particular spatial analysis, and possibly improve accuracy. It also facilitates decentralization of work process by means of Internet data download or CD-ROM delivery rather than big image prints. Digital data management allows ad-hoc image enhancement and band compositions. On-screen zoom functions help improving drawing accuracy. The outputs will be more efficiently stored and managed and will allow direct query and analysis during the process.*"

On-screen digitising is software unspecific, i.e. it can be done using a wide range of public domain as well as commercial image interpretation and GIS software packages. But also other more advanced interpretation techniques may be used depending on country preferences and skill level. A number of different programmes for automated/semi-automated segmentation and labelling are currently being tested.

The proposed decentralized interpretation/validation process of several tens of thousands of image samples (e.g. about 9,000 sample units x 4 reference years = roughly 36,000 image samples to be interpreted) by a large group of interpreters will necessarily introduce a considerable interpreter bias. The following can help to reduce this bias and keep interpretation accuracy at sufficient levels:

- Quality training of a sufficient number of image processing trainers who will support and guide the national expert teams.
- Provision of intuitively comprehensive multi-lingual interpretation and validation manuals with stepwise work process descriptions for the national and regional interpretation crews.
- Random visits of remote sensing specialists to national and regional image processing centres to provide assistance and help review results.
- Independent quality assessment process of results delivered.

Typical limiting factors in validating large area mapping exercises are:

- Lack of current sample site information: Sample site field visits are budget and time intensive, especially in big forest countries with hundreds of sample sites.
- Lack of historical site information. Field visits often do not clarify land use / land cover history.

However, validation of multi-temporal forest use and land cover interpretations is of crucial importance to ensure outputs with an equally high quality across national boundaries. Especially the decentralized interpretation approach with a large number of image interpreters requires strict application of clear and standardized validation procedures that will be determined during the implementation process.

Validation options are likely to include:

- Targeted field visits to sample units with specific interpretation issues.
- Crosscheck by different interpreters at national and regional level or within multi-national regional interpretation teams.
- Crosscheck with automated classification results that are based on input from national interpreters.
- National and regional validation workshops with local forest use and land cover specialists.
- Another potentially useful tool for validation might be the website http://www.confluence.org that intends to provide photos of all integer lat./long. crossing points.

4.1.4 Centralized statistical analysis

After in-country validation the sample interpretation results, including vector layers of forest area and its change, will be compiled and analyzed at regional, biome and global levels by FAO.

4.2 Medium resolution full coverage monitoring

The proposed methodology for full coverage of assessment and mapping of forests is able to provide globally consistent tree cover change information on an annual basis, without varying interpreter bias and at low cost using a largely automated approach. The advantage of resulting annual tree cover and tree cover change is the detection of forest cover changes at a level of detail that cannot be captured in 5 or 10 year monitoring intervals. Such an annually updated product is likely to increase the utility and provide opportunities for additional analyses.

Annual change maps can be augmented by 5-10 year change assessment efforts to pick-up finer scale, forest area changes, improving reliability of data in areas currently poorly understood.

The method is affordable compared to field inventories or wall-to-wall photo interpretation of Landsat imagery. However, no reliable quantification of forest area change is possible due to the moderate pixel resolution.

Currently the proposed method is based on the use of MODIS imagery. However, with some customizing it could also be applied to other similar types of imagery, e.g. MERIS or imagery from future satellite missions.

MODIS based forest monitoring can be fully transferred to national and regional partners, as currently under evaluation in Indonesia, leading to locally relevant products while retaining global consistency.

4.2.1 Full coverage interpretation and validation

The vegetation continuous fields algorithm (VCF), recommended for monitoring global tree cover within the FRA 2010 RSS, is the result of collaborative research at UMD and SDSU, supported by NASA.

Continuous fields of tree cover represent an improvement over discrete land cover classifications. Continuous fields depict sub-pixel land cover proportions and are more appropriate representations of thematic information in areas of spatial heterogeneity. Continuous fields are particularly of use with moderate and coarse spatial resolution data sets such as MODIS where most land cover exists as mosaics of multiple cover types (Hansen *et al*., 2002). Due to the fact that many areas of human-induced land cover change are marked by increased spatial heterogeneity and fragmentation, continuous fields offer a tool for detecting changes that could not be detected by comparisons of discrete classifications.

MODIS forest mapping is undertaken using temporally composited data rather than instantaneous orbital swath data. This is because composites have less data volume and because the compositing process reduces remotely sensed variations that are considered as noise in the mapping process (Roy, 1997). These noise sources include: cloud and atmospheric contamination, changes in the effective spatial resolution across the image swath, and by variable sensor response caused by angular sensing and illumination variations combined with the anisotropy of reflectance of most natural surfaces and the atmosphere (Roy, 2000). Monthly composites are used for MODIS forest mapping as a monthly period adequately captures vegetation phenology whilst being sufficiently long to reduce these noise sources.

Monthly cloud-free MODIS composites of 250 m and 500 m MODIS reflectance data in the seven MODIS land bands, land surface temperature and Normalized Difference Vegetation Index (NDVI) data, are used as inputs to the mapping algorithm. The composites are processed into annual metrics of vegetation phenology, which are the independent variables used to predict percent tree cover and represent the salient points of the annual phenological curve. Metrics describe a global signature space, in which is independent of time of year, by preferentially selecting green, low reflectance and high surface temperature pixels. They capture the common signal shared by dominant vegetation cover types, enabling them to be used in the estimation of percent tree cover.

To develop information for the continuous field method, training data from high-resolution satellite imagery (predominantly 30m Landsat data) are aggregated to the MODIS 250m resolution (Hansen *et al*., 2002). The training data for percent tree canopy cover are derived from high-resolution images that are characterized into tree cover strata (e.g. 0-10%, 10-40%, etc.). Each Landsat pixel is classified into tree canopy cover strata. These data are used to develop a 250m continuous tree canopy cover training dataset ranging in value from 0 to 100 percent canopy cover. The training data are manipulated to characterize the nation-wide MODIS metrics using a regression tree algorithm. Regression trees are statistically robust and transparent in their operation (Hansen *et al*., 1996). They allow for interpreters, such as forestry agency staff, to interact with the algorithm to iteratively improve algorithm outputs.

The MODIS VCF method for forest monitoring is appropriate for national to global scale detection of change. Currently the MODIS forest VCF product is automatically derived within the NASA production system. Although the NASA processing ensures globally consistent datasets, regional users may wish to adjust the algorithm’s results to their specific application needs. Regional adoption of MODIS forest mapping also ensures ownership of data inputs and outputs, reducing the need for reliance on external data sources and expertise.

