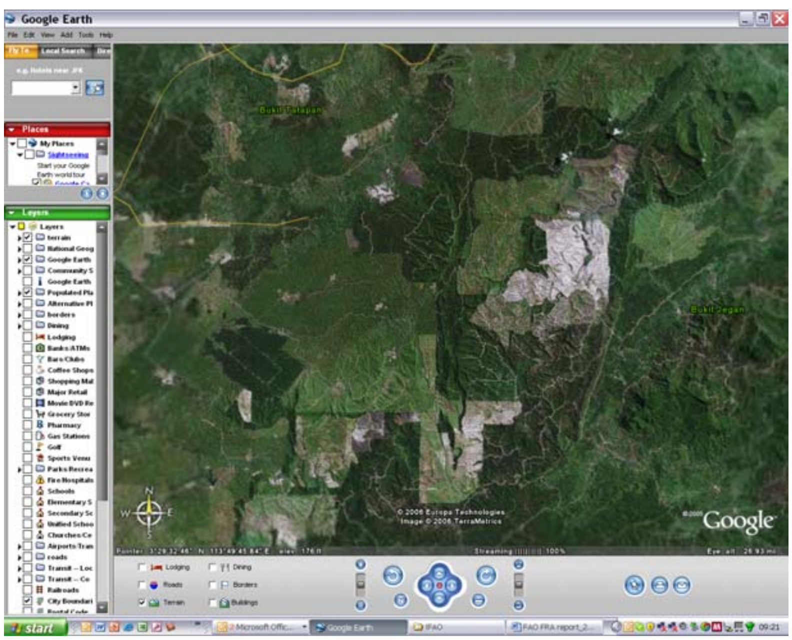
Forestry Department

Food and Agriculture Organization of the United Nations

DRAFT, 22 May 2006

GLOBAL FOREST RESOURCES ASSESSMENT

FRA 2010 GLOBAL REMOTE SENSING ASSESSMENT - A NEW APPROACH



ROME, 2006

Forest Resources Assessment Programme **Working paper xxx**

Rome 2006

The Forest Resources Assessment Programme

Sustainably managed forests have multiple environmental and socio-economic functions important at the global, national and local scales, and 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 Forest Resources Assessment Programme. The Global Forest Resources Assessment 2005 (FRA 2005) is the most comprehensive assessment to date. More than 800 people have been involved, including 172 national correspondents and their colleagues, an Advisory Group, international experts, FAO staff, consultants and volunteers. Information has been collated from 229 countries and territories for three points in time: 1990, 2000 and 2005.

The reporting framework for FRA 2005 is based on the thematic elements of sustainable forest management acknowledged in intergovernmental forest-related fora and includes more than 40 variables related to the extent, condition, uses and values of forest resources. More information on the FRA 2005 process and the results - including all the country reports - is available on the FRA 2005 Web site (www.fao.org/forestry/fra2005).

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The FRA Working Paper Series provides an important forum for the rapid release of information related to the FRA programme. Should users find any errors in the documents or would like to provide comments for improving their quality they should contact fra@fao.org.

The image on the title page shows the Google Earth interface looking at managed forests in Sarawak, Malaysia (earth.google.com).

Acknowledgement

I am grateful to Peter Holmgren and Mette Løyche Wilkie for enabling and guiding this concept review study. I am also thankful to FAO FRA national correspondents and their national networks for their invaluable inputs. Special thanks go to Matt Hansen, Anthony Janetos, John Latham, Greg Reams, Ron McRoberts, Brad Smith and Steve Stehman who contributed constructively through their relevant experiences and elaborate discussions on methodology options. In the annex of this report, I provide a list of experts for whose valuable input I am grateful.

Ralph M. RIDDER Rome & Washington DC, May 2006

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 on 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 global estimates of FAO's Forest Resources Assessment (FRA) program are largely based on national statistics and inventory reports, which contain detailed information on the forests of individual countries reported by each UN member 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 gross changes and on (ii) land use dynamics.

To complement the FRA national reporting, to provide an independent picture of forest cover trends and to specifically address regional forest gross changes and land use dynamics in the 1980s and 1990s, FAO conducted two pan-tropical remote sensing surveys that were 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 inventory capacity FAO is planning to carry out its first **global** Remote Sensing Assessment (RSA) within the framework of the upcoming FRA 2010.

The recommended objectives for the FRA 2010 RSA 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**.
- As an integral part of the FRA 2010 remote sensing assessment, **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 RSA compared to previous FRA 1990 and FRA 2000 remote sensing surveys" (FAO, 2004). New components of the 2010 global RSA are:

- All land area of the world will be represented by the RSA, 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). Thus, in large countries and on specific request by a national government the RSA can support and probably increase accuracy of national reporting where recent inventory information is lacking. (For small countries additional samples may be needed to come up with national level estimations.)
- The assessment will include both forest cover and forest use to ensure higher compatibility of RSA with national reporting.
- 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. Knowledge of forest location and its changes is planning and policy relevant, especially in places with high rates of land and forest cover change.
- 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) that in-country technical mapping and inventory capacities are increased to a needed minimum level across all participating countries.

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

- The RSA will be **complementary to the national reporting** by providing a regionally harmonized picture on specific variables (forest extent, forest characteristics and forest cover) and forest change dynamics that will allow to better understand the causes of forest degradation, fragmentation and deforestation.
- The RSA will contribute to **increase national capacity** in mapping, monitoring, reporting and inventory techniques. In certain countries this may initiate the preparation of a national monitoring system and testing of additional variables.
- On specific request by national governments the RSA can help to **strengthen** the FRA **national reporting**, e.g. in large countries where recent forest inventory information is outdated.

Thus the RSA is likely to improve FRA's overall scope and accuracy in the following ways:

- A comprehensive 2010 RSA will help governments to better understand and subsequently reduce forest definition and reporting inconsistencies with neighbour countries. E.g. up-to-date regional full coverage tree cover information will show possible trans-border inconsistencies.
- Regional RSA forest area and area change estimates (for both forest use and cover) can provide useful input information to national reporting on FRA

forest extent, characteristics and functions. This can help to adjust possible extrapolations from previous national forest inventories and update such information where outdated.

The following approach is recommended for the FRA 2010 global RSA:

- Landsat type (Landsat imagery and equivalent, and complementary SAR imagery where available) sampling to produce (i) area and area change statistics and (ii) change matrices on
    - Forest extent and forest characteristics.
    - Forest cover using FAO LCCS.
- Complement the statistical sampling with full coverage MODIS vegetation continuous fields (VCF) monitoring of forest cover and cover changes.

Details and options of the recommended approach are described in this report.

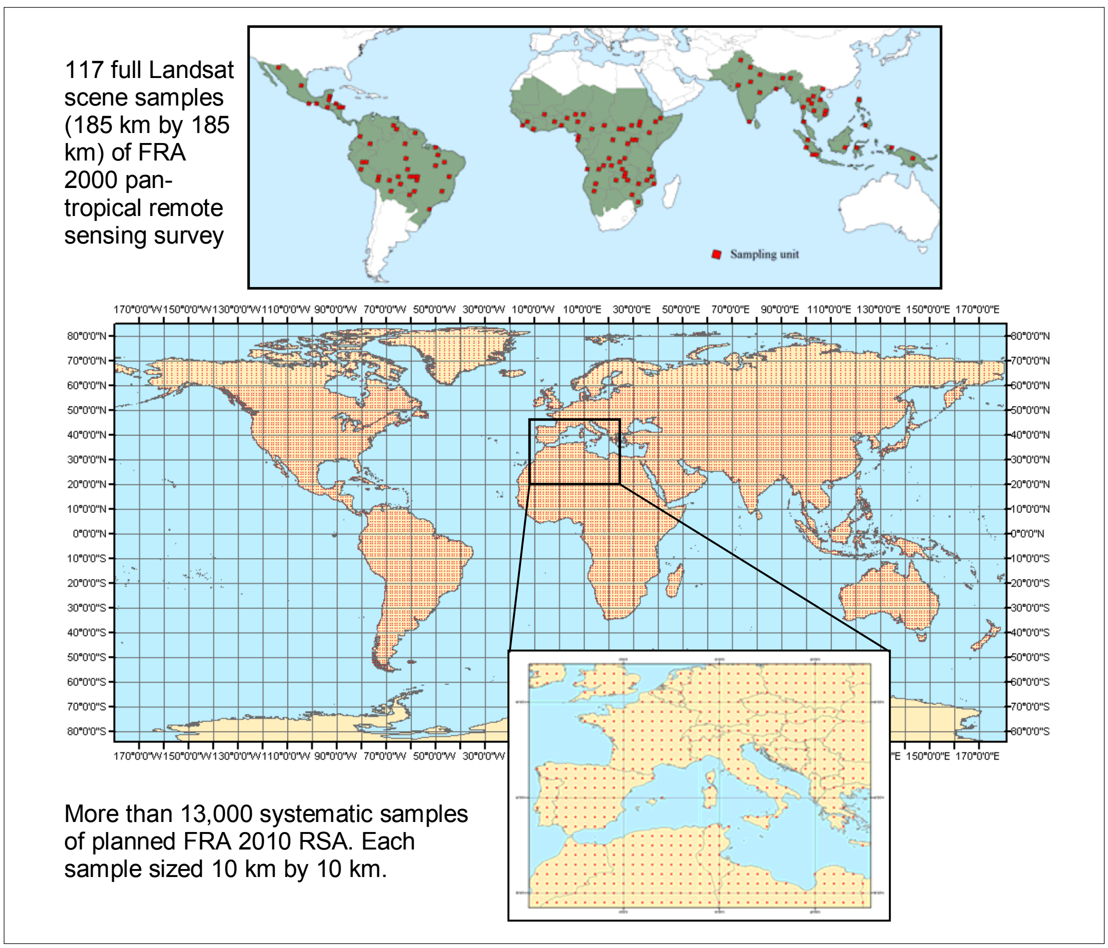

Figure: Comparison of sampling units between FRA 2000 pan-tropical remote sensing survey and the planned global 2010 RSA.