At present, testing of the MODIS VCF algorithm does not incorporate training data for all regions and countries. Development of such national or at least regional datasets is required and feasible for more precise monitoring of global annual tree cover with the

MODIS VCF method. The above-described global Landsat sampling can provide the required training data to calibrate the VCF results as can input information from forest inventory plots.

Required calibration and validation work is labour intensive and a protocol for the simplest, most easily replicated approach possible still needs to be written, building on undertaken efforts (Strahler *et al*., 2006).

It is proposed that the interpretation of the 2000 and 2005 Landsat sample units will be used to validate MODIS VCF results.

4.2.2 Central processing

Currently SDSU and UMD are jointly executing two NASA funded global VCF projects:

Enhanced land cover and land cover change products from MODIS: UMD is pre-processing global 250 m MODIS data for VCF inputs. SDSU is generating global annual percent tree cover and tree cover change data, 2000 to current, using UMD's input information. This work is part of the MODIS Land Science Team and is schedule to end mid 2007. There are plans to extend it further.

Establishing a Global Forest Change Monitoring System using Multi-Resolution and Multi-Temporal Remotely Sensed Data Sets: In 2006 SDSU and USGS EROS are starting a three year project, extending previous NASA-sponsored research on global forest cover dynamics (Hansen and DeFries, 2004) and land cover change estimation (Loveland *et al*., 2002; Stehman *et al.*, 2003) to establish a robust, operational forest monitoring and assessment system with the following intended outputs:

- Generation of global forest area change indicator maps based on VCF using full coverage moderate resolution imagery, 8 km and 1 km AVHRR from 1990 through late 1990s, and 500 m and 250 m MODIS from 2000 and 2005. These indicator change maps will be validated and the accuracy will be assessed by application of an advanced high resolution sampling strategy.
- Generation of global forest area and area change estimates based on a stratified sampling strategy for high-resolution imagery, Landsat 1990, 2000 and 2006. Change and no change strata will be objectively derived per biome from global moderate resolution change indicator maps (see Figure 7). This should help to

overcome sampling problems associated with infrequently occurring change classes.

The strategy combines the strengths of global forest change mapping to produce a spatially explicit depiction of change at moderate resolution and statistical sampling to provide precise area estimates of change in forest cover based on more accurate, higher resolution data. In addition, the monitoring strategy generates the data necessary for a statistically rigorous validation of the global forest change maps, thus successfully integrating accuracy assessment within a forest-monitoring framework (Stehman *et al*. 2000).

This MODIS / Landsat data fusion approach, if it proves to be successful, can provide a model for post-stratification of FRA 2010 Landsat sampling to improve the forest area and area change estimations.

Based on the above described unique experience, it appears highly recommendable that SDSU and UMD continue to generate MODIS full coverage percent tree cover analysis for the FRA 2010 RSS while taking advantage of validation opportunities offered by the Landsat sampling.

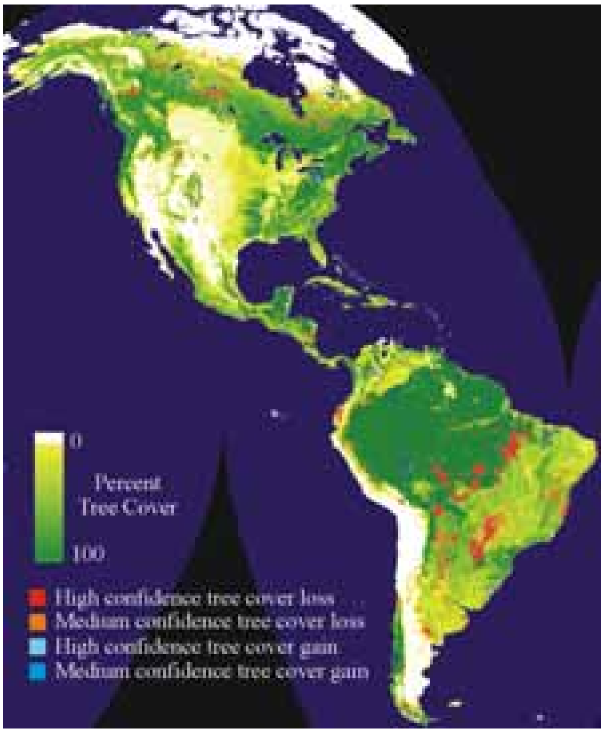

Figure 7: Example of AVHRR tree cover change for the Americas from 1982-1999 8km data (Hansen and DeFries, 2004).

4.3 Information framework

FAO proposes to build an "Information Framework" for Monitoring of forest, land use and the environment. This Information Framework (IF) will serve international agencies and organizations in their monitoring efforts related to forests, land use and the terrestrial environment and will greatly reduce required resources to implement such monitoring programmes.

The IF can also serve as a conceptual framework when designing national monitoring systems and may thus fill an important function in national capacity building in countries where such systems do not readily exist. The IF will also serve academic and non-governmental organizations, and the public at large, by providing access to data and information.

The IF will facilitate decentralized and distributed data provision. This means that, e.g. space agencies can efficiently provide data for policy-related analyses, and thereby increase the utility of the public investments in remote sensing.

The Information Framework will support progress towards sustainable land management, through improved analyses in policy formulation, implementation and follow-up at national and international levels, emerging from enhanced information quality and knowledge sharing on environmental and land use changes.

The following proposed immediate objectives (Holmgren, 2006) show the possible link between the IF and the FRA 2010 RSS:

- Establish an internet gateway with interface to download and upload data from / to FRA 2010 RSS sample locations.
- Populate IF with time series of geo-referenced satellite images at each FRA 2010 RSS sample location.
- Establish synergies between sampling and full-cover remote sensing approaches to monitoring of global changes.
- Support implementation of the FRA 2010 RSS, taking both sample and full-cover approach into account, and applying a decentralized approach for image interpretation.
- Enable additional applications and analysis, e.g. crosscut RSS results with information on forest fires, protected areas, poverty mapping.
- Expand the scope of IF monitoring applications to other sectors.

Figure 8: The Google Earth interface (earth.google.com).

The Google Earth inistiative (see Figure 11) could be enriched with FAO FRA information on forest cover, afforestation and deforestation. This would boost global forest information transparency and could open many economic opportunities.

5. Implementation process

5.1 Consultation process

Before implementing the proposed FRA 2010 RSS, FAO gathered advice and preferences from Kotka V experts, from the remote sensing community from the FRA Advisory Group and from individual countries.

5.1.1 Kotka V expert consultation

Kotka V, 12-16 June 2006, agreed on the proposed scope, purpose and need for the FRA 2010 RSS. Specific recommendations and requests were made and are reflected in the Kotka V report (see Annex 6). Intergovernmental conventions (CBD and UNFCCC), international organizations (ICRAF, UNEP, World Bank) and the UNFF secretariat welcomed and endorsed the RSS plan.