Kotka V, 12-16 June 2006, is expected to provide recommendations on the 2010 RSA to COFO that is foreseen to meet next in March 2007. To do this appropriately the following questions are expected to be discussed in the Kotka FRA 2010 RSA working group:

- Is an RSA useful and needed? Should it be implemented within the FRA 2010 framework?
- If so, what should be the scope of the RSA? Which variables should be included and assessed?
- Which partner institutions are most appropriate to collaborate within the RSA?
- Type and number of interpretation nodes and hubs: Kotka might be a good venue to start assessing the technical capacity as well as number of national and regional interpretation centres that are ready to participate in the 2010 RSA.
- Decentralized RSA implementation: Is the Information Framework considered an appropriate and operational execution and dissemination platform for the 2010 RSA?

More technical questions concerning the RSA implementation are expected to be discussed during a remote sensing expert consultation, likely to be held in Washington, DC, short after the Kotka meeting.

Based on the results of Kotka V and the remote sensing expert consultation a tentative execution and budget plan will be elaborated, and subsequently discussed with interested donor agencies.

Assuming (i) positive recommendations from Kotka and (ii) support from donors the 2010 RSA will require a quick start off to ensure that the ambitious approach can be tested and implemented in time. An initial short test and preparation phase in 2006 could seamlessly blend into the implementation phase from 2007 through 2010.

Abbreviations

ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
CBD	Convention on Biological Diversity
COFO	Committee on Forestry of FAO member governments
FAO	Food and Agriculture Organization of the United Nations
FGDC	Federal Geographic Data Committee
FORM	Forest Resources Development Service
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
LCTC	Land Cover Topic Center
LULC change	Land use and land cover change
MDG	Millennium Development Goals
MERIS	Medium Resolution Imaging Spectrometer
NASA	National Aeronautics and Space Administration
NFA	National Forest Assessment
RS	Remote sensing
RSA	Remote sensing assessment
SDRN	Natural Resources Management Service
SDSU	South Dakota State University
SPOT	System Probatoire pour l'Observation de la Terre
UNFCCC	United Nations Framework Convention on Climate Change
VCF	Vegetation Continuous Fields algorithm
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 on 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 global estimates of FAO's Forest Resources Assessment (FRA) program are largely based on national statistics and inventory reports, which contain detailed information on the forests of individual countries reported by each UN member 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 through 3. 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.

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).

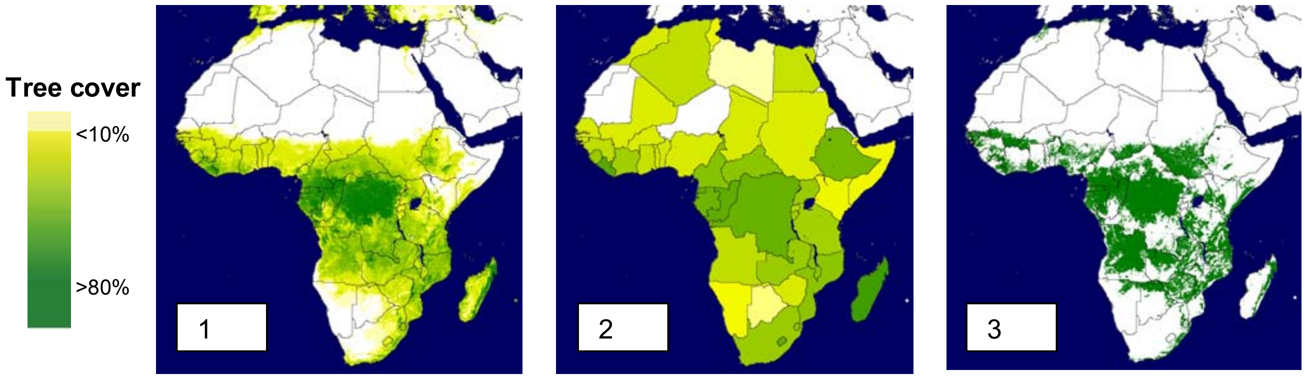


Figure 1: 1997 percent tree cover for Africa (Hansen, 2005).

Figure 2: Percent tree cover threshold which yields an area estimate that matches FAO 2000 By starting at the densest tree cover per country and sliding the threshold down from there until it matches FAO 2000 (Hansen, 2005).

Figure 3: Resulting forest map where per country forested area match FAO 2000 totals. By starting at the densest tree cover per country and sliding the threshold down from there until it matches FAO 2000. Green = forest, white = non-forest (Hansen, 2005). 1 through 3 confirm that national reporting and remote sensing analysis diverge for Africa (Mayaux *et al.*, 2005).

Resulting key issues are the lack of regionally harmonized information on (i) forest gross changes and on (ii) land use dynamics to characterize the causality visualized in figure 4.
There is no quick solution to this issue. To ease 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.

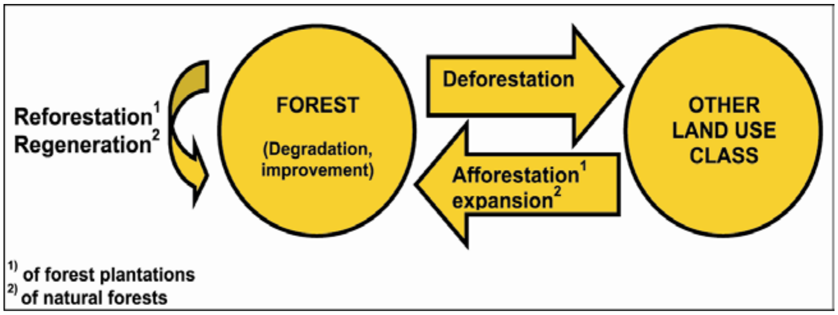


Figure 4: Clear understanding of forest dynamics result in regional forest and land use change matrices and change statistics with known precision (FAO, 2000).

To complement the FRA national reporting, to provide an independent picture of forest cover trends and to specifically address regional forest gross changes and land use dynamics in the 1980s and 1990s, FAO conducted two pan-tropical remote sensing surveys that were part of FRA1990 and FRA2000. "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).

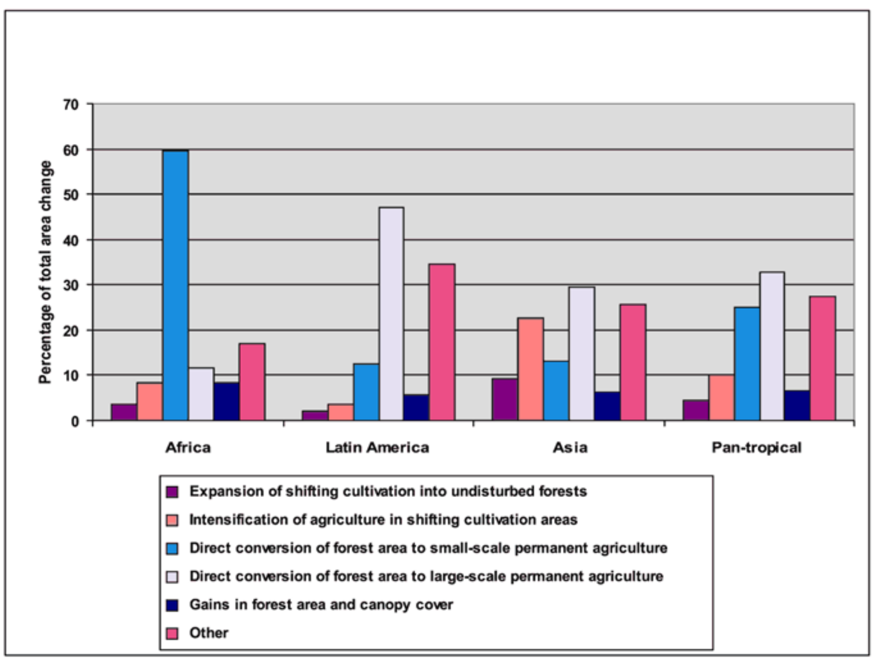


Figure 5: Example of how the 2000 remote sensing survey complemented the FRA 2000 national reporting and provide regionally harmonized information on land use dynamics (FAO, 2000).

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 its first **global** Remote Sensing Assessment (RSA) within the framework of the upcoming FRA 2010.

2. The new FRA 2010 RSA strategy

2.1 Objectives and new components

The recommended objectives for the FRA 2010 remote sensing assessment 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**.
- As an integral part of the FRA 2010 remote sensing assessment, **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 RSA compared to previous FRA 1990 and FRA 2000 remote sensing surveys" (FAO, 2004). The 2010 global RSA should be complementary to the national reporting process and comprise new components that offer a range of advantages over past surveys and can be repeated in future FRAs:

- All land area of the world will be represented by the RSA, 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). Thus, in large countries and on specific request by a national government the RSA can support and probably increase accuracy of national reporting where recent inventory information is lacking. (For small countries additional samples may be needed to come up with national level estimations.)
- The assessment will include both, forest cover and forest use to ensure higher compatibility of RSA with national reporting.
- 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. Knowledge of forest location and its changes is planning and policy relevant, especially in places with high rates of land and forest cover change.
- 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) that in-country technical mapping and inventory capacities are increased to a needed minimum level across all participating countries.

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

2.2 Justification

FRA 2010 is expected to be requested by COFO in March 2007. This future COFO mandate would also cover the FRA 2010 global RSA. The main reasons and justification for promoting the FRA 2010 global RSA is that:

- The RSA will be **complementary to the national reporting** by providing a regionally harmonized picture on specific variables (forest extent, forest characteristics and forest cover) and forest change dynamics that will allow to better understand the causes of forest degradation, fragmentation and deforestation.
- The RSA will contribute to **increase national capacity** in mapping, monitoring, reporting and inventory techniques. In certain countries this may initiate the preparation of a national monitoring system and testing of additional variables.
- On specific request by national governments the RSA can help to **strengthen** the FRA **national reporting**, e.g. in large countries where recent forest inventory information is outdated.

Thus the RSA is likely to improve FRA's overall accuracy in the following ways:

- A comprehensive 2010 RSA will help governments to better understand and subsequently reduce forest definition and reporting inconsistencies with neighbour countries. E.g. up-to-date regional full coverage tree cover information will show possible trans-border inconsistencies (see figure 1 to 3).
- RSA forest area and area change estimates (for both, forest use and cover) can provide useful input information to national reporting on FRA forest extent, characteristics and functions. This can help adjust possible extrapolations from previous national forest inventories and update such information where outdated.

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

Further reasons to promote the 2010 RSA are:

- Accurate and timely information on forest and forest area change is 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 RSA approach promises to provide 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, global forest fire applications, as well as 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 have or do not have the intended impact on forests.
- Advance science in global natural resources monitoring.
- Showcase the usefulness of remote sensing technology which can help to justify investments in current and future satellite missions.

3. Introductory considerations

3.1 Statistical sampling or 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 LULC 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 LULC 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 Strategic or operational monitoring

Another aspect to be considered is the monitoring purpose. Frequent and detailed monitoring of forestry operations and relevant financial flows to detect and prevent illegal logging within the FLEG and FLEG-T framework requires a different monitoring approach than FRA monitoring that is assessing and addressing longer-term overall forest sustainability aspects in a less-frequent and less detailed manner. The FRA purpose seems well served with a global 5-year or decadal 30 m pixel sampling assessment and a 250 m to 500 m pixel full coverage monitoring. Illegal logging requires other types of assessments.

Box 1: Need for short repeat cycles

To ensure operational and frequent national level forest monitoring daily satellite repeat cycles are imperative, at least in environments with persistent cloud cover. According to the Ministry of Forestry in Jakarta a meaningful national level monitoring interval in tropical areas is 6 to 12 months (Hermawan Indrabudi, 2006). This frequent monitoring enables sufficiently detailed forest change mapping in tropical environments with rapidly closing tree canopies. For such frequent monitoring the Landsat repeat cycle of 16 days, meaning one image acquisition per scene every 16 days, is not sufficient. In tropical environments Landsat often delivers less than one usable image (with less than 20% cloud cover) per scene per year.
The three existing global Landsat data sets demonstrate that Landsat cannot even fully ensure decadal monitoring in the tropics. Due to cloud cover issues the global 1975 data set was acquired from 1973 through 1984, the 1990 data set was acquired from 1986 through 1992, and the 2000 data set was acquired from 2000 through 2003. Yet, these data are not free of atmospheric influences, nor are they free of seasonality. Ideally satellite forest monitoring should be based comparison of imagery from vegetation peak seasons to avoid that mapped changed is mixed with seasonal changes. Landsat is not delivering on this consistently at the global level due to its repeat cycle.

3.3 Suitable satellite imagery

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

- Available at low or no 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, best daily repeat cycle (see box 2).

- Available for entire or at least major parts of the intended monitoring period of 1975 to 1990 to 2000 to 2005.
- Satellite sensor should have a long future lifespan to enable imagery use in future FRA assessments and to justify possible interpretation development cost.

Image type	Free / low cost	No copyright	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 stripy	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						
TerraSAR-X	-	-	+/-	Not relevant	2007?	unclear
ALOS PALSAR	-	-	+	Not relevant	2007	unclear

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

* ESA currently has problems in supplying MERIS users with requested imagery.

Based on table 1 Landsat and MODIS imagery, appears to be best suited for the FRA 2010 RSA, 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: (i) circa 1975 (acquisition period 1973 through 1983), (ii) circa 1990 (acquisition period 1986 through 1992) and (iii) circa 2000 (acquisition period 2000 to 2003). 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 SDRN. The Landsat MSS images provides the opportunity to expand the planned FRA 2010 RSA monitoring period by 15 years into the past using the 1975 global data set.
  All 3 global data sets were ortho-rectified by EarthSat Corporation (now called MDA Federal) in Rockville, thus mosaic and edge-match well. Further details are given in annex 3.
  Within the next couple of months NASA and other agencies will decide on a possible free mid-decadal data set. The currently discussed minimum solution would be 1,000 free Landsat 5 and 7 scenes from 2006. The maximum solution would be a fourth global data set consisting of Landsat TM and ETM+ as well as other imagery filling in the data gap caused by the malfunctioning ETM+ (since May 2003 ETM+ delivers stripy images / SLC off).
  As explained in box 1, the above-mentioned global Landsat data sets are more or less impacted by atmospheric conditions like haze and clouds, as well as by seasonality. Where combined cloud cover and cloud shadow amounts to more than 10 % per images or where imagery is affected by inappropriate seasonality additional images (Landsat or equivalent) will need to be purchased.
- MODIS appears to be the best vegetation monitoring instrument: (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 the annex 1.

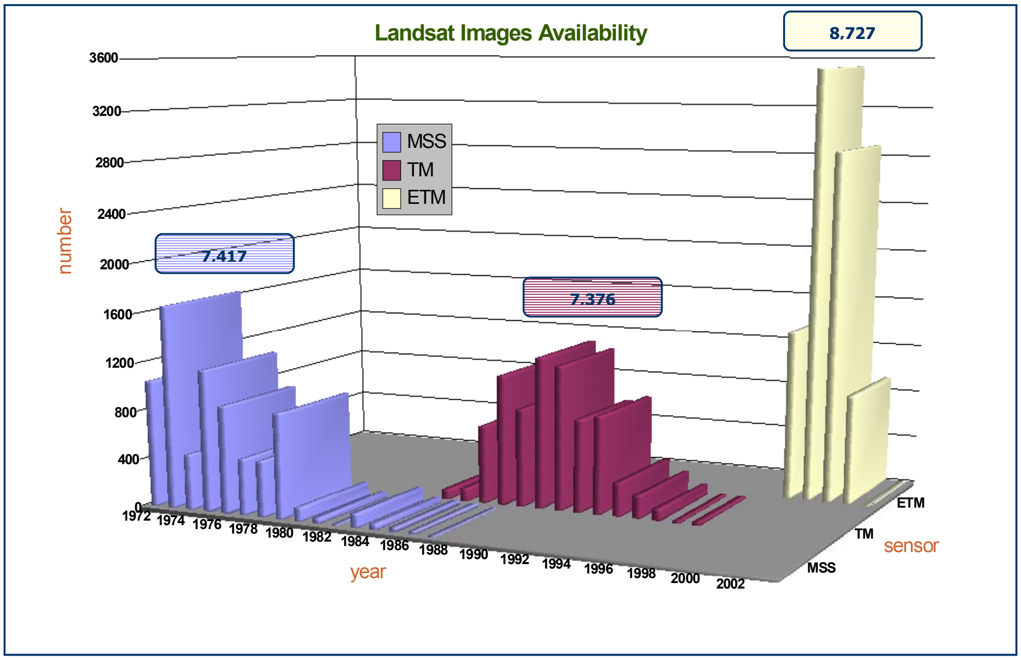


Figure 6: Type, number of satellite images per acquisition year archived in SDRN's LCTC. All these images are distributed on request free of charge to UN agencies (Latham, 2006).

4. Planned new approach

Based on the above considerations, FAO's preparatory methodology (see box 2) and recommendations from the FAO stakeholder consultation in January 2003 the following approach is recommended for the FRA 2010 global RSA:

- Landsat type (Landsat imagery and equivalent, and complementary SAR imagery where available) sampling to produce (i) area and area change statistics and (ii) change matrices on
  - Forest extent and forest characteristics.
  - Forest cover using FAO LCCS.
- Complement the statistical sampling with full coverage MODIS vegetation continuous fields (VCF) monitoring of forest cover and cover changes.