5.1.2 Remote sensing expert community

The planned FRA 2010 RSS was presented to the remote sensing community during the 'global vegetation monitoring workshop' at the University of Montana, in Missouri, Montana, in August 2006. The received feedback was very encouraging.

To give remote sensing experts the opportunity to comment in more detail on the FRA 2010 RSS approach, a 2-day FAO-UNEP technical meeting was held in Washington, DC, in October 2006. The group of experts present at the meeting endorsed the general approach and methodology and noted that they are ready to assist in its implementation. The participants further agreed to continue to play an advisory role in the process. The minutes of the meeting are copied in annex 4.

5.1.3 FRA Advisory Group

The FRA Advisory Group endorsed the recommendations from the Kotka V Consultation and took note of the outcome of the FAO-UNEP Technical Meeting. See the minutes of the 6th meeting at http://www.fao.org/forestry/site/24693/en/ for details.

5.1.4 COFO mandate for FRA 2010

Based on the Kotka V agreement on the need for the RSS and the remote sensing community's confirmation of the RSS approach, The FAO Committee on Forestry (COFO) provided FAO with a mandate to execute the RSS at its 18th meeting held in March 2007.

5.1.5 Country participation and preferences

FAO will invite all countries to participate in the FRA 2010 RSS. The following options for country participation exist:

- Some countries have a functioning national forest inventory system (sometimes supported by remote sensing) in place, which can provide the information to be gathered by the FRA 2010 RSS. There may thus not be a need to implement a RSS for such countries.
- Countries may wish to actively participate in the RSS and execute data processing themselves.
- Some countries may wish to expand the RSS data processing towards building a national forest monitoring system, in some cases with assistance from FAO. This goes beyond the scope of FRA and will require a specific request from the national government to FAO.
- Other countries, especially those with very few plots according to the proposed sampling design, may opt for playing a less active role in the RSS and leave data processing to regional expert teams, with or without national participation.

FAO is committed to accommodate country preferences as much as possible. Country participation and local forest knowledge are needed to generate and validate results and to transform information on land cover into land use. In all cases, the results for sample sites in a given country will be sent to the countries for information and validation before final analysis and publication of results.

5.2 Implementation process

The next step after having learnt about overall country preferences and capacities, is to set up a network of national and regional implementing agencies.

The network will need to be enriched by institutions that can provide specific technical support and build capacity based on country needs. Therefore the FRA team is in contact with the following potential key partner institutions and initiatives:

European Commission

The EC's Joint Research Center (JRC) is funded through 2013 to carry out the TREES 3 project, monitoring forest cover of the tropical belt, all sub-Saharan Africa and northern Eurasia. The JRC FOREST project is monitoring forest cover in Europe. Both projects have expressed an interest in collaborating with FRA 2010 and can offer substantial expertise in global / regional forest monitoring using high and medium resolution imagery.

FAO's Land Cover Topic Center

The Land Cover Topic Center (LCTC) of FAO's Natural Resources Department (previously Sustainable Development Department) has assisted many countries in national and regional land cover mapping based on Landsat and equivalent imagery. LCTC has offered to help with RSS capacity building in a range of contries.

GOFC-GOLD

The Global Observation of Forest Cover-Global Observation of Land Dynamics (GOFC-GOLD), a panel of the Global Terrestrial Observing System (GTOS), offered to support the RSS through the expertise of its Land Cover Implementation Team, as well as its six Regional Networks, which are mainly located in developing and remote regions around the world. GOFC-GOLD specifically offered support in determining validation procedures and providing access to validation information in form of very high resolution imagery for around 500 sites globally.

Jena University

Jena University has offered to support and complement land cover monitoring in areas with persistent cloud cover with interpretation of satellite radar imagery. Jena specifically offered to provide free access to latest SAR imagery, e.g. TerraSAR-x and ALOS, as well as to historical imagery, e.g. ERS and JERS imagery, and provide training in interpreting these data.

MDGLS

The NASA-USGS MDGLS project is of vital importance to the FRA 2010 remote sensing survey by providing the 2005 global Landsat dataset. It further offers a range of opportunities for exchange of experience concerning best practices for interpretation and validation as well as direct collaboration in data processing.

South Dakota State University

As mentioned above South Dakota State University (SDSU) is already generating global tree cover and tree cover change products based on MODIS imagery. Beyond customizing these products to RSS needs, SDSU has offered to assist in building high resolution land cover capacity in a range of countries. In addition, SDSU will extract the Landsat images needed, normalise these and clip the 20x20 km samples and make these available.

Several other institutions offered support including the GEO secretariat, UNEP and WRI.

5.2.1 Remote sensing data acquisition and pre-processing

Imagery cost will be the main reason for *a priori* limiting the high resolution RSS component to the freely available 3 global Landsat datasets, the soon available MDGL and freely available radar imagery for cloudy regions.

Even if only about 9,000 multi-temporal samples will be interpreted – about 4,500 samples will fall in deserts and built up areas that do not need to be interpreted for forest cover and use – all 13,500 samples will be clipped, pre-processed and made publicly available as a service to other monitoring efforts.

For cost and time reasons it may not be possible to centrally provide global multi-temporal sample imagery of equally good quality, i.e. free of clouds and without seasonality issues. However, countries are invited to replace poor sample imagery, e.g. cloudy sample imagery or imagery acquired outside the optimal season for land cover mapping, with other high resolution optical imagery. Partner organisations will assist as much as possible.

5.2.2 Information Framework and gateway set up

Within the proposed Information Framework component (see chapter 4.3) a web interface will be developed to provide public access to the multi-temporal sample imagery database, containing readily clipped and normalized sample imagery generated by data pre-processing. The interface is likely to be based on existing GeoNetwork meta data catalogue facilities (see www.fao.org/geonetwork and geonetwork-opensource.org).

Further information to be accessible via this interface will include sample image meta data, recommended high resolution interpretation methodology descriptions, manuals for interpreters, recommended interpretation validation guidelines and guidelines for country data uploading, e.g. for draft and final multi-temporal sample interpretations, meta data and various types of auxiliary data.

Detailed web interface functionalities will need to be further defined but should certainly include possibilities to view, search, up and down load. It may be useful to complement the interface with an activity tracking system to keep an overview on information use and data processing.

The Information Framework gateway is expected to develop into the communication and data backbone of the remote sensing survey. Proper gateway maintenance will be of vital importance to ensure progress.

In countries with limited Internet access data can be exchanged via ftp sites. In countries with no Internet access off-line CD or DVD versions of the gateway will be made available to ensure data access.

5.2.3 Capacity building, sample interpretation and validation

The ideal decentralized interpretation and validation scenario would entail self-sufficient national interpretation and change analysis by a specialized and recognized entity per country following a common methodology. In countries without an appropriate specialized agency, national experts could be trained and guided in sample image interpretation and validation during regional workshops. This will contribute to increase the data processing capacity that can be used for national assessments later on.