Key reasons for adding full coverage monitoring to the FAO preparatory methodology:

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

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

Box 2: Essentials of FAO FRA 2010 preparatory RSA methodology

Land use and land cover (LULC) change survey covering the period of 1975 to 1990 to 2000 to 2005; based on visual interpretation of Landsat imagery by national experts; using a systematic 1 degree by 1 degree longitude-latitude sampling grid of from the equator to 60 degrees northern latitude, and a 2 degree by 1 degree grid north of 60 degrees northern latitude; resulting in about 13,000 samples worldwide; size of each Landsat sample is a 10 km by 10 km square; in sum this represents a 1 % sample of the Earth's landmass.

4.1 High resolution sampling assessment

4.11 Sampling design

Sampling frame

Previous FAO remote sensing surveys and other LULC assessments used the Landsat WRS2 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). A sampling frame that is independent of satellite sensors and sensor orbit geometry is recommendable.

Different grid systems are available for spatial sampling purposes, including rectilinear grids based on degrees of longitude and latitude, 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 (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 the proposed lat-long grid system for the FRA 2010 RSA raises a key issue: The samples will not be equidistant nor truly systematic. At the equator, where most LULC change is expected, the sampling density will be lowest, increasing towards northern and southern latitudes. Hence, the grid does not provide equal probability for detecting LULC change, e.g. comparing the tropics with temperate areas. However, considering that RSA results will mostly be used at regional or biome level then the lack of equal probability will have limited impact.

Advantages of the proposed lat-long grid system are:

- A 'presumably' systematic latitude-longitude grid is easy to understand and to communicate to national governments.
- Sample locations can be easily identified on every map.
- FAO supported NFAs use this latitude-longitude grid. It would be consistent to use the same grid for the FRA RSA.
- The European commission's Joint Research Centre is expected to start the a sampling based monitoring programme, TREES III programme, that will use the same 1 degree by 1 degree lat/long grid. FRA and JRC are currently discussing options for collaboration.
- 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 RSA 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 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 longitude-latitude grid.

Box 3: Number of sampling units in latitude-longitude grid

FAO and the University of Maryland calculated that the use of a 1 degree latitude-longitude sampling frame results in 13,482 one degree intersection points on land, including islands, based on the following conditions (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.

As a next step the number of samples that fall in non forest areas, e.g. in deserts, 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.

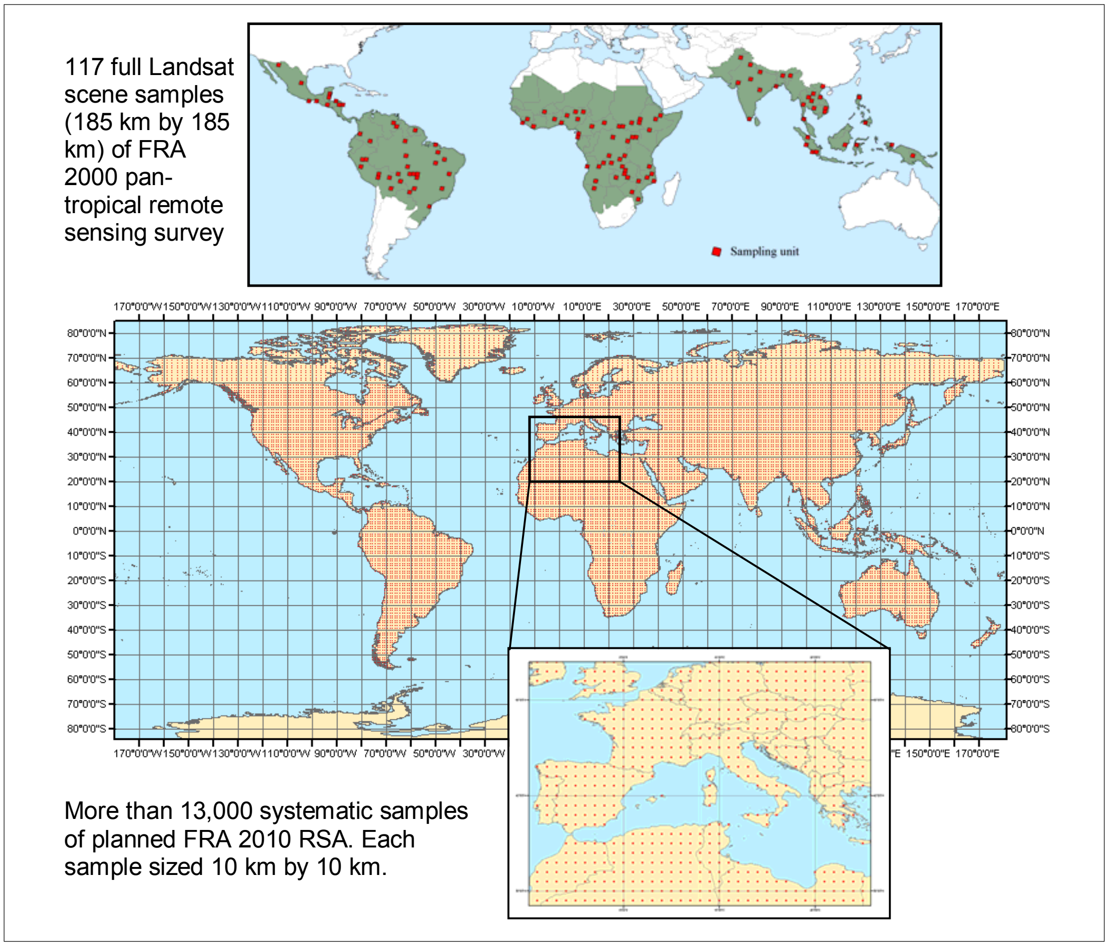


Figure 7: Comparison of sampling units between FRA 2000 pan-tropical remote sensing survey and the planned global 2010 RSA.

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, tailored to each countries needs. Hence they work well for each country.
- If the grid related national inventory information is available to the RSA this could save time and cost for Landsat sample interpretation and validation.
- Use of national grids may ensure country buy-in better 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.

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

Square shape harmonizes better with raster format of remote sensing imagery to be used in comparison to circle shape. 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 LULC change assessment based on stratified random sampling per eco-zone, a sampling unit size of 10 km by 10 km is sufficient for LULC 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 that goes beyond LULC change 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 RSA results 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). Therefore typical national forest inventories use very small sample plots - too small for a remote sensing based monitoring exercise.

Sampling protocol

The preparatory FRA 2010 RSA methodology foresees a systematic global sampling protocol without stratification. Considering all countries in the same way certainly reflects a democratic element and is politically appealing. This 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

LULC 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 it can be achieved with systematic sampling. Hence, stratification can save interpretation time and resources.

Effective stratification for precisely estimating LULC 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 & Needle, 2000).

A promising option to avoid stratum assignment error is the use of post-classification estimators to increase precision of LULC change estimations. This allows strata construction after the sample has been selected and incorporated in a postclassification 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 FAO proposed 1 % sample of the defined study area consisting of about 13,000 sample units appears to be very adequate (Stehman *et al*., 2003) assuming that a good proportion of the sample units fall into forest and hit change areas.

4.12 Forest use legend and land cover classification system

Previous FRA remote sensing surveys provided information on land cover only. It is proposed that the 2010 RSA includes a dual sample interpretation: mapping (i) forest use and (ii) forest cover.

Previous FRA Landsat land cover survey results were not compatible with the FRA tables in the national reporting process. This made the surveys appear disconnected from the FRA national reporting. To overcome this issue a forest use interpretation is needed. Thus, the RSA results and national reporting could be translated into each other. If feasible this would allow national governments to take better advantage of the 2010 RSA, designed as FAO support to its member governments. This would turn FRA into a more comprehensive exercise.

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	
Forest cover	Forest (> 10%, etc.)	Forest (Primary forest, Modified natural forest, Semi-natural forest, forest plantation)	Other land with tree cover
	Non forest < 10% cover	Temporarily unstocked forest	Other land

Table 2: Example of a forest cover / use matrix.

Forest use legend

The RSA forest use legend should ideally be fully consistent with and linked to the FRA 2010 national reporting (see table 3). The question is if it is feasible to distinguish these classes on Landsat imagery. Well-published experts in the remote sensing community doubt that this is possible without *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 government participating in the FRA 2010 RSA. Without the planned decentralized 2010 RSA implementation approach such required *in situ* knowledge could not be accessed.

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.

Forest extent	Definition	Characteristics	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.	**Primary forest**	Forest / Other wooded land of native species, where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed.
		Modified natural forest	Forest / Other wooded land of naturally regenerated native species where there are clearly visible indications of human activities.
		Semi-natural forest	Forest / Other wooded land of native species, established through planting, seeding or assisted natural regeneration.
		Productive forest plantation	Forest / Other wooded land of introduced species, and in some cases native species, established through planting or seeding mainly for production of wood or non wood goods.
		Protective forest plantation	Forest / Other wooded land of native or introduced species, established through planting or seeding mainly for provision of services.
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.	Primary forest	See above
		Modified natural forest	See above
		Semi-natural forest	See above
		Productive forest plantation	See above
		Protective forest plantation	See above
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. Another option for Landsat interpretation are the designed forest functions (production, protection of soil and water, conservation of biodiversity, social services, multiple purpose).

Land cover classification system

In 2000 FAO published its first edition of the Land Cover Classification System (LCCS). Since then LCCS turned 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 RSA.

LCCS allows each country participating in the FRA 2010 RSA to define or bring in and translate its own specific land cover legend. These national legends can then be aggregated to a simplified global LCCS land cover legend that is compatible to MODIS (see figure 6). This was tested by FAO SDRN and SDSU for an area in Africa.

4.13 Sample interpretation

Sample image pre-processing

The ortho-rectified Landsat images from the 3 existing ortho-rectified NASA / USGS global datasets, 1975, 1990 and 2000, can be provided free of charge by USGS EROS to SDSU for central pre-processing of samples. These 3 datasets are not copy right protected and can be freely exchanged. Furthermore each image is accompanied by Federal Geographic Data Committee (FGDC) meta data. When available the NASA / USGS mid-decadal Landsat dataset, year 2006, will be added for the following pre-processing steps:

- Clipping of 36,000 Landsat samples (4 times 9,000 multi-temporal samples) for 1975, 1990, 2000 and 2005. Each sample image clipping should 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.

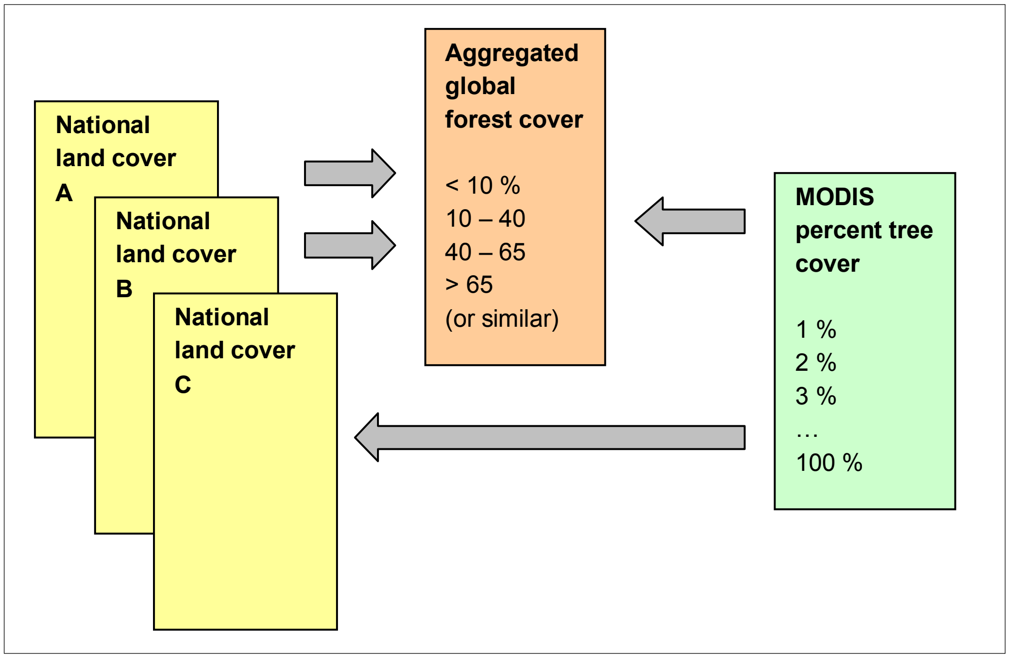


Figure 8: National LCCS based land cover legends can be aggregated to a global forest cover legend. And the MODIS based percent tree cover legend can be translated into each national legend as well as into the aggregated global legend.

- Normalize the clipped image samples to support interpretation by eliminating haze and similar atmospheric influences and make forest look alike in all samples.
- Provide a MODIS VCF based vector layer for each 2000 and 2006 sample indicating forest cover and forest cover change (aggregated tree cover increase and tree cover decrease) classes.

Within the proposed Information Framework (see chapter 4.3) SDSU has agreed to set up a website from where all clipped and pre-processed samples can be accessed and to which the completed multi-temporal sample interpretations can be uploaded.

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

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

- Preliminary VCF based tree cover interpretation will guide the interpretations crews providing them with an advanced interpretation starting point.

Box 4: 10 km by 10 km Landsat sample characteristics

- Sampling area located between 84° North and 56° South latitude.
- WGS 1984.
- Sample imagery is EarthSat Corporation ortho-rectified.
- Each sample has a 5 km buffer to facilitate interpretation work, thus resulting in 20 km squares.
- Off shore lat/long degree points or hexagon center points will not be part of the sample base.
- Use of least cloud and atmosphere impacted image if centroid falls on WRS overlap area. If both image parts are cloud free then use of whichever scene centroid is closer to the point.

Sample unit interpretation

The FRA 1990 and 2000 RSAs 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 RSA 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.

Image interpretation will start from the most recent image 2005 backwards to 1975. The resulting 2005 polygon layer will then be overlaid on 2000 image and differences will be digitised with a recommended minimum mapping unit of 5 ha or about 55

Landsat 30 m pixels. Then this layer will be overlaid onto the 1990 image to digitise differences and so on.

It is recommended to first interpret samples for land cover and land cover change. This requires prior elaboration of a national or possibly regional land cover legend. Subsequently forest use and change in forest use will be mapped. This will require sufficient auxiliary data and good knowledge of sample sites.
For both types of interpretation it is recommended to provide detailed stepwise execution manuals to make sure that all interpretation teams follow the same work process and results are fully compatible.

Four forest use change matrices and four land cover changes matrices will be created per sample site: Matrix 2005/2000, matrix 2000/1990, matrix 1990/1975, matrix 2005/1975. The change matrices can be expressed in hectares or pixels.

Standardization of transition matrices to references years 1975, 1990, 2000 and 2005 should follow the FAO description (see annex, FAO, 2002, pages 18-22).

Validation of sample interpretation

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 that harbour several 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 RSA outputs with an equally high quality across national boundaries. Especially the decentralized interpretation approach with a large number of national interpretation experts requires a clear and standardized validation procedure that will need to be defined and strictly applied.

Validation options could 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.

- The 'information framework on monitoring of forests and the environment' can be used as additional validation mechanism. Public access to all FRA 2010 RSA sampling site input (multi-temporal imagery, different types of ancillary data) and output data (forest use and land cover interpretation results) will enable public scrutiny and feedback.
- 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.

It will be important to ensure the availability of a sufficient validation budget.

Institutional scenarios

The recommended scenario is self-sufficient national interpretation and change analysis by a specialized and recognized entity per country following FAO guidelines and detailed interpretation manuals. In countries without an appropriate specialized agency, image processing training and guided sample interpretation by national experts can be done in a regional remote sensing centre. This will increase the national data processing capacity.

Such a decentralized visual image interpretation process of several tens of thousands of Landsat samples (e.g. about 9,000 sample units x 4 reference years = 36,000 Landsat samples) by a large group of photo interpreters will necessarily be affected with 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 manuals with stepwise descriptions of work process to national and regional interpretation crews. SDSU offered support in compiling such manuals.
- Random visits of senior remote sensing specialists at national and regional processing centres to spot-check work process and results.
- Centralized quality assessment process of results delivered from countries or regions e.g. by FAO or an internationally renowned centre of excellence with the required processing capacity.

FRA 2010 RSA budgeting and fundraising should sufficiently consider these quality assurance options.

4.14 Global statistical analysis

After in-country validation the Landsat sample interpretation results (vector layers of forest use and forest cover and its change, change matrices) will be sent from national and regional FRA 2010 data processing hubs to a central analysis unit that will take care of further data processing and global statistical analysis. This unit could be located inside FAO or in an outside centre of excellence. A cost analysis of both options may guide a decision.

Key tasks for this central analysis unit include:

- Carry out quality / plausibility checks on received sample interpretation results.
- Eventually re-process poorly performed photo interpretation in agreement with and by national experts.
- Assess forest use area and area change estimations based on the known FRA categories (see table 2) at regional, biome and global levels.
- Aggregate national and regional LCCS land cover legends to simplified regional, biome and global legends.
- Assess land cover area and area change estimations at regional, biome and global levels.
- Per request provide results of statistical analysis to country governments in time to support the compilation of national reports to FAO FRA.
- Integrate feedback from governments in FRA 2010 RSA summary report before it is published.

Excellent communication links between the central unit and all data processing hubs will be of vital importance.

4.2 Medium resolution full coverage assessment

The proposed full coverage methodology is able to provide nationally / regionally / biome-wide / globally consistent tree cover change information on an annual basis, without interpreter bias and at low cost using a largely automated, push-button approach. Annual change maps can be augmented by 5-10 year change mapping efforts to pick-up finer scale, long term deforestation, improving reliability of data in areas currently poorly understood. Such a product would conform to FRA reporting intervals.

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

Required calibration and validation work is labour intensive, a protocol for simplest, most easily replicated approach possible still needs to be written.

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

MODIS based forest monitoring can be transferred to national and regional partners, as currently under evaluation in Indonesia, leading to locally / nationally relevant products while retaining global consistency. This will foster the development of an integrated, globally consistent forest monitoring approach.