The capacity building support will respond to the country needs and preferences, which will depend on existing and planned national forest inventory and monitoring systems. The training shall be based on a set of recommended interpretation and validation methodologies that will be identified, tested and described by a working group process facilitated by the FRA team. This process will start with a meeting at JRC in early March 2007. Results are expected by the end of 2007 and shall include:

- A set of recommended methodology alternatives for multi-temporal land cover and land use interpretation, including on-screen digitizing and some more advanced interpretation techniques. The recommendations shall further include detailed stepwise descriptions and execution manuals, recommended minimum mapping units and recommended types of ancillary information.
- Recommended interpretation validation procedures.
- Recommended standardization of transition matrices to references years 1975, 1990, 2000 and 2005.

Several methodology options should enable each country to choose the interpretation technique that fits best its national requirements.

5.2.4 Statistical analysis and reporting of results

National and regional interpretation results will either be uploaded to the information gateway or otherwise transferred to FAO for centralized global statistical analysis.

Furthermore the sample interpretations will be used by SDSU to validate their MODIS VCF tree cover and tree cover change analysis.

The results and findings of the FRA 2010 remote sensing survey will be summarized and published in a printed report as well as made available on the FAO website.

Updates of the global annual map of tree cover and tree cover change based on medium resolution MODIS VCF will be accessible on the FAO website when available, thus well before the publishing of the FRA 2010 RSS report.

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Annexes

Annex 1: Technical specifications of Landsat data

Satellite	Launch Date	Sensors	Status
Landsat 1	7-23-72	MSS	Expired 1-6-78
Landsat 2	1-22-75	MSS	Expired 2-5-82
Landsat 3	3-5-78	MSS	Expired 3-31-83
Landsat 4	7-16-82	MSS, TM	Sensors no longer operational since 1993; expired 6-15-01.
Landsat 5	3-1-84	MSS, TM	Operational
Landsat 6	10-5-93	ETM	Lost at launch
Landsat 7	4-15-99	ETM+	Operational, SLC failure 31 May 2003

Table 5: Overview on Landsat program history (from NASA website).

	MSS	TM	ETM+
Type	opto-mechanical sensor	opto-mechanical sensor	opto-mechanical scanner
Spatial resolution	79m	30-120 m	15/30/60 m
Spectral range	0.5-1.1 micro meter	0.45-12.5 micro meter	0.45-12.5 micro meter
Number of bands	4-5	7	8
Temporal resolution	16-18 days	16 days	16 days
Size of image	185 x 185 km	185 x 172 km	183 x 170 km
Swath	185 km	185 km	183 km
Stereo	n	n	n
Programmable	n	y	y

Table 6: Landsat technical specifications (from NASA website).

Bands	MSS			TM		ETM+	
	Landsat1-3 [micro meters]	Landsat4-5 [micro meters]	[m]	[micro meters]	[m]	[micro meters]	[m]
1	-	0.5 - 0.6	80m	0.45 - 0.53	30m	.45 to .515	30
2	-	0.6 - 0.7	80m	0.52 - 0.60	30m	.525 to .605	30
3	-	0.7 - 0.8	80m	0.63 - 0.69	30m	.63 to .69	30
4	0.5 - 0.6	0.8 - 1.1	80m	0.76 - 0.90	30m	.75 to .90	30
5	0.6 - 0.7		80m	1.55 - 1.75	30m	1.55 to 1.75	30
6	0.7 - 0.8		80m	10.40 - 12.50	120m	10.40 to 12.5	60
7	0.8 - 1.1		80m	2.08 - 2.35	30m	2.09 to 2.35	30
8	10.41 - 12.6		237m				
pan						.52 to .90	15

Table 7: Landsat spectral bands (from NASA website).

Annex 2: Technical specifications of MODIS data

Orbit:	705 km, 10:30 a.m. descending node (Terra) or 1:30 p.m. ascending node (Aqua), sun-synchronous, near-polar, circular
Scan Rate:	20.3 rpm, cross track
Swath Dimensions:	2330 km (cross track) by 10 km (along track at nadir)
Telescope:	17.78 cm diam. off-axis, afocal (collimated), with intermediate field stop
Size:	1.0 x 1.6 x 1.0 m
Weight:	228.7 kg
Power:	162.5 W (single orbit average)
Data Rate:	10.6 Mbps (peak daytime); 6.1 Mbps (orbital average)
Quantization:	12 bits
Spatial Resolution:	250 m (bands 1-2) 500 m (bands 3-7) 1000 m (bands 8-36)
Design Life:	6 years, continuation in VIIRS program

Table 8: MODIS technical specifications (from NASA website).

Band	Bandwidth[1]	Resolution	Spectral Radiance[2]	Required SNR[3]
1	620 - 670	250 m	21.8	128
2	841 - 876	250 m	24.7	201
3	459 - 479	500 m	35.3	243
4	545 - 565	500 m	29.0	228
5	1230 - 1250	500 m	5.4	74
6	1628 - 1652	500 m	7.3	275
7	2105 - 2155	500 m	1.0	110

Table 9: MODIS first 7 spectral bands (from NASA website).
[1] Bands 1 to 19 are in nm; Bands 20 to 36 are in µm
[2] Spectral Radiance values are (W/m^2 -µm-sr)
[3] SNR = Signal-to-noise ratio

Annex 3: Coverage of free global Landsat datasets

Mid-Decadal Global Land Survey imagery for the year 2005

MDGLS will mainly consist of Landsat 7 and Landsat 5, roughly 9,500 scenes. Islands and reefs will be covered by ALI and ASTER imagery.

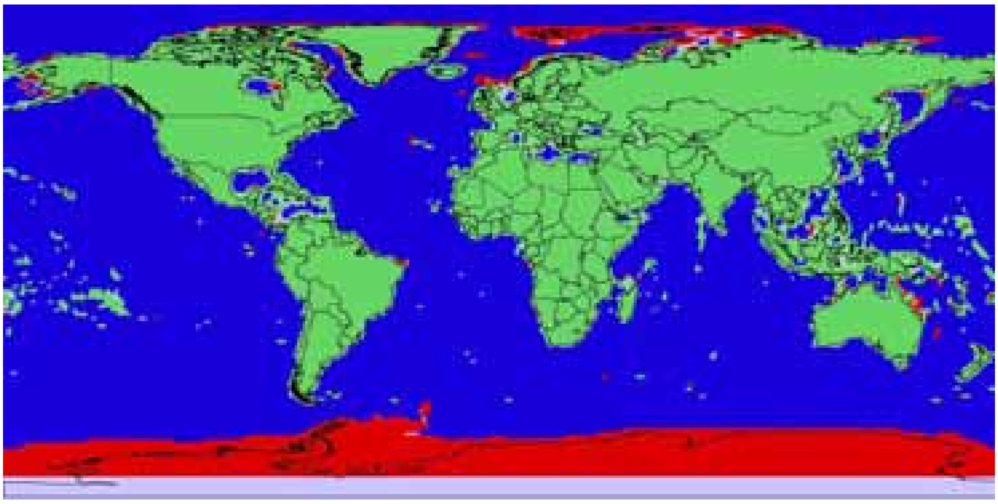

Figure 9: MDGLS coverage Year 2005 (image acquisition from 2004-2007).Green = GeoCover 2000 Coverage, Red + Green = New MDGLS Coverage (Masek *et al.*, 2007).