4.21 Full coverage interpretation

The vegetation continuous fields algorithm, recommended for monitoring global tree cover within the FRA 2010 global RSA, 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 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.
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.

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 MOF staff, to interact with the algorithm in iteratively improving algorithm outputs.

The MODIS VCF method for forest monitoring is appropriate for national to global scale monitoring. 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 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 NFAs.

4.22 Institutional set up for full coverage assessment

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 to which FAO is associated, 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 LULC 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 its accuracy will be assessed by application of an advanced high resolution sampling strategy.
- Generation of global LULC 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 LULC area and area change estimations.

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

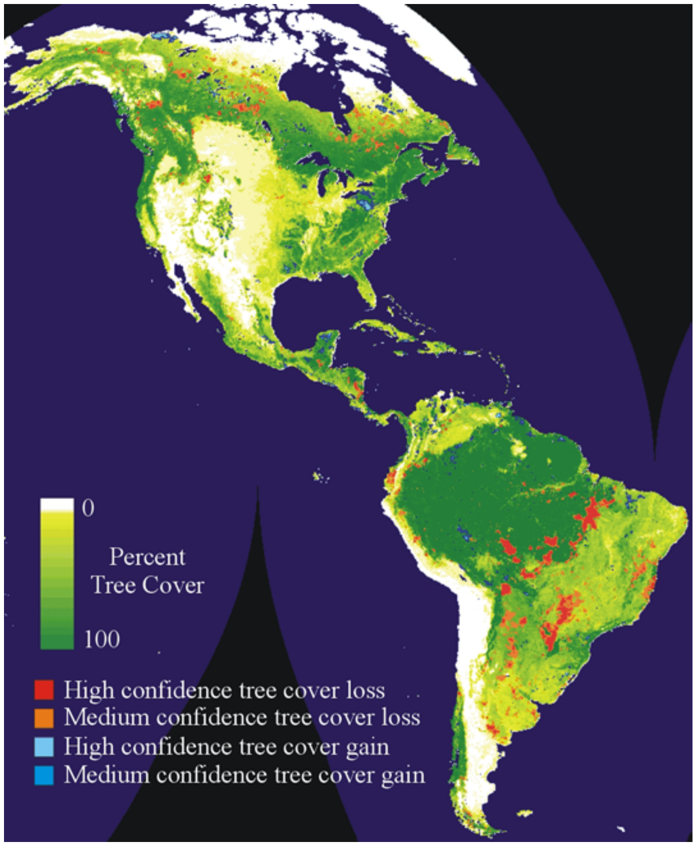


Figure 9: Example of AVHRR tree cover change for the Americas from 1982-1999 8km data (Hansen and DeFries, 2004). These data and 1km AVHRR 1992 and 1996 VCF maps (Hansen *et. al.*, 2002) will be used by SDSU to refine change / no change strata for 1990-2000.

4.3 The "Information Framework" and the FRA 2010 RSA

FAO proposed to build the "Information Framework on 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. The resources required to implement monitoring programmes can be greatly reduced, and the quality of results greatly enhanced by sharing input data and results.

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

The Information Framework 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.

IF development objective: 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 RSA:

- Establish IF internet gateway with interface to download and upload data from/to FRA 2010 RSA sample locations.
- Populate IF with time series of geo-referenced satellite images at each FRA 2010 RSA sample location.
- Establish synergies between sampling and full-cover remote sensing approaches to monitoring of global changes.
- Support implementation of the FRA 2010 RSA, 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 RSA results with information on forest fires, protected areas, poverty mapping.
- Expand the scope of IF monitoring applications.

Current partners of the information framework are FAO, SDSU, UNEP / GRID and USGS. Their currently foreseen key contributions are:

FAO (FORM and SDRN)

- Lead the conceptual development and coordinate partnership process.
- Apply IF to FRA through distributed participation of national expertise.
- Coordinate and provide IF Internet gateway.
- Training, outreach and capacity building.

SDSU / UMD

- Provide clipped and pre-processed Landsat image samples (including meta data) and interpretation manuals via the Internet.
- Provide regional interpretation training courses.
- Assist in validating the Landsat sample interpretations.
- Produce annual global forest cover and cover change maps based on MODIS VCF.

- Provide data management support to FAO FRA.

UNEP / GRID

- Take over a coordination and technical liaison function.
- Bring Google Earth into the IF partnership.
- Host guest scientist from UN member countries to work on specific IF / RSA issues.

USGS

- Provision of ortho-rectified Landsat data sets: MSS 1975, TM 1990, ETM+ 2000, ETM+/TM/other sensors 2006

The partnership will remain open to other contributing institutions. Further likely partners are:

- National and regional specialized agencies.
- Jena University is interested in testing the use of TerraSAR-X and ALOS images to support the sample analysis in certain regions.
- Joint Research Center of the European Commission and their planned TREES III programme. Initial contacts with JRC indicate a possible close collaboration.
- World Resources Institute expressed interest in collaborating.

Figure 10: This screenshot shows the Google Earth interface (earth.google.com). It could be enriched with FAO FRA information on forest cover, afforestation and deforestation. This would certainly boost global forest information transparency and could open many economic opportunities.

5. Kotka V and next steps

5.1 Questions for FRA 2010 RSA working group at Kotka V

Kotka V, 12-16 June 2006, is expected to provide recommendations on the 2010 RSA to COFO that is foreseen to meet next in March 2007. To do this appropriately the following questions are expected to be discussed in the Kotka FRA 2010 RSA working group:

- Is an RSA useful and needed? Should it be implemented within the FRA 2010 framework?
- If so, what should be the scope of the RSA? Which variables should be included and assessed?
- Which partner institutions are most appropriate to collaborate within the RSA?
- Type and number of interpretation nodes and hubs: Kotka might be a good venue to start assessing the technical capacity as well as number of national and regional interpretation centres that are ready to participate in the 2010 RSA.
- Decentralized RSA implementation: Is the Information Framework considered an appropriate and operational execution and dissemination platform for the 2010 RSA?

5.2 Questions for remote sensing expert consultation

More technical questions concerning the RSA implementation are expected to be discussed during a remote sensing expert consultation, likely to be held in Washington, DC, short after the Kotka meeting.

- **Use of Landsat MSS data**: Should the global Landsat MSS 1975 dataset (data acquisition ranges from 1973 through 1980) be included in the global 2010 RSA? The use of these MSS data will extend the monitoring time frame 15 years into the past, to the beginnings of civil satellite remote sensing.
- **Choice of global grid**: Which global grid should be chosen for the Landsat sampling? (i) The initially proposed 1 degree by 1 degree Latitude / Longitude grid, or (ii) a hexagon grid, or (iii) should existing national inventory grids be stitched together? A related question: The US Forest Service offered to contribute to a comparative study evaluating the pros and cons of lat / lon and hexagon grids. Is such a study deemed useful and necessary? Which other institution is interested in contributing to such a study?
- **Choice of sampling protocol**: Should systematic sampling with about 9,000 sample units (to be interpreted 4 times: 1975, 1990, 2000, 2005) be favoured

over a considerably smaller number of samples using a stratified approach that is expected to be comparably precise?

- **Feasibility of forest use legend**: Is it feasible to apply the given FRA forest use legend to interpret the Landsat samples? Will the national interpreters have sufficient *in situ* knowledge to map forest use?

Based on the results of Kotka V and the remote sensing expert consultation a tentative execution and budget plan will be elaborated, and subsequently discussed with interested donor agencies.

Assuming (i) positive recommendations from Kotka and (ii) support from donors the 2010 RSA will require a quick start off to ensure that the ambitious approach can be tested and implemented in time. An initial short test and preparation phase in 2006 could seamlessly blend into the implementation phase from 2007 through 2010.

6. Annexes

Annex 1: Technical specifications of Landsat and MODIS

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 4: 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 5: 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 6: Landsat spectral bands (from NASA website).

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 7: 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 8: MODIS first 7 spectral bands (from NASA website).

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 2: Coverage of global Landsat datasets

The Landsat scenes are processed in photogrammetric blocks of up to 400 individual Landsat scenes. This annex provides information as to which blocks have been completed and when the future blocks are scheduled for completion. The complete GeoCover-Ortho data base will include 7100 orthorectified Landsat Thematic Mapper scenes. These 7100 scenes are being produced in large contiguous blocks consisting of between 150 and 400 images per block. The status images below show the approximate layout of these blocks and provides their current production status for year 2000, 1990 and 1975 data. Green areas have been completed and red areas are currently under production. Tan blocks have yet to be processed (from MDA website).

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)

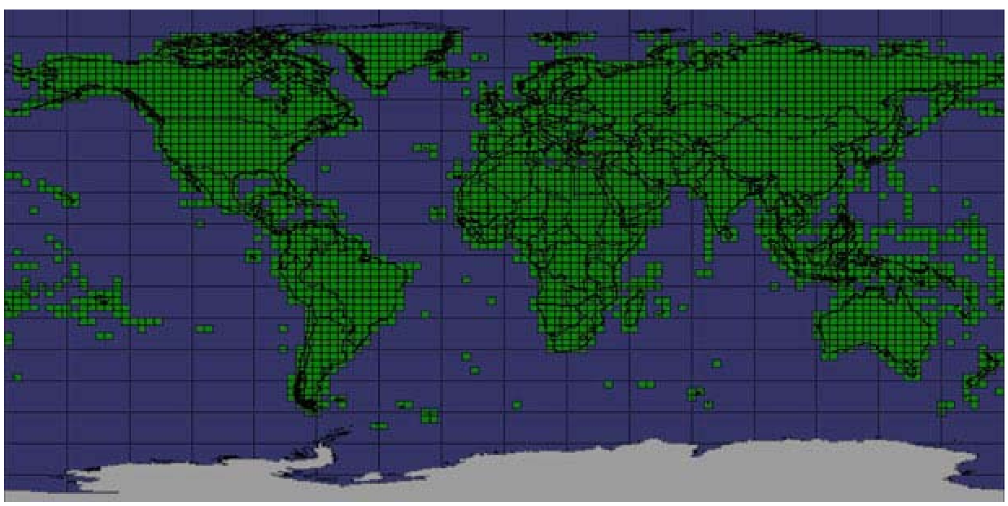


Figure 11: GeoCover-Ortho Year 2000. Green: Completed; Grey: Not Available (from MDA website).

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.

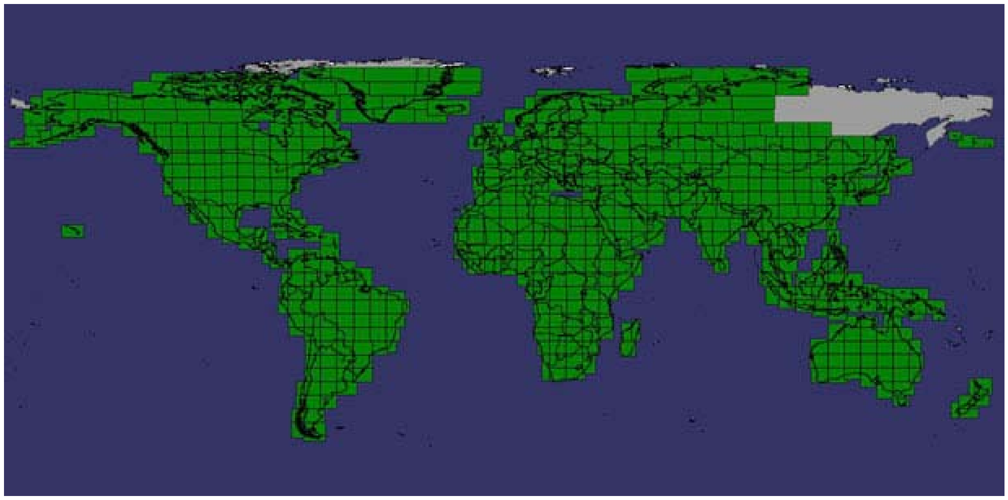


Figure 12: GeoCover-Ortho Year 1990. Green: Completed; Grey: Not Available (from MDA website).

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.

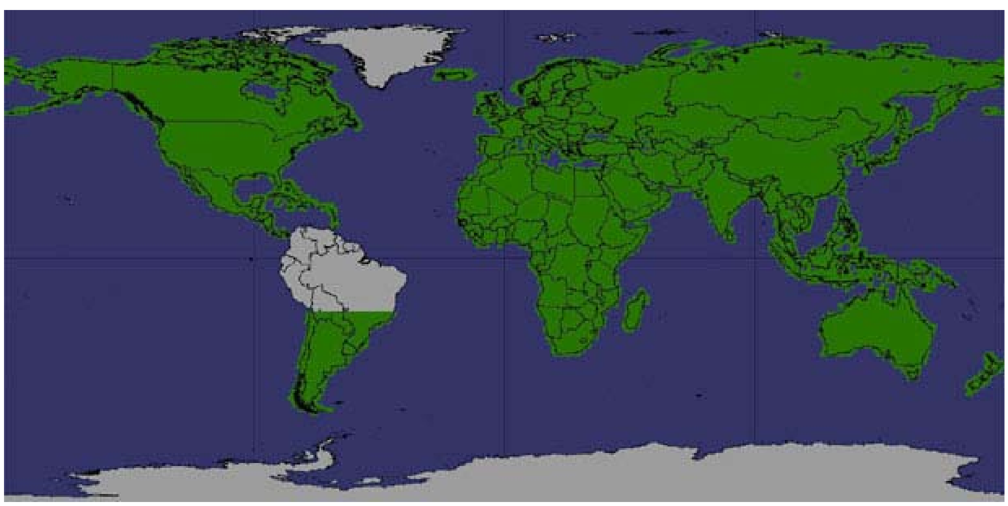


Figure 13: GeoCover-Ortho Year 1975. Green: Completed; Grey: Not Available (from MDA website).

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

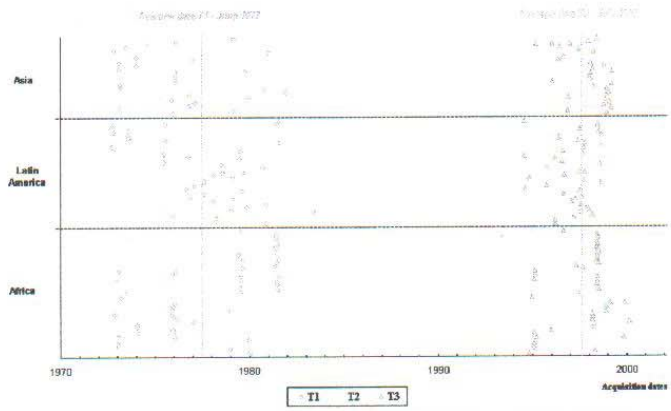
Annex 3: Standardization of transition matrices to reference years

From FAO (2002), pages 18-22:

2.4. Standardisation of the transition matrices to the reference years 1980, 1990, 2000

While the images were selected to be as close as possible to the reference years 1980, 1990 and 2000, they rarely corresponded exactly to the reference years and varied considerably between sampling units (Figure 2-7).

Figure 2-7. Temporal distribution of satellite images used for the survey



Each dot corresponds to an image used during the survey. T1 corresponds to the first observed image of the time series, T2 to the second, T3 to the third. The average dates for T1, T2 and T3 images are mid-1977, end-1988 and mid-1997.

Before making estimates at the various aggregate levels, data from the sampling units had to be standardised to the reference years 1980, 1990 and 2000. The processes involved were to either extrapolate or interpolate the statistics from the sampling units (states and transition matrices) starting from the original date of acquisition of the imagery (T1, T2 and T3) to the various reference years (Figure 2-8).

Figure 2-8. Example of standardisation issue

Notes: The figure presents an example of the time standardisation problem. The observed matrices for the period T1-T2 and T2-T3 (and corresponding states T1, T2, T3) must be either extrapolated or interpolated to represent the periods 1980-1990 and 1990-2000.

Calculations were based on the observed area transition matrices for the common area to all images of the time series (T1, T2 and T3). It is in principle possible to make the same kind of calculations and adjustments for other areas, e.g., the area common to only T1 and T2 and for the T2 and T3 common area. However, this could not, without further assumptions, be used for comparisons of the changes of the class-to-class area transitions between the two periods but, for example, for forest cover estimates. Due to time constraints, this work wasn't carried out. Moreover, an average of about 90 percent of the area common to T1 and T2 was also found in the T3 image. Restricting all calculations to the common area made the estimates of forest cover, deforestation rate, area transition matrices and their comparisons between the two periods consistent to each other.

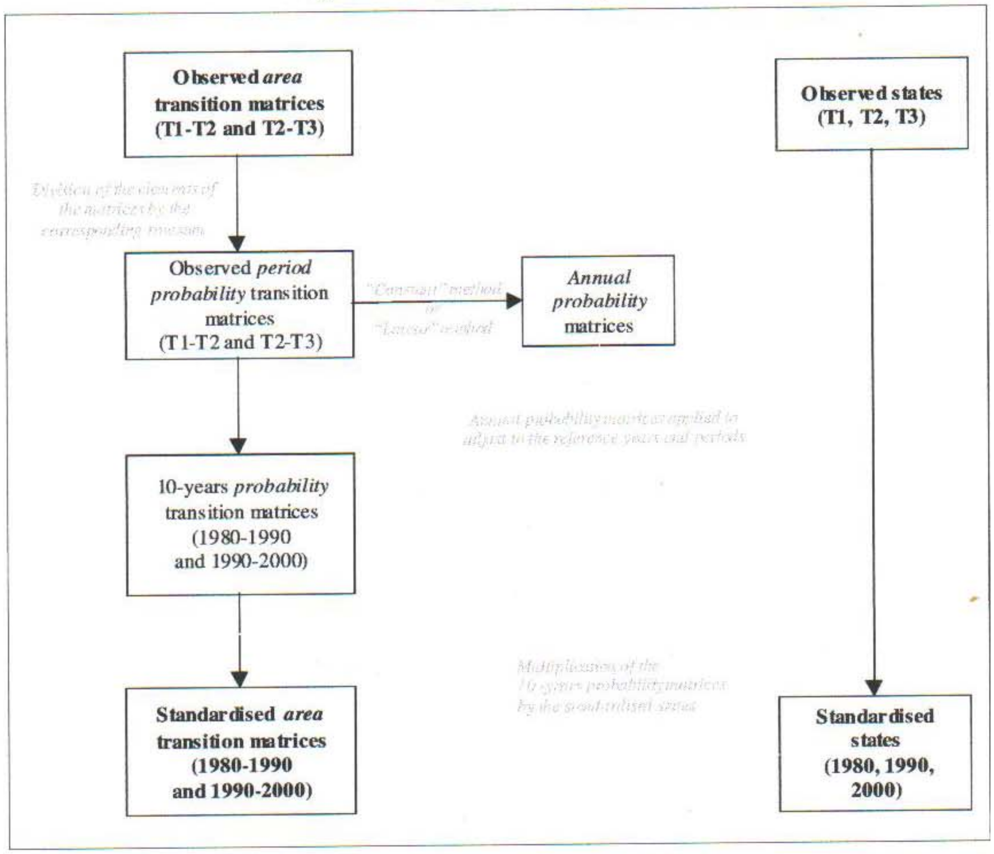
If the sampling unit was partitioned into several scenes (e. g. two T1 images used for the observation closed to 1980) with notably different acquisition dates the standardisation was made separately for each part.