Landsat ETM+ scenes for the year 2000

The individual scene circa year 2000 GeoCover-Ortho database includes 8,500 orthorectified Landsat ETM+ scenes. Areas covered by the circa 2000 data, that could not be covered by the circa 1990 data, include Siberia, Antarctic, and the majority of the ocean islands. (from MDA website)

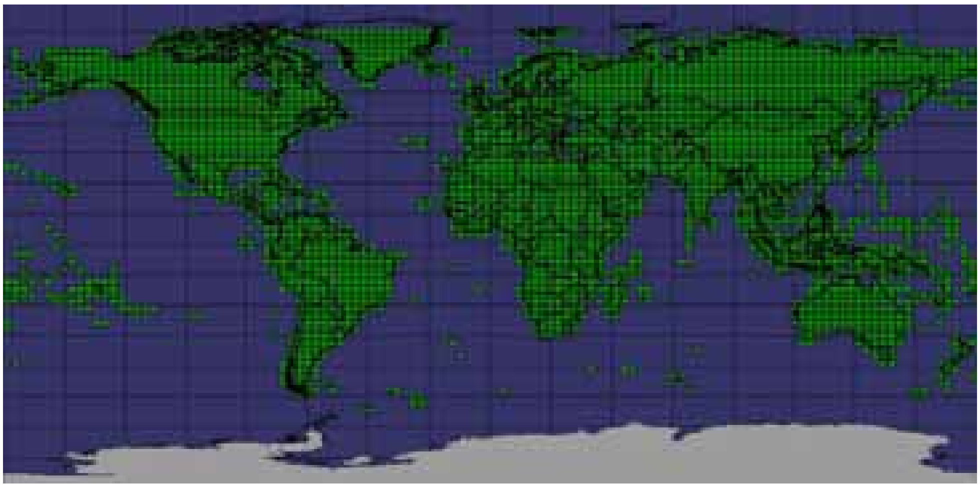

Figure 10: GeoCover-Ortho Year 2000. Green: Completed; Grey: Not Available (from MDA website).

Landsat TM Scenes for the year 1990

The individual scene circa year 1990 GeoCover-Ortho database includes 7,600 orthorectified Landsat TM scenes. The map below shows the approximate production status.

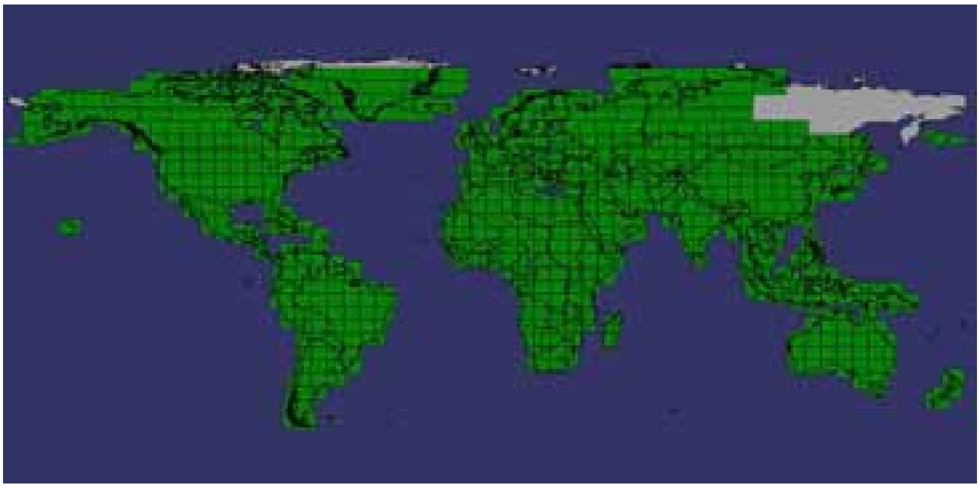

Figure 11: GeoCover-Ortho Year 1990. Green: Completed; Grey: Not Available (from MDA website).

Landsat MSS scenes for the year 1975

The individual scene circa mid-70s GeoCover-Ortho database includes 8,100 orthorectified Landsat MSS scenes. The map below shows the approximate production status.

Figure 12: GeoCover-Ortho Year 1975. Green: Completed; Grey: Not Available (from MDA website).

For further details see:
http://edc.usgs.gov/products/satellite/PERSMarch_04_313-322.pdf
http://edc.usgs.gov/products/satellite/landsat_ortho.html
http://www.mdafederal.com/geocover/geocoverortho/prod_status/scene_prod_status

Annex 4: Kotka V recommendations on 'FRA 2010 remote sensing support'

The 'remote sensing support proposal' outlines a methodology using remote sensing, in combination with other information and local expertise, to provide global and regional estimates of afforestation / expansion of forests and deforestation over time. Such estimates are requested by many of the international conventions and processes and are not currently available. The project would also offer an opportunity for technology transfer and capacity building in countries with limited resources or experience of forest monitoring.

The meeting recommended that a remote sensing component should be included as part of FRA 2010. It should provide complementary information on the spatial distribution of forests and on forest and land cover and land-use change dynamics at the biome, regional and global level.

It further recommended that implementation of the project should be integrated into or coordinated with existing national forest inventory and monitoring initiatives, with the intention of avoiding conflicting results, and that FRA national correspondents should review the results.

It was recommended that FAO requests information on deforestation and afforestation / expansion of forests directly form those countries that already have this information, or where it is available in reports to other international organizations as an alternative to implementing the project in these areas.

It was requested that the project clearly state the confidence limits and scale limitations of the results and strongly discourage presentation of maps or results outside these limits. Public access to statistics generated by the project should only be provided at regional or greater scales and not for individual countries.

Some participants requested extra time to consider the proposal more fully and consult with colleagues in their countries. **It was agreed that** further written inputs from national correspondents would be considered in the project design, and **it was requested that** if there were any further comments by national correspondents, they be provided to FAO by 31 July 2006.

(Excerpt from FAO, final report from Kotka V expert consultation)

Annex 5: Minutes of FAO-UNEP technical meeting, Washington DC, October 2006

Meeting minutes

FAO-UNEP technical meeting
on methodology and implementation aspects of the planned
FRA 2010 Remote Sensing Survey

Washington, DC, 18-19 October 2006

Funded by NASA

Background and objectives

FAO has been coordinating global forest resources assessments (FRA) every five to ten years since 1946 (FAO, 2006), with the objective of providing a periodic global and uniform picture of the status of existing forests as well as derived trends and statistics. The backbone of the FRA process is country-based information where the most accurate national-level reports are used to generate country-level, regional and global statistics on forests, their condition, management and uses. A growing need for more detailed information on the dynamics of forest area changes led to the plan to complement the FRA country reporting by FAO member governments with a global remote sensing survey, which, at the same time, should increase national mapping and forest inventory capacities. The remote sensing survey objectives are:

- To monitor forests for the time period 1975 to 1990 to 2000 to 2005 delivering (i) area change statistics, (ii) information on land use dynamics (change matrices), and (iii) forest maps.
- As an integral part of the FRA 2010 remote sensing survey, to establish a publicly accessible information framework in support of monitoring of forests, land use and the environment, including to facilitate further global or regional monitoring of the terrestrial environment at large, as well as to assist national monitoring efforts.

The recommended dual approach of (i) systematic sampling using Landsat and (ii) full coverage monitoring using MODIS vegetation continuous fields is described in the FAO draft working paper “FRA 2010 Global Remote Sensing Assessment of Forests - A New Approach” (available at www.fao.org/forestry/site/34989/en).

At the FRA Kotka V expert consultation in June 2006 convention secretariats (CBD, UNFCCC), international organizations and bodies (World Bank, UNEP, UNECE, ITTO, ICRAF, UNFF) and government forestry officials from 45 countries endorsed the proposal for a global remote sensing survey as part of FRA 2010.

The land cover remote sensing community provided positive feedback on the proposed survey during the global vegetation monitoring workshop in Missoula, in August 2006.

To further review and refine the approach, NASA provided funding to the Heinz Center to organize an FAO-UNEP technical meeting on the methodology and implementation aspects of the planned FAO FRA 2010 remote sensing survey. The objectives of this meeting were to:

- Assist FAO and UNEP in further refining the methodology for the planned FRA 2010 Remote Sensing Survey by (i) informing meeting participants on the current status of the plans and (ii) collecting specific methodology feedback and suggestions from participants, e.g. sampling design, available input data, preprocessing options, classification system and legends.
- Assist FAO and UNEP in setting up an operational global partnership for the implementation of the survey and prepare a draft work plan.

The meeting took place at the H. John Heinz III Center for Science, Economics, and the Environment, 1001 Pennsylvania Ave. NW, Suite 735 South, Washington, DC 20004. It was attended by 24 land cover/land use mapping and forest monitoring experts. The meeting was chaired by Anthony C. Janetos, Joint Global Change Research Institute. The agenda and the list of participants are found in Annex 1 and 2 respectively.

A summary of the main steps involved in the planned systematic sampling of Landsat imagery is shown in Figure 1 below.

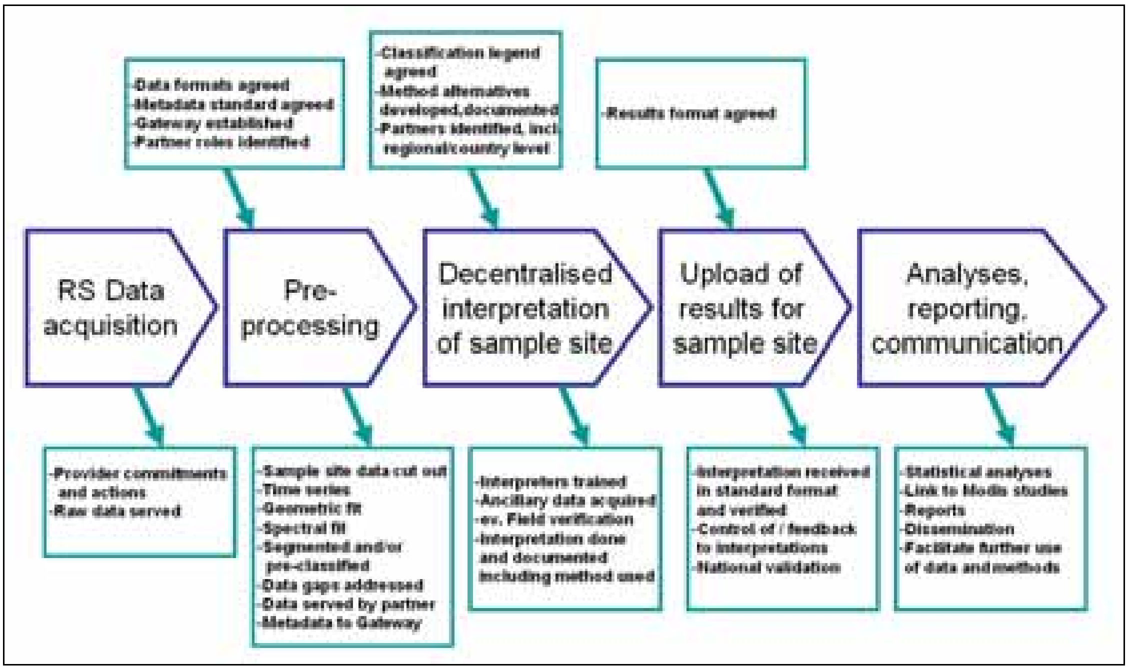

Figure 13: The FRA 2010 Remote Sensing Survey main information process, presented by FAO.

Conclusions and Recommendations

The group of experts present at the meeting endorsed the general approach and methodology proposed for the planned FRA 2010 Remote Sensing Survey and noted that they are ready to assist in its implementation.

The participants further agreed to continue to play an advisory role without the need of a formal partnership agreement. However, FAO may need to formalize its collaboration with individual institutions that are willing to actively contribute to the Survey.

The experts made the following key recommendations:

General feedback

- The FRA 2010 Remote Sensing Survey should focus on forest / tree cover monitoring as well as on forest and land use change dynamics.
- Climate / carbon reporting and other types of monitoring are likely to have further needs that cannot be addressed by the FRA 2010 Remote Sensing Survey in sufficient detail. But the planned initiative may be able to establish an overall information and monitoring framework that allows for data integration (standard setting required) and can be used for subsequent more detailed carbon monitoring as well as other types of monitoring, e.g. other environmental services, desertification, food security, poverty. Such a framework is expected to reduce transaction cost for further monitoring activities, e.g. World Bank due diligence efforts.
- Incentives for national governments to participate and actively engage in FRA 2010 will be highly important. Capacity building and linking FRA 2010 with existing or planned national / regional monitoring efforts will be key aspects. This should stimulate, enhance and integrate national / regional forest assessment and monitoring systems.
- The FRA 2010 Remote Sensing Survey will rely heavily on NASA satellite imagery, mainly MODIS imagery and 4 global Landat datasets (1975, 1990, 2000 and 2005). However, NASA's plans to make the ca. 2005 Mid-Decadal Global Landsat dataset (MDGL) publicly available in 2008 is of concern, as this may be too late for the FRA 2010 process. Efforts should be undertaken to speed up the MDGL production process.