Details on the standardisation process and formulae can be found in Appendix 9.

The standardisation was achieved through four main consecutive steps (Figure 2-9):

1. Transformation of the two observed area transition matrices into period probability matrices by dividing each element with its corresponding row sum. The elements of the resulting matrices represent the area proportion of a class that changed to another during the observed period;
2. Calculation of annual probability matrices. The elements of the annual probability matrices correspond to the probability of a class to change to another class during one given year;
3. Application of the annual probability matrices to adjust the period probability transition matrices and observed states by projecting backward and forward. 10-years probability matrices and states adjusted to the reference years are thus obtained;
4. Multiplication of the 10-years probability matrices with the adjusted state at the beginning of the reference period, to get the 10-years area matrices.

Figure 2-9. Standardisation process



Annual probability matrices were calculated through two different methods (step 2): the constant method, the same as the one used in the FRA 1990 (see FAO 1996, Appendix 9, and Rovainen 1994), and a method called linear worked out especially for the current survey to deal with the standardisation of three-date time series.

In the constant method, the annual probability matrices are assumed constant during the observed period. They are calculated using only one of the two observed transition matrices.

At the opposite, the linear method assumes that the annual probability matrices are gradually and linearly changing. They are obtained using both observed transition matrices from the two periods T1-T2 and T2-T3.

The linear method, more complex, was developed as the first choice for two reasons:

- logically, it was difficult to motivate a sudden change in the class-to-class transitions at the second point in time (T2). This is the consequence of using the constant method for the two observation periods separately;

- the method gives the same results for the state at the 1990 reference year whether it is interpolated or extrapolated from the T1-T2 or the T2-T3 periods. In other words, the 1990 values, and subsequently the transition matrices are unique.

The principles of the *linear* method for calculating the annual probability matrices are described briefly in the following and can be found with more details in Appendix 9:

- For each year t an annual probability matrix $\mathbf{P}(t)$ was assumed, where

$$\mathbf{P}(t) = (1 - t/T) \cdot \mathbf{P}_1 + (t/T) \cdot \mathbf{P}_2$$

$t = 0$ corresponds to time T1 and $t = T$ corresponds to time T3. It means that the *annual probability matrix* is gradually changing from the matrix $\mathbf{P}_1$ to the matrix $\mathbf{P}_2$ from the time T1 to the time T3.

- The two fixed matrices $\mathbf{P}_1$ and $\mathbf{P}_2$ were calculated by a special algorithm to fit the two observed period probability transition matrices. Consequently all *annual probability matrices* $\mathbf{P}(t)$ were also obtained.

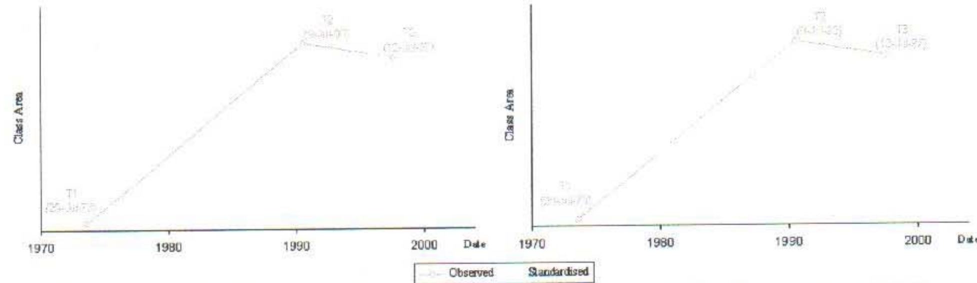
To give an example on how the annual probability matrices $\mathbf{P}(t)$ were used for the adjustment (step 3), lets say T1 is 1978 and T2 is 1991. The observed state 1978 is multiplied by $\mathbf{P}(0) \cdot \mathbf{P}(1)$ to get the 1980 adjusted state. The first period probability matrix (T1-T2) is pre-multiplied by the inverse of $\mathbf{P}(0) \cdot \mathbf{P}(1)$ and post-multiplied by the inverse of $\mathbf{P}(12)$ to get the probability transition matrix for the 1980-1990 period. Thus the observed 1978-91 matrix was adjusted to the reference period 1980-1990 by calculating the changes during the years 1978, 1979 and 1991. The 10-years area transition matrix 1980-1990 was obtained (step 4) by multiplying the probability transition matrix 1980-1990 with the 1980 adjusted state. All adjustments are consistent.

For all the estimation and application stages, fractional time was used. That is, if a probability transition matrix should apply only for a fraction α of a year, the corresponding annual probability matrix is raised to the power α. For example, if T1 is the 30 June 1978, then $\alpha = 0.50$, and $\mathbf{P}(0)$ in the example above is replaced by $\mathbf{P}(0)^{0.5}$.

The linear method was generally preferred and used, for the reasons given above. The constant method was applied for adjustments that imply extrapolation outside the time interval T1-T3. Indeed, the matrix function used for calculating the annual probability matrices $\mathbf{P}(t)$ by the linear method is risky to use for extrapolation, in the same way as is the use of polynomials for real-valued extrapolations. It was generally the case for the adjustment to the year 2000, since most of the T3 images were acquired before 2000.
Moreover, the linear method is based on the assumption of a smooth change over the entire T1-T3 period. Sometimes this was not supported by the data: no matrices $\mathbf{P}_1$ and $\mathbf{P}_2$ could be found or the results produced were unrealistic. In these cases, the more robust constant method was used: two period constant annual probability transition matrices were calculated, for each period, and used for adjustments in the same way as above. The 1990 state was calculated as an interpolation within the period containing this year. One consequence of the use of the constant method for all adjustment is a break at the time T2.

An example of standardisation results is given in Figure 2-10.

Figure 2-10 Example of adjustment to the reference years 1980, 1990 and 2000 for a state by using the linear method (left) or only the constant method (right)



Notes: The figure gives an illustration of the adjustment of an observed state to the reference years made using the different methods (linear and constant). Only one class is considered here. The observed states at the dates T1, T2 and T3, as well as the standardised states at the reference years (1980, 1990 and 2000) are represented.

The graph on the left gives the results of the standardisation method commonly applied in the survey. The linear method, which used observed data from both periods T1-T2 and T2-T3, allowed adjusting the T1 and T2 states to the years 1980 and 1990. For the adjustment to the year 2000, the constant method was applied since it consisted in an extrapolation outside the observed period T1-T3.

The graph on the right describes the standardisation results by using only the constant method. A "break" is visible at the time T2, the 1980 and 1990 standardised states was obtained using only the observations for the period T1-T2 (1990 is inside the time interval T1-T2); the 2000 standardised state was given using the observed data for the period T2-T3.

Very often the probability matrices obtained from both methods contained negative elements, which is not logical. For this reason the linear and the constant method was further developed for finding non-negative annual probability matrices that, according to a reasonable criteria, best fit the two observed period transition matrices. However, except in few cases, the final area transition matrices comprised also negative values, and the solutions were very similar to the ones resulting from the basic methods. So the restriction was used for a very few cases.

If the linear method resulted in realistic adjusted period area transition matrices and states it was accepted. Otherwise the results obtained with the non-negative annual matrices were inspected for realism and acceptance. Finally, if none of these solutions was accepted, the results with period constant transition matrices were checked.

The realism of the solutions was estimated looking at the negative values in the adjusted matrices (number and value in the probability and area matrices) and looking at the graphs for all classes showing the standardised and observed states.

It should finally be emphasised that the degree of truth of the assumption made for calculating varying probability matrices (linear method) can never be checked and the truth is by no way claimed. The assumption was essential in order to standardise the observed matrices to the reference years. Hence, the standardised transition matrices should be just interpreted as calculated changes during the two 10-year periods. Nothing is known about the true changes during single years. For the same reason, since the 1990-2000 standardised matrices in most cases are obtained by extrapolation they strictly reflect the changes up to a couple of years before 2000.

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