Country participation

- A decentralized approach to interpretation and validation should be employed.
- FRA should build on existing national / regional forest assessment and monitoring initiatives and stimulate such efforts where they do not exist yet. The global remote sensing survey is unlikely to succeed if implemented as a top down approach. Country participation and local knowledge are needed to validate the results and to transform information on land cover into land use. National data generation and national capacity building will be very important. Countries may be interested in further assistance supporting the crucial step from data generation to data use for governance purposes, e.g. national policy review and reform (examples were shown for Indonesia), even if this goes beyond the scope of FRA.

- The situation differs widely from country to country:
  - A few countries have a national forest inventory system (sometimes supported by remote sensing) in place, which can directly provide the information to be gathered by FRA 2010. Here FAO has to deal with data integration issues rather than information production issues.
  - For a few very large countries the planned sampling design will be detailed enough to provide accurate national level statistics (even if this is not the objective), e.g. Brazil, DRC, Russia.
  - Medium-sized countries will need to intensify the sampling density (1 sample very 0.5 or 0.25 degrees lat/long) if they wish to be able to derive valid national level estimates. This will fall outside the scope of the FRA 2010 process but support might be provided through the FAO programme on support to national forest assessments.
  - Small countries, especially small island states will need to substantially modify the sampling grid to be able to derive valid national level estimates. The immediate benefits of participating in the survey may thus be limited.

Medium resolution full cover mapping of tree cover and tree cover change

- The MODIS Vegetation Continuous Fields (VCF) approach, developed and applied by University of Maryland and South Dakota State University was considered appropriate for annual assessment of tree cover and cover change at the global and regional levels, even if it should not yet be considered a fully operational approach. Transparency on where MODIS works well and on where further R&D is needed seems advisable.
- MODIS results indicate likely hotspots of deforestation and allow for identification of major degradation corridors. Whether it allows the pinpointing of more fine scale forest degradation has yet to be investigated.
- The planned annual 250 m MODIS VCF product complements the Landsat sampling, e.g. annual changes indicated by MODIS cannot be assessed by Landsat.
- A MODIS-high resolution fusion approach as promoted by SDSU appears most promising.
- Even with daily or near daily data acquisition mapping of some persistently could covered areas remains problematic, especially for change assessments, e.g. coastal Gabon and Cameroon.
- Open questions on product validation still need to be answered, e.g. accuracy of low tree cover areas in arid zones.
- The global MODIS product can be customized at regional levels.
- The best use of the MODIS product has yet to be decided. Possible uses are: (i) validation of high resolution sampling results using MODIS; (ii) using MODIS tree cover to inform high resolution interpretation for 2000 and 2005; (iii) use of MODIS change product to prioritize Landsat sampling in 2000 and 2005; (iv) validation of MODIS using high resolution sample interpretation; (v) use of MODIS product for illustration and communication purposes.

High resolution sampling of forest cover and forest use

Sampling design

- In spite of many solid technical and pragmatic reasons favoring the systematic lat/long grid, concern was raised that a triagonal grid (equal area hexagons) might be more appropriate for long-term monitoring, e.g. USDA Forest Service switched to triagonal grid after using a lat/long grid for 50 years (issues with over-sampling towards northern areas).
- Advantages of systematic 1 degree by 1 degree lat/long grid are:
  - it is a well established and well-known grid which appears to be intuitive to lay people and politicians, and can be easily communicated;
  - the statistical accuracy of a triagonal grid is only marginally higher compared to the lat/long grid;
  - the lat/long grid can account for variation in sampling rate (higher latitudes) while variations in sampling rate within regions or biomes are marginal;
  - tests by JRC support the systematic lat/long grid for the topical region;
  - FAO used the lat/long grid in National Forest Assessment (NFA) programs implemented in 10 countries, planned in 30 further countries;
  - the confluence initiative (www.confluence.org) provides useful information on many grid points.
- The European Commission (TREES 3 and European FOREST program, 2007-2013) offers FAO the opportunity of a substantial work and cost share. A FAO-EC agreement on a joint sampling grid and classification system / legends would be required to ensure a cost-effective collaboration.
- FAO and EC should take a decision on sampling grid within the coming weeks including the question of possible grid corrections at higher latitudes.

Remote sensing data acquisition

- The FRA sampling approach should remain sensor independent, even if imagery from different sensors will introduce integration issues. Landsat Geocover and mid-decadal data should remain the FRA backbone, while due to cloud cover and seasonality issues many data gaps will need to be filled with further optical and SAR imagery. This will require accessing historical archives. It will also require coordinated / integrated future acquisition strategy ensuring data continuity for the FRA global sampling units. The latter should be brought to the attention of CEOS (virtual constellation), GCOS and GEO. Well formulated FRA needs should soon be communicated. Exceptions from existing space policies might be achieved for a high profile project like FRA 2010, following the successful IGBP precedent.
- Expanding the high resolution sampling to the near-global ca. 1975 MSS dataset may be technically challenging. Difficult questions: (i) how to fill cloud and seasonality gaps? (ii) Legends to be used for 1990, 2000 and 2005 may have to be simplified for 1975. (iii) how to validate forest cover and use on 30 year old imagery? Lack of reference data.
- Useful imagery for filling data gaps include ASTER, AVNIR, AWIFS, CBERS-2, Corona, DMC, historical Landsat, SPOT, Sentinel2, ALOS, ERS, JERS, TerraSAR-X (FRA-SAR project, see presentation by Chris Schmullius and John Tonwshend), and other types of data.

From 2007 onwards Landat may need to be replaced by other sensors. Data access to gap-filling data needs to be negotiated on a case by case basis to ensure that clipped sample unit imagery can be made publicly available via the FRA 2010 web-based Information Gateway, ensuring its potential use by further monitoring efforts.

- Mid-decadal dataset (MDGL) production seems rather slow for the needs of FRA 2010. According to current NASA planning MDGL should be available by early / mid 2008. MDGL timing should be closely monitored and if possible influenced to make it more compatible with FRA 2010 deadlines. GOFC-GOLD has an advocacy function, a NASA member on its Executive Committee, and will assist in this area.

Preprocessing

- Central pre-processing tasks were summarized as
  - setting of data and meta data standards;
  - establishing of an information gateway that serves FRA and other monitoring initiatives by providing public access to all input data or meta data and possibly more limited access to interpretation results;
  - allowing partner and in-country institutions upload imagery and auxiliary data supporting and informing image interpretation.
- An issue to be solved is co-registration of Geocover, MDGL and gap-filling imagery.
- It was recommended to set up working group on pre-processing and image interpretation to evaluate and recommend best available methodology option. This may require running trials. Possible WG members are Alan Belward, Mathew Hansen, John Latham, Mette Wilkie and Ralph Ridder.
- Visual interpretation of several thousands of multi-temporal (4 dates) sampling units by many skilled experts will necessarily be impacted by considerable interpreter bias. Certain types of automated classification or image segmentation techniques may offer solutions to minimize such bias, e.g. central multi-temporal image segmentation with in-country polygon editing and labeling. This would decrease the work load of national interpreters and speed up the process. The above mentioned working group should analyze / investigate existing techniques and provide recommendations.

Interpretation and validation

- A decentralized approach is advocated.
- Classification system and legends to be used: The land cover community increasingly favours the UN Land Cover Classification System, even if e.g. burnt areas are not foreseen but considered important. However, there is no equivalent system for forest / land use yet.

  TREES 3 suggested an initial legend that will need to be further evaluated and harmonized with forest cover and use legends used for the FRA process.
- It was recommended to map classifiers such as life forms and to skip the “Cultivated and Managed Vegetation” versus “Natural and Semi-Natural Vegetation” classification of the LCCS.
- Land use interpretations should be added as additional attribute.

- A minimum mapping unit (MMU) of about 1 to 5 ha was recommended. The smaller the MMU the easier it will be to resolve most problems with mixed classes. However, a small MMU results in many more polygons to be labeled and verified, so a suitable compromise needs to be found.
- Adjustment of image acquisition years scattered around the 4 reference years 1975, 1990, 2000 and 2005: Linear adjustment as applied in previous FRAs seems most recommendable.
- The validation process needs to be further determined, starting with clear validation objectives and intended types of validation. GOFC-GOLD offered support through the expertise of its Land Cover Implementation Team, as well as its six Regional Networks, which are mainly located in developing and remote regions around the world. The Networks provide opportunities to establish test sites as well as for capacity building and training. It was also recommended to check the usefulness of the CEOS cal./val. experiences and resources.

AGENDA OF THE MEETING

Agenda day 1, 18 October 2006

Time	Presentation / introduction of topic
8:00-8:30	Registration, coffee
	Introduction, welcome
8:30-8:40	Anthony Janetos, Joint Global Change Research Institute: Welcome
8:40-9:00	Peter Holmgren, FAO & Ashbindu Singh, UNEP: Welcome, meeting objectives, agenda Round of short self introductions by participants
	Session 1 – Setting the scene – Information needs and the proposed scope and approach
9:00-9:30	Kenneth Chomitz, World Bank: The usefulness of forest monitoring information for policy and project analysis
9:30-10:00	Mette L. Wilkie, FAO: Proposed scope and overall approach of FRA 2010 and the FRA 2010 Remote Sensing Survey
10:00-10:30	Discussion and recommendations on overall scope and approach, facilitator: Ashbindu Singh, UNEP
	Coffee break
	Session 2 – Methodology (Short introductions followed by discussions)
11:00-11:45	Matthew Hansen, South Dakota State University: Global full coverage monitoring using MODIS vegetation continuous fields
11:45-12:30	Alan Belward, JRC: Sampling design for high resolution imagery
	Lunch
13:15-14:00	Woody Turner, NASA, John Townshend, UMD & Chris Schmullius, Jena University: Available high resolution optical and SAR imagery
14:00-14:45	Peter Holmgren, FAO: Data supply, preprocessing and dissemination for decentralized classification/interpretation work
	Coffee break
15:00-15:45	Mette L. Wilkie, FAO: Classification system and legends – Harmonization of FRA, TREES 3, LCCS and other systems
15:45-16:30	Alan Belward, JRC: Image interpretation (automatic, semiautomatic, manual) and incorporation of auxiliary data
16:30-17:00	Ralph M. Ridder, Heinz Center / FAO: Day 1 conclusions and recommendations

Agenda day 2, 19 October 2006

Time	Introduction of topic
8:30-8:45	Anthony Janetos, Joint Global Change Research Institute: Comments on day 1, day 2 agenda
	Session 3 – Towards a FRA 2010 Remote Sensing Partnership
8:45-9:30	Mette L. Wilkie, FAO: Structure, components and tasks for a partnership to implement the FRA 2010 Remote Sensing Survey
9:30-10:15	Ralph M. Ridder, Heinz Center / FAO: Provisional work plan and current status of institutional commitments
	Coffee break
10:45-12:15	Review of work plan and commitments of partner institutions: outputs, lead organization(s), delivery dates, funding needs, facilitator: Ralph M. Ridder
	Lunch
13:00-14:30	Review of work plan and commitments of partner institutions: outputs, lead organization(s), delivery dates, funding needs, facilitator: Ralph M. Ridder
	Coffee break
	Session 4 – Links with other initiatives, fund raising support and opportunities
15:00-15:45	Douglas Muchoney, GEO: The Rapid Land Cover Mapping Tool, and the Global Forest Monitoring Symposium 2007
15:45-16:30	Michael Brady & Martin Herold: Contributions and cooperation with GOFC-GOLD
16:30-17:00	Mette L. Wilkie, FAO, & Anthony Janetos, Joint Global Change Research Institute: Wrapping up, next steps, closing of meeting

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5.3 Annex 6: Remote sensing survey planning process to date

Event	Date
FAO-JRC information exchange on global / regional assessment plans, FAO, Rome	May 06
Expert consultation on Global Forest Resources Assessment: Towards FRA 2010, Kotka (Kotka V)	June 06
Global vegetation monitoring workshop, University of Montana, Missouri	August 06
Satellite image based sampling for global forest cover monitoring, JRC, Ispra	September 06
FAO-UNEP technical meeting on methodology and implementation aspects of the planned FRA 2010 Remote Sensing Survey, Heinz Center, Washington DC	October 06
FRA 2010 Remote Sensing Survey work planning meeting, FAO, Rome	December 06
FRA advisory group meeting, FAO, Rome	January 07
Mid-Decadal-Global-Landsat data workshop: Strategies for Global High Resolution Mapping of Land Cover / Change and Vegetation Dynamics, Annapolis	February 07
Workshop on Methods for Interpretation of Large Datasets of Landsat-type Satellite Imagery in the framework of Global Forest Monitoring, JRC, Ispra	March 